

Contents.

Empire Marketing Board Bulletins.

Vo. Month

21. Sept. 1929.	Wool - A Study of the Fibre. By S.G.Barker.	pp. 1- 84.
22. Nov. "	<i>λ783:78 F9</i> The Demand for Cheese in London.	pp. 85--99.
23. Dec. "	<i>X9(λ311):75-3CL.N3 F9</i> The Growing Dependence of British Industry upon Empire Markets. By F.L. McDougall.	pp.100-116.
24. Dec. "	<i>X9:51.1-3.N3 F7</i> Report on Insect Infestation of Stored Cacao. By J.W. Munro and W.A.Thomson.	pp.117-140.
25. Feb. 1930.	<i>J482:78:80k4 F9</i> Indian (Sunn or Sann) Hemp - Its Production and Utilisa- tion.	pp.141-162.
26. Mar. "	<i>X9(MJ73):2.2.N3 G6</i> British Industries and Empire Markets. By A.J. Sargent.	pp.163-191.
27. May "	<i>X9:51.30k1-3.N3 G6</i> Cocoa - World Production & Trade.	pp.192-244.
28. June "	<i>X9(J482):2.1.N3 G6</i> Empire Marketing Board - May 1929 to May 1930.	pp.245-293.
29. June "	<i>X9(J):51.1-3.2.12:1 G6</i> Biological Control of Insect and Plant Pests. By W.R. Thompson.	pp.294-361.
30. June "	<i>J:423.5 G6</i> Canadian Fruit Shipments.	pp.362-392.
31. " "	<i>X9(J37):54.72k3 N3 G6</i> The Production of Tung Oil in the Empire.	pp.393-406.
32. Aug. "	<i>X9(J58A):2.1-3.N3 G6</i> Report on the Cultivation Treatment and Prospects of Rice in British Guiana. By C.E.Douglas.	pp.407-449.

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Frontispiece. Pure bred Dorset ewes. Lambs Dorset-Wensleydale, first cross.
(Reproduced by the courtesy of Sir Frederick Aykroyd, Bart., J.P.)

E.M.B. 21.



WOOL

A STUDY OF THE FIBRE

By

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CONTENTS.

	PAGE
Preface	5
Introduction	7
History	10
Biology of Wool—	
The Evolution of the Coat of the Sheep	18
The Fleece of the Sheep from the Point of View of Biology	22
Variations in Fibre Types	24
Variations in Fibre Structure	25
Variations in Growth Rate	27
Variations in Shedding	27
Variations in Pigmentation	28
Variations in Total Amount of Fleece	29
Variations in Group Characteristics of Fibres	30
The Interrelationship of Fleece Characteristics	30
Conclusion	32
Chemistry of Wool—	
General	33
The Nature of Wool Keratin	35
Wool Grease	38
Physical Characteristics of Wool—	
Hygroscopic nature of Wool	46
Thermodynamic considerations regarding moisture absorption	58
Swelling	61
Elasticity	67
Rigidity	76
Measurement of Elasticity	79
X-Ray Analysis of Wool	84
Various physical properties	86
Dimensional Characteristics—	
Fibre length	93
Determination of fibre fineness	98
Crimp or waviness	121
Scales on Wool	143
Felting or milling	147
Microbiology	149
Conclusion	153
Acknowledgments	155
Appendix	156
Bibliography	157

PREFACE.

The economic importance of wool to the British Empire is strikingly shown in the trade returns of the United Kingdom, Australia, New Zealand and South Africa. In 1928 wool accounted for 19 per cent. of the United Kingdom's imports of raw material, 48 per cent. of Australia's exports, 30 per cent. of New Zealand's and 56 per cent. of South Africa's exports of merchandise (excluding gold and precious stones). Nearly one-half of the United Kingdom's own production, amounting to about 100 million lbs. annually, is exported. The Empire as a whole exports two-thirds (1,400 million lbs.) and Australia alone more than one-third (750 million lbs.) of the total quantity of wool entering world trade (2,150 million lbs.).

During the Imperial Agricultural Research Conference of 1927 the Empire Marketing Board invited representatives of the wool-growing Dominions to discuss the part that scientific research could play in raising the standard of wool production and enhancing the value of wool in relation to other fibres.

The last few decades have witnessed the rapid growth of a new textile industry using artificial fibres produced under scientific control as a direct result of laboratory research. Wool has for so long held an unrivalled position as a textile material that until recent years comparatively little attention has been devoted to a scientific study of its qualities. The physical and chemical characteristics of wool as a natural product and the conditions that determine the special qualities prized by the manufacturer have remained for the most part a closed book.

The practical skill of the wool buyer can of course appraise these qualities with sufficient accuracy. For practical purposes microscopic measurement cannot take the place of a well-trained sense of touch, any more than chemical analysis can rival the senses of smell and taste in appraising perfumes and flavours. But when an attempt is made to find means of deliberately increasing the supply of wools most favoured by the manufacturer, scientific research has to be invoked to determine the physiological conditions of production and to interpret the requirements of the technician into objectives that can be realised by the breeder and pastoralist.

Wool research thus provides unrivalled scope for concerted action between different parts of the Empire. The activities of workers in diverse fields, if inspired by a common goal and co-ordinated by personal contact and the freest interchange of projects and results, may well lead to advances in knowledge and technique that may prove of the utmost practical value to all engaged in the industry. The manufacturer looks for improvements in the raw material and in the processes of manufacture, while the breeder and sheep farmer seek guidance as to the methods of producing those qualities in the fleece which will most enhance its market value. In both fields, co-operative research in the Empire holds out promise of achievement.

The British Research Association for the Woollen and Worsted Industries, under the direction of Dr. S. G. Barker, has already found it necessary to study the nature of wool in its physical, chemical and biological aspects. Its work on the raw material brings it into close relation with those problems of breeding, nutrition, and animal husbandry in which both home and Dominion wool growers have a special interest. It has accordingly been recognised by the Empire Marketing Board as one of the chief centres for wool research in the Empire and has been encouraged with the aid of grants from the Board to fulfil an important role in this field. Next year it is hoped to invite the leading wool research workers in the Dominions to a conference in this country when matters of common interest can be thoroughly discussed.

The present volume has been written by Dr. Barker at the request of the Empire Marketing Board to prepare the way for future developments. It is designed to serve both as a summary of the existing state of scientific knowledge, and to some extent also as a confession of scientific ignorance. It is written not only for specialists but also for agriculturists, industrialists and administrators interested in wool problems ; and especially perhaps for new recruits to biological research who are looking for fresh fields to conquer and new problems of interest in themselves and of economic importance to the Empire.

T. DRUMMOND SHIELS,
Chairman of the Research Grants Committee.

Empire Marketing Board,
September, 1929.

WOOL.

A STUDY OF THE FIBRE.

INTRODUCTION.

THE spirit of scientific enquiry would naturally prompt one to search for the answers to the "How, when, where and why?" of any raw material. Wool has been known throughout the ages, and the fact that it is grown on the sheep's back and is subsequently used for the manufacture of clothes, seems to have been accepted with every degree of finality. It is remarkable that such an important Imperial product of agriculture, furnishing as it does the raw material for one of our greatest manufacturing industries, should have been allowed to remain unexploited and uninvestigated for so many years from a scientific standpoint.

Figures relating to the world's population of sheep will show that, roughly, there are nearly 700,000,000 sheep in the world to-day, and when one considers that in June, 1928, the Dominion sheep population was given as:—

Australia	98,865,000
New Zealand	27,000,000
Union of South Africa	35,945,000*
Canada	3,266,000

the importance of wool as an Imperial product is self-evident.

What do we know of wool—not from the textile point of view, not from the production point of view, but purely regarding wool as a material substance of a highly complex scientific nature? Wool has extraordinary properties, both chemical and physical. It is highly elastic; it is extremely hygroscopic; it has the property of retaining warmth; it creates heat in itself when wetted; it transmits ultra-violet radiation, and it is durable and strong. Chemically, it is a keratin, and its precise constitution is as yet largely unknown. Certain it is, however, that it contains a large proportion of sulphur, and equally certain that this sulphur contributes largely to its elastic and other properties, an effect analogous to the process of vulcanisation of rubber.

* Including 1,499,000 Angora goats.

Scientific research of a fundamental character on the inherent characteristics, physical, chemical and biological, of wool itself could only lead to a fuller knowledge of the exact reactions occurring within the wool substance during periods of production and manufacturing manipulation. It might even suggest new methods and new fields for the utilisation of wool produce. It might possibly result in better processing and better production. It would certainly place the producer in possession of information as to which of the characteristics of the fibre should be encouraged and enhanced, and secondly as to the modifications of nutrition, environment, pasturage, breeding and selection which would best accomplish this end.

It is noteworthy that in the case of artificial fibres, these are produced under strict chemical supervision, so that their constitution and physical attributes are designed in order to leave them at each stage of the process of production and manufacture in such a condition as to further the most economic handling during subsequent treatment. Finally, the fibres are designed with a definite consideration as to the finished product into which they are to be woven.

In the case of wool, however, on the one hand we have the producer of the raw material with little knowledge as to its subsequent use, and on the other we have the manufacturer crying out for improved raw material, but again with little knowledge of the limitations of production or how this improvement might be accomplished.

The question of the precise definition of the manufacturer's requirements in good wool, and the methods to be adopted by the producer to meet these demands, which would seem to link up all branches of the wool industry into one entity—as in the case of artificial fibres—has been more or less untouched. An effective link between the two must be forged, and only if this link is made on the sound basis of scientific fact, will it ever be effective and strong.

It is therefore essential that, previous to the prescription of definition of wool quality as related to spinning power or felting ability, a very intimate and precise knowledge should be obtained of the fibre itself, its construction, its structure and its reaction to various conditions. The question of the definition of wool quality and its relationship to spinning power would seem to point, in the light of subsequent investigation, to the fact that any classification of this kind would naturally be based on at least two attributes of the fibre ; namely, its purely dimensional, and its inherent constitutional

characteristics. It will be shown during the course of this study that, particularly with regard to crimp, the nature of the crimp is defined by these two attributes, as expressed by the cross sectional area of the fibre and its elasticity.

The discussion which now follows has been grouped into certain compartments, but each and every one of these is closely inter-related, showing that unless co-ordinated work of a comprehensive character, taking in every aspect of the situation, is undertaken, the objects of scientific research on wool will be largely abortive.

First of all, it is a point of interest to trace something of the history of wool, followed by a review of the biological side of wool production. A survey of the chemistry of wool leads to a discussion of the physical aspects of the fibre, including its hygroscopic nature, its elasticity, plasticity, etc. From the point of view of the wool-man and producer, probably a more important factor is dealt with under dimensional physics, whereby a discussion is given of the relative importance of the various dimensional attributes of the fibre, with an attempt to show how they can be measured and related to one another, thus defining the factors influencing wool "quality" determination. Under this heading fibre length, contour, cross sectional area, crimp and scaliness, each play their part and are discussed in detail.

Lastly, a brief review is made of some of the important attributes of the fibre which affect its commercial value as well as its merits as a textile fibre for the manufacture of cloth.

Thus we may confine this present study to the attributes of the fibre itself, never assuming in any instance, that any degree of finality has been reached, but indicating the true necessity for further intimate scientific investigation and knowledge. The field for wool research is vast, and the workers so few that close co-operation and co-ordination of effort are essential. If wool has, as is often remarked, never been fully exploited, this can be largely attributed to the fact that the precise nature of the structure and constitution of the fibre has never been fully known.

For the security of the future of the wool industries, it is essential, therefore, that this valuable raw material should be examined, analysed and investigated, with all that meticulous care and exactitude that scientific research implies.

Fundamental scientific research may seemingly be a far cry from the farm or from the mill, but it is only when the work of many, perhaps obscure, workers is co-ordinated in a logical manner, each and every one adding his little quota, that the final goal hailed as "scientific discovery" is attained.

There are those to-day who still enshrine the scientist in an atmosphere of mystery, and imagine his having dealings with the occult. There are those who, however, prefer openly to disclaim all knowledge of science and style themselves as essentially practical, with the obvious inference that scientific men are the reverse. It would seem that it is only, however, when the scientist has applied his methods of investigation to intimate and seemingly insignificant details of commonplace materials and happenings, that a new discovery for the benefit of mankind becomes possible.

The scientific facts, concerning wool, which are now arrayed and placed before the reader, are a modest attempt to survey something of our present knowledge of the wool fibre, and to illustrate the great distance to be travelled before that knowledge can assume any guise of completeness and finality.

HISTORY.

The history of wool takes us back to the very earliest times, even to periods when no records were kept. The earliest references to wool and sheep are found in Babylonian records made approximately 4,000 years before Christ. The Babylonian carvings of Urmina, attributed to about 4000 B.C., show a figure "clad in a ribbed woollen stuff from shoulder to ankle", while the splendid flounced robe of Ishtar on the Annubanini stele (3600 B.C.) is evidence of the skill of the Babylonian craftsmen in wool weaving. There is a representation of a fulling mill on the tomb of Useratesen II (1800 B.C.), whilst it is established that woollen carpets were made and used by the ancient Empires. It is recorded that a purple Babylonian carpet was spread over the tomb of Cyrus, and Calixenus of Rhodes, describing a banquet given by Ptolemy II, about the third century before Christ, records that "underneath two hundred golden couches were strewn purple carpets of the finest wool with patterns on both sides." Varro, who lived about 50 B.C., describes his visit to the temple of Janus and records having seen there the distaff and spindle of Tanaquil, the wife of Tarquinius Priscus, who lived about 600 B.C. To this

lady is accredited the first use of a perpendicular loom for the production of the straight tunic worn for many years by the younger Roman citizens under the white toga.

The Bible contains over 50 references to sheep and wool, as well as woven fabrics of wool, and there is little doubt that the Children of Israel used wool whilst in Egypt. Biblical records are particularly clear with regard to sheep-breeders and their flocks. We read of Jacob as a successful sheep-breeder who became very rich as a result of his husbandry—wealth in those days being estimated by the magnitude of the flocks and herds possessed by the individual owner. To quote a passage from the 2 Kings iii, v. 4: "Mesha, king of Moab, was a sheepmaster and rendered unto the king of Israel an hundred thousand lambs and an hundred rams, with the wool." Wool, sheep and lambs were, therefore, considered as legitimate tribute even as early as 896 B.C., the approximate date of this record.

Apart from Holy Writ, classical writers, throughout early literature, include many references to wool. Homer in the *Odyssey* gives precise dissertations on the subject, whilst Virgil in the *Georgics*, Lib. iii, v. 381–93, addresses himself to the sheep-owners, offering advice that is still pertinent to-day. Virgil's significant remarks are worthy of note, and as translated by Hawkesworth read:—

"Is wool thy care? Let not thy cattle go
Where bushes are, where burrs and thistles grow,
Nor in too rank a pasture let them feed;
Then of the purest white select thy breed.
E'en though a snowy ram thou shalt behold,
Prefer him not in haste for a husband of thy fold;
But search his mouth; and if a swarthy tongue
Is underneath his humid palate hung,
Reject him, lest he darken all thy flock;
And substitute another from thy stock."

The present day relevance is obvious, but it is also a point of interest that even in those remote days the philosopher was advising the farmer on the same factors as the scientist is dealing with to-day on behalf of the modern agriculturalist. Wool research is not new evidently; not that, however, the Director of Wool Research can claim to be the descendant in office of Virgil! Ovid, in his "Metamorphoses" (45 B.C.), describes the practice of woollen manufacture, whilst Pliny in A.D. 23 gives notes on wool production as a feature

of his "Historia Naturalis." The legend of Jason's quest of the Golden Fleece in ancient mythology affords still further evidence of the antiquity of knowledge concerning wool.

The origin of the sheep itself is somewhat obscure and is largely a matter for conjecture. Booth gives a description of a probable story of the early beginnings, in his paper on "British Sheep and Wool." Archeological discoveries have shown that in prehistoric times there lived an animal called the "mouflon." This animal was somewhat similar in nature to the South American yak, which has long, outstanding horns and a long, shaggy coat. The moufflon was apparently ill-adapted to life on the plains and also largely unable to defend itself against beasts of prey and other animals of the lowland countries. As possessor of an agile frame it made its home in the mountainous districts, being content to live upon the plainer fare provided at the higher altitudes. It also acquired a certain measure of hardiness. To trace the history further, it may be supposed that the moufflon was hunted, captured and slaughtered; the trophies of the chase furnishing a hairy skin of great value to man as a clothing for his body. In the process of evolution of the world, mankind finding these captive animals of great practical utility, studied the development of their usefulness in other directions. Thus began wool research. The animals were restricted in their localities and kept under observation and control. Thus, by constant association with man they gradually became domesticated. It is certain that these pioneers of the wool-producing industry kept two points steadily in view in their breeding methods:

- (1) They chose animals which were largest in size, because they provided the largest skins, each of which was taken off as one piece, thus providing an adequate covering for a single person, without any attempt at tailoring.

- (2) Those animals were selected for future breeding which yielded the skins of softest wool, because of the greater comfort derived from them when worn on the human body.

Thus our present day requirements were probably anticipated. There is little or no scientific evidence of this procedure, but it seems a justifiable conjecture in view of the results which were attained, the evidence of which is certain. The primitive sheep had two coats: an outer hairy coat serving as a protective covering, and a skin-covering of softer, finer fibre, necessary for keeping the animal warm, which

was the forerunner of the wool of commerce of to-day. By careful selection and breeding the outer hairy coat was gradually eliminated, leaving a well-developed inner coat of wool as we know it to-day. It is significant that Nature, in endowing the animal with a skin-coat of wool, suggested to mankind the use of the fibre for clothing, the use of wool next the skin being essentially a development of the natural laws established on the animals themselves.

Primitive sheep, which are probably very similar to the ancestors of our modern breeds, possess the two coats described as typical. The outer coat is extremely coarse and the inner coat extremely fine. In modern sheep the inner coat has been largely developed and the outer coat greatly suppressed. In some sheep, for example the Sudanese, the reverse process has taken place, the inner coat having disappeared. The question of prevalence or disappearance of either coat would seem to depend on climatic conditions and environment to a pronounced degree. Species of mammals that are exposed to conditions of cold and high altitudes would naturally tend to possess more highly developed inner coats in order to preserve the warmth of the body of the animal. Warmth is all-important under such conditions, the function of the outer coat taking second place. In hot countries, however, the reverse would take place, as for instance in the case of the Sudanese sheep mentioned above. There, warmth is a secondary factor, and Nature, therefore, calls forth the function of the outer coat more strongly to the elimination of the inner, now unnecessary, warm covering. It is probable that primitive man, by taking advantage of this modification, domesticated sheep that had a highly developed inner coat, and by centuries of selection, isolated strains that had the tendency most developed. In many modern sheep, however, traces at least, of the outer coat still persist in the form of coarse, brittle fibres known as "kemp," especially is this the case in some mountain breeds. It is also noticeable in the birth coat of the lamb, although it is soon afterwards almost completely lost.

In primitive breeds, as will be shown later, both coats are shed annually, though at different times, whilst in modern breeds the wool grows continually, shedding having been eliminated. Nevertheless, to-day we find all stages between shedding and continuous growth still extant. In certain breeds an intermediate stage is signalized by an annual thinning of the fibres at times corresponding to shedding in the primitive forms. It is significant that kemp, the remnant of the outer coat, retains its primitive condition and is shed annually. It is

rarely realized, in considering the coat of the sheep, that its white colour is a peculiar characteristic for an animal not associated with Arctic conditions. The inner coat of the original breeds is much lighter in hue than the outer, coloured fibres being usually confined to the latter. Here again, in the production of an all-white fleece, by selection, man has probably encouraged natural processes.

From Roman times a race of sheep has existed round the borders of the Mediterranean, having a crimped wool similar to that of the merinos. It is unknown if these were the direct ancestors of the Spanish Merino, but it is stated that this is probable. There are at the present time two races of merino sheep presumably derived from the same stock: Merino Transhumantes (or travelling merinos, so called because their winter and summer pastures were different) and Merino Estantes, kept continuously on the same pasture. The subsequent dissemination of this breed will be referred to later.

Turning now to the development of wool in Great Britain and the Empire, we find that sheep rearing existed in England in Roman times. As early as A.D. 54 a guild of wool staplers was established at Winchester, and it is probable that just as agriculture was our first industry, wool stapling was one of the first trades. Dionysius of Alexandria wrote that British wool was well known in Rome, and that it was "so fine as to be comparable with a spider's web."² In the third century an edict of Diocletian mentioned British cloth, and at the end of the seventh century, Ine, king of the West Saxons, promulgated a law regulating the value of a sheep and its lamb at one shilling, and the fleece at two pence. It is impossible to say when the wool export trade began in this country, but there is little doubt that the numerous breeds of sheep established throughout the various districts of Great Britain are a result of the enterprise of the early suppliers of the wool stapling trade. It is interesting to note that the wool industry had royal patronage in the early days, for in A.D. 901 it is recorded that Edward the Elder, on his accession, "sette his sonnes to schole and his daughteris he sette to wool worke." It is well known that the Cistercians were great wool growers, and at the end of the thirteenth century a large part of Richard Cœur de Lion's ransom was paid in Cistercian wool.

One of the earliest taxes was on exports of wool. In 1275 the Statute of Westminster fixed a definite rate on what is described as "the ancient custom" on exports, namely 6s. 8d. on a sack of wool, consisting of 364 lbs., of 52 cloves of 7 lbs. each. There is a record

of a live sheep being sold at Scarborough for one penny in 1298, whilst in 1355 a fat mutton sheep sold for fourpence. At the same time a stone of wool (16 lbs.) cost ninepence. There is also a record in the rolls of the Priory of Finchale, in the county of Durham, that three sacks of wool were sold at Giggleswick in 1338 for the sum of £15, that is, just over 3½d. per lb., a very good price for wool in those days.

France, Belgium and Holland were all keen buyers of British wools, and Winchester, Chichester and other towns in the southern counties became important markets for the purchase of wool to be sent overseas.

Although cloth must have been manufactured in England on a small scale from the earliest times that sheep were bred in Britain, the chief object of wool growing was, until the middle of the fourteenth century, for the purpose of trade in raw wool. The countries on the Continent bought British wool and manufactured it into cloth. Flemish weavers followed William the Conqueror to England, and in 1080 the first weavers' guild was formed in England. In 1107 a colony of Flemish weavers settled in Norwich, where they practised their art. The English began to realize that if they themselves learnt and practised weaving, thus selling their cloth instead of raw wool, it would be of tremendous advantage. Henceforward we find numerous laws encouraging and protecting the infant industry of cloth manufacture in England. In 1265 we hear of the cloth of Stamford being sold in Venice. In 1271 the Government invited skilled workers from Flanders to settle in England, and about 60 years later forbade the import of cloth into England except such as was brought in by the nobility. Edward III in 1331 brought 70 families of Walloons to England. These people were weavers, and he settled them under royal protection, and they practised their art and taught English youth their "mystery." From this time onward the woollen textile trade in England was destined to grow until it reached such proportions that it completely overshadowed the industry on the continent, and became in very truth, as described by Defoe (1724) "the richest and most valuable manufacture in the world." The whole country became largely dependent for its prosperity on the wool industry; as early as 1454 a Parliamentary record states that "the making of cloth within all parts of the realm is the greatest occupation and living of the poor commons of this land." Camden (1607) spoke of English cloth as "one of the pillars of the State," and Bacon referred to the industry as "this great wheel" of the

realm. Almost every session of Parliament made laws protecting and regulating the woollen industry. In the seventeenth century an Act of Parliament stipulated that every person who died should be wrapped in a woollen shroud, and another that all women should wear flannel next to the skin. The former could be strictly enforced, but the latter Act would probably be a difficult proposition, even in those days, especially if fashion decreed otherwise ! During the Civil War a writer describes the origin of the Woolsack as follows : " To put our judges in the House of Lords in mind of preserving and advancing the trade and manufacture of wool."

The worsted industry first centred at Norwich, the little village of Worstead becoming, in the fourteenth century, the centre in England in which wool was first combed, and where worsteds were first made. To-day it is nothing but a small hamlet, entirely dependent upon agriculture.

The sixteenth century saw the invention of the Brunswick spinning wheel, and towards the end of the seventeenth century the stocking frame was invented by the Rev. William Lee, M.A., of Calverton. During the latter part of this century the woollen trade received great impetus by absorbing the skill of the many Huguenots who settled in this country upon the revocation of the Edict of Nantes.

During the eighteenth century machinery was gradually introduced into the woollen textile industry, due to such inventors as John Kay, John Wyatt, Lewis Paul, James Hargreaves, Richard Arkwright, Samuel Crompton and Edmund Cartwright, whose fame is world-wide.

Until the beginning of the nineteenth century the raw material for the woollen industry was chiefly raised in Britain, although we hear of Spanish wool being imported as early as the fourteenth century. During the Middle Ages, British wool was reputed the best in Europe, and an Elizabethan antiquary records that "the sheep of this realm . . . be now . . . worthy of great estimation both for the exceeding fineness of the fleece, which passeth all other in Europe at this day, and for the abundant store of flocks so increasing everywhere that the whole realm might rightly be called Sheppey." Further, Dryden speaks as follows :—

" Though Jason's Fleece was fam'd of old
The British wool is growing gold ;
No mines can more of wealth supply :
It keeps the peasant from the cold,
And takes for kings the Tyrian dye."

Towards the end of the seventeenth century, however, English writers were compelled to say: "We must submit to Spain in the utmost curiosity of fineness." The reason for the deterioration in the quality of English wool was a matter of dispute, but very probably it was partly because interests were divided and breeders were trying to produce a larger animal that would supply good fat mutton, in place of the small breed of English sheep. Efforts were made to improve the quality of English wool, and George III imported into this country Spanish merino rams and ewes of the famous Negretti breed. These sheep were used for cross-breeding purposes with the Down breeds of the southern counties of England, and have undoubtedly left their mark there. About 1812 there was published a book entitled "The Merino Sheep," which gives an account of the farms in the South of England that received King George III's importation of Merino rams.

George III kept at Kew, from 1787-1791, a flock of pure Merinos, which had been raised from rams, and 36 ewes received as a present from Spain, and in 1804 this flock was purchased by Captain MacArthur. These sheep were taken to Australia, where sheep farming had been started in 1788 with a tiny nucleus of 29 sheep of Spanish breed that had been picked up at the Cape of Good Hope by the first fleet from England that sailed for New South Wales. The introduction of merino blood into English sheep did not produce the desired result of obtaining wool equal in fineness to Spanish wool, and although the English agriculturalists pressed the Government for the taxation of imported raw wool, this protection was not granted, and between the years 1766 and 1907 the quantity of raw wool imported and retained in the United Kingdom increased from about 2 million to 393½ million pounds. The chief sources of supply were Spain and the Canaries, and later Germany, but after sheep farming had had time to become established in Australia, that Dominion became England's chief supplier instead of foreign European countries. The first merino bale of wool, in weight 2½ cwt., was sent from Sydney to London in 1830 and sold at 3s. 3d. a lb.

Progress in the last thirty years has been remarkable, and the outstanding feature is probably the enormous development of wool production in the Empire. The matter is largely complicated by the fact that the sheep is not produced for wool alone, but also for mutton, which, thanks to the development of cold storage transport, has also become an important economical factor in the producing

industry. It is undoubtedly a world problem to produce a good mutton sheep with small joints which will meet the public demand, and at the same time produce a wool of even thickness and good manufacturing value, immune from black hairs, and suitable for the modern requirements in textiles. (Frontispiece.) These factors, beyond the scope of the present treatise, have to be borne in mind in any experiments on wool production, and any scheme of Imperial Wool Research must necessarily co-ordinate these relevant material matters.

From the scientific aspect of wool, the facilities for research have just begun to develop during the last decade, and to-day we find ourselves on the threshold of new knowledge. The question of wool structure, however, has engaged the attention of the scientific world from early times. With the limited microscopic facilities at his disposal, Dr. Hooke in 1664, presented a paper to the Royal Society on the subject of hair and wool structure, whilst in 1690 Leeuwenhoek published a treatise recording his microscopic examination of the wool fibre. The Royal Society again considered the subject in 1742, when Henry Baker presented a thesis on a microscopic study of wool; but until the advent of the compound microscope little further development was possible.

In 1835, Youatt gave a demonstration of the true nature of the wool fibre, and it is interesting to record that his audience included a woollen manufacturer, a cloth merchant, a Leeds veterinary surgeon, a medical man, and an optician (the maker of the microscope)—a combination of scientific and industrial thought that one might almost describe as the first "Wool Research Association." And thus we arrive at the study of the fibre as it is known to-day—a record of patient scientific work, serving to illustrate how much more there is to be done.

BIOLOGY OF WOOL.

The Evolution of the Coat of the Sheep.

Hair is the characteristic covering of mammals, and consists typically of three layers. The outer layer is composed of extremely thin flat scales, known as the cuticle. The next layer, the layer that forms the main strength of the structure, is the cortex, which is composed of a tightly packed mass of long spindle-shaped cells. In the case of most hairs, the cortex forms a hollow cylinder enclosing

the medulla, usually air-filled. A modification is found in certain cases involving the disappearance of the medulla; in general it is the fine fibres that have no medulla. The most important characteristic that distinguishes wool from the hairy covering of many animals is that it is a solid rod without medulla, but this is by no means an absolute distinction. Fibres can be found that are certainly not wool and yet have no medulla, whilst many wool fibres show traces of medulla formation, or may even have quite a well-developed one. To make the presence of the medulla the distinguishing criterion begs the whole question. It must be admitted that no absolute criterion exists that distinguishes wool from hair.

Much fundamental work is required on the minute structure of skin and hair. The intimate details of the process of keratinisation during which the soft cells, full of protoplasm, become converted into horny hard structures have yet to be explored. The precise stimuli which affect the hair in its growth are not known. How far hairs can be affected in their growth by local factors, or how far factors are general, is equally unknown. Nevertheless, this histological study is absolutely fundamental, and progress in other directions, as regards wool research, cannot long be maintained without reference to wool as the product of a living animal.

Many mammals possess a coat which has a double function. The outer coat serves mainly to protect the skin from injury and to prevent the inner coat from becoming entangled. Owing to the characteristic slope of the hairs of this coat, a smooth surface is presented to obstacles. It is usual to find that the fibres of which the outer coat is composed are relatively coarse. The inner coat, on the other hand, serves to conserve body heat, the fibres of which this inner coat is composed usually being relatively fine. It is to be noted that this distinction is a functional one, and in some animals the same fibre may contribute to the formation of both coats. To a certain extent this is the case in the rabbit and some other rodents. Very fine inner coat fibres exist, but while the portion of the outer coat fibres that is farthest from the skin is extremely coarse, the inner portion of these fibres is relatively fine. The result is that the fibre bends over at the junction of the coarse and fine portions, giving the smooth glossy coat. In animals allied to the sheep, it is usual to find that the two coats are structurally distinct. There is an outer coat of coarse fibres and an inner coat of fine ones. Nevertheless, fibres having the double structure, to which the name heterotypes

has been given, are sometimes found. Primitive wild sheep that are held closely to resemble the ancestors of the domestic breeds, possess this double coat made up typically of two entirely distinct types of fibre.

There are few structures in the animal body in which closer adaptations to environment are to be discovered than the coat. To quote only a few examples: the covering of bats is exceedingly short and fine; hairs in the case of aquatic mammals largely disappear, the warmth-retaining function being taken over by subcutaneous fat. Animals that originally possessed the typical double coat, if living under conditions of great heat and dryness, tend to have the inner coat reduced, the warmth retaining function becoming of less importance. On the other hand, in animals living under conditions of great cold, the warmth retaining function becomes exceedingly important. A good example is the case of the musk ox, which has a well-developed inner coat composed of very fine fibres. If the common rabbit and the common hare are compared, it is found that the hare has considerably more inner coat than the rabbit, and less outer coat. Doubtless the difference is associated with the fact that the hare lives under exposed conditions, unlike the rabbit, which lives in a warm burrow. The result is a great increase of the inner coat at the expense of the outer coat, which is proportionately reduced.

Many wild sheep live at great altitudes, and it is extremely probable that this process occurred in the case of the ancestors of domestic sheep. Man, assisting this tendency by a process of conscious selection, eventually has obtained an animal in which the outer coat has almost disappeared, the great bulk of the covering being developed from the under coat. In the modern sheep, however, remnants of the outer coat are still to be found in the form of thick coarse fibres making up the bulk of the birth coats of the lambs of many breeds; in the form of the short stiff hairs of the face and legs; and, most important economically, in the form of kemp, coarse, short, brittle fibres which are to be found in varying amount scattered throughout the fleece.

It was pointed out that the heterotype fibres, *i.e.*, fibres one portion of which belongs functionally to the inner coat, and the other portion to the outer coat, are characteristic of some animals, and are not unknown in the primitive sheep. These heterotype fibres are to be found in some modern domesticated sheep.

It is especially interesting to note that a compensation effect appears to take place in the fleece ; the outer coat having practically disappeared, the inner coat has to take over some of its functions, and, as a result, in many forms the developed, modern inner coat is very much coarser than the fibres of the inner coat of the primitive sheep, which are extremely fine. It is held by some observers that the long, straight and extremely coarse fibres characteristic of the coat of the Scots' Blackface are to be regarded as inner coat fibres that have undergone this process of secondary modification.

It is characteristic of the coat of many animals that a periodic moulting or shedding occurs. In the case of the primitive sheep, both coats are shed annually. The inner coat, which is essential to the well-being of the animal during the winter months, is shed in the spring, and the new inner coat thereupon commences its growth. It is to be noted that this shedding takes place very rapidly, the entire inner coat appearing to become detached from the skin during a relatively short period of time. The coarse outer coat fibres are also shed, but not at the same time. This process occurs later in the year, and in contradistinction to the shedding of the inner coat, the fibres do not appear to cease their growth simultaneously. The shedding process extends over a considerable period.

In the case of the derivatives of the outer coat found in the modern sheep, the same process of shedding can be made out. For example, kemp appears to be shed during a considerable period, which is probably August–October in the northern hemisphere ; this is followed by a period of quiescence during which no kemp is growing. The new growth commences in early spring. An interesting modification of the process of shedding can be made out in the bulk of the fleece, *i.e.*, the inner coat. In some domestic varieties of a relatively primitive type, the shedding of the inner coat seems to take place much as in the primitive breeds and the fleece comes away naturally in large masses, the whole process of shedding being finished in a comparatively short period. At the other end of the scale comes the Merino, which may be regarded as possessing the most highly developed fleece of any sheep, and in this type, under normal conditions, practically no shedding of wool fibres occurs at all. The fibres grow on continuously. In the case of other breeds, between these two extremes, intermediate conditions are found, depending upon two modifications. In the first place, some of the fibres may be shed,

but not all. In the second place, the fibres may not be shed but become reduced in diameter at a time corresponding to that at which the primitive inner coat would be shed. These two modifications may lead to a condition in which the fleece is eventually shed, but not so cleanly as in the primitive sheep, because a proportion of the fibres do not actually cease their growth, but are broken. Other sheep may shed patches of their fleece in this way, but if they were not shorn, not all the fleece would be shed. In yet other cases, the fleece would not be shed at all, but a very definite line of weakness would be found if the fleece were allowed to grow on continuously. There are a number of practical considerations connected with the shedding of the fleece that will be referred to later, but it may be pointed out here that the production of cotted or matted fleeces is due to a shedding of some of the fibres without a shedding of the whole coat, the fine terminal portions of shed fibres becoming entangled. The "rise" in the wool which is taken as the indication for shearing in some of the English breeds, depends upon the thinning of the fibres. It does not appear to occur in the Merino, at least not to any extent.

Primitive sheep are usually coloured, and it is found that the colouration is often not the same in the inner and outer coats. There is a tendency for the outer coat to develop much more pigment than does the inner coat. In some cases the inner coat may be white. In modern breeds this tendency may also be noted in a breed such as the Suffolk. Derivatives of the outer coat, viz., face and leg hair, kemp, and the portions of the birth coat that are derived from the outer coat, are mainly black. The wool fibres are, for the most part, white, except that the tips are sometimes coloured. It will be shown later how closely these considerations are linked up with questions of the occurrence of scattered coloured fibres in the fleece, a defect of the greatest economic significance.

The Fleece of the Sheep from the Point of View of Biology.

From the point of view of biology, the unit for study is the complete fleece. This must also be the unit from the point of view of the sheepbreeder, but it is not necessarily or even usually the unit from the point of view of the manufacturer, because fleeces are often divided into different portions that are then used in entirely different ways.

The study of the fleece from the biological point of view consists, in the first place, of a close study of the development and fundamental structure of skin and hair. Every investigation must be checked up against research of this kind.

This is followed by the study of differences. Individual fleeces differ as regards all their numerous characteristics from point to point over the skin. Differences are found in the fleeces of individual sheep of the same strain and the same breed. Larger differences between breeds may also be distinguished. It is necessary to analyse these variations and to elaborate suitable systems of measurement that shall define the differences in strict terms.

Many of the differences characteristic of fleeces are of a hereditary nature. It is, therefore, necessary to study the inheritance of fleece characteristics. It cannot be emphasised too strongly, however, that success in breeding analysis depends upon the success with which the fleece differences that have been studied can be measured and expressed.

There is no doubt that the nature of fleeces can be affected by environmental agencies, such as climate, food, and the rest. Again, the prerequisite to successful experiment is a system of fleece analysis.

Fleece characters are frequently interrelated, *i.e.*, it is impossible to secure variation in one direction without a corresponding change in others. The study of such interrelationships forms a large portion of the field. In addition, in the study of wool from the sheep-breeding point of view, it is not sufficient to consider only the fleece. The entire sheep must be studied as an economic unit. In the first place, the sheep has to live and thrive at all stages in its life-history in relation to a particular set of environmental conditions, and relationships do exist between fleece characteristics and hardiness in this wide sense. In many parts of the world, mutton production is more important than wool production ; in others, mutton production is a less important factor. Again, there is a complex series of interrelationships that must be studied if success is to be obtained.

In conclusion, it must be pointed out that physical, chemical, technical, and other investigations on wool have as their material a substance that is a characteristic structure of a living organism. A knowledge of the biology of the fleece is the essential and fundamental basis for subsequent work.

Variations in Fibre Types.

It has been pointed out in the brief note on the evolution of the coat of the sheep that different fibre types are to be recognized. The first step in fleece analysis is to recognize such types, to estimate their relative proportions in different areas in the fleece and their relative proportions in different fleeces. The clearest distinction that can be made out is that between kemp and other fibres. In some forms such as the Merino a distinction between kemp and the other fibres is clear and unmistakable. In other sheep in which the fleece is coarser, the distinction is not so clear. Fibres may be found which are structurally difficult to classify. Attention to the method of growth, however, makes it possible to draw a sharp distinction. It was pointed out that kemp is invariably annual in its growth, whereas wool in the modern sheep usually grows continuously, and even when it is shed this takes place at a different time from the kemp. On these lines it has been possible to distinguish this particular fibre type and to estimate its proportion quantitatively. If relatively large amounts of kemp are present as in some English breeds, the proportion by weight is determined. If the quantity of kemp is relatively small, this is determined as the number of fibres per unit weight. The first method for the elimination of kemp presents itself here, *viz.*, rigid selection against the outer coat in all its forms, whether kemp itself, hairy birth coat, or face and leg hair. This is done in practice in the case of the Merino, except possibly as regards the birth coat.

Heterotype fibres present in some ways a special problem. The hairy birth coat is normally shed, in some sheep being replaced by wool without subsequent regeneration of kemp to any extent; in other cases there is regeneration in the form of kemp annually. There is some reason for supposing that one and the same follicle can produce at one time a kemp fibre, at another a wool fibre, and in certain cases the hairy fibre characteristic of the birth coat is not shed before the wool fibre takes its place, but a wool fibre is developed with the complete kempy birth coat fibre forming its outer end. In practice, however, heterotype fibres are not likely to cause much difficulty, because they tend to vary with the ordinary kemp, *i.e.*, reduction of ordinary kemp secures a corresponding reduction of heterotypes.

It is possible to draw distinctions between types of fibre occurring in the same fleece, and separation of samples into these types is occasionally useful; but up to the present, except in the case of

kemp, rigid distinctions cannot be drawn. The differences, while marked in extreme cases, are yet not absolute, as fibres can be found that represent every gradation between extremes. Separation of fibre types, therefore, except in the case of kemp, must depend upon the establishment of arbitrary standards, and involves an individual judgment that limits useful analysis on these lines.

Variations in Fibre Structure.

From the point of view of the manufacturer, wools are classified largely upon the characteristics of fibres which may be regarded as of the same general type, but which exhibit great variations in structure. For example, wool fibres in different cases differ enormously as regards fineness, length, waviness, strength, and so on. Individual fleeces show great variations in these respects from point to point, and the differences between different sheep are frequently enormous. For biological purposes, it is necessary to measure these differences, recognizing that they are quantitative, and not qualitative, in fact to analyse a fleece as one would a soil. In view of the use to which wool is put, the simplest and most obvious characteristics that immediately affect the value are dimensional, but nevertheless there are other chemical and physical properties of no less importance directly or indirectly, although they may not be of so obvious a nature.

It has been pointed out that the biological unit is the complete fleece, and the first question that arises is that of sampling. How to sample a fleece in order to measure each of the various characteristics for which an accurate method of analysis has been devised, represents an enormous task, that, when completed, will introduce some certainty into observation and experiment.

A single fibre may vary considerably in its cross-sectional area from point to point. This is normally measured microscopically, and a determination of thickness in this way may in certain cases be of great importance. Different fibres from the same particular small sample may show very great differences in average thickness. There will also be a mean thickness for a whole group of fibres, a section of a fleece, or a complete fleece. The mean thickness of an entire sample may be determined by estimating the number of centimetres of fibre that weigh a milligram. On this system of measurement a Lincoln sample may give a thickness of the order of

60 cms. per mg. A fine Merino will give a thickness of 350 cms. per mg. Variations in the average thickness of individual fibres in a sample may in certain cases be of great importance. This is usually determined microscopically, but it can also be determined by obtaining a weight-length ratio as above for each individual fibre. This process is carried out with the microbalance, an instrument capable of weighing individual fibres. It is interesting to note that considerable variations in mean fineness may occur in different samples taken from a relatively small area. Numerous determinations with the object of estimating sampling errors have shed a great deal of light on the nature of fibre variations over areas of different size; these variations add greatly to the difficulty of determining sampling errors.

The lengths of individual fibres showing a complete year's growth are important, and here again remarkable variations are found. If a number of samples are taken from a small area, it can readily be seen that neighbouring locks differ considerably in length, and it is doubtful how far a measurement of the lengths of individual fibres is useful practically, or how far a mean figure possesses much significance.

Differences are to be made out as regards scale structure and as regards the presence or absence of an air-filled medulla. Some writers, concentrating mainly on the finer wools, call "kempy" any fibre that shows an air-filled medulla, but this is a distinction that it is impossible to maintain. There is a certain correlation between thickness and presence of medulla, but it is far from perfect, and in two wools of equal thickness one may contain many fibres that are medullated, whilst the fibres of the other will be quite free from it. The presence of medulla in this sense is to be regarded quantitatively, not qualitatively.

In addition to the few examples that have been given, there are numerous other quantitative differences that can be observed and measured. A number of them that are of great importance, such as tensile strength, crimp or waviness, shape of cross-section, etc., are of a nature that demand adequate physical analysis in the first place. From the biological point of view, it is to be hoped that from this physical study methods will be evolved that permit of the rapid and accurate analysis of fleeces. It is the province of biology to measure the differences between fleeces, to study the hereditary and

environmental factors that affect them, but other sciences must pronounce an opinion on the practical significance of the characteristics measured, and in many cases to the other sciences must be left the task of elaborating technique.

Variations in Growth Rate.

The final length of fibres after a year's growth is the expression of a growth rate. Again, variations in this growth rate have to be measured. It is of importance to note how far the rate of growth of fibres is relatively constant or how far it is seasonal or affected by factors in the normal life of the sheep. Experiments up to the present have tended to show that under normal conditions the rate of growth of fibres in the case of the sheep is remarkably constant. When this conclusion can be confirmed and amplified, it is probable that a study of growth rate will be one of the most useful methods of attack in determining the effect of environmental influences on fleece growth.

Variations in Shedding.

In discussing the evolution of the coat of the sheep, some stress was laid upon the question of the shedding of fibres. Variation in this respect is important practically; the "rise" in the wool is regarded as a convenience in shearing in the breeds in which it occurs, but any process of this type would be a definite disadvantage in a fine and valuable wool. The cotted or matted fleece is a special case. These fleeces are sometimes so closely matted that they can be used as rugs without further treatment. It has been shown that cotting is due to the shedding of some, but not all, of the fibres composing the fleece. It is characteristic of fibres that when they are shed the actual shedding is preceded by a period during which the fibre becomes finer. In the case of the cotted fleece, the fine terminal ends of the shed fibres become closely intertwined. It has been shown that cotting occurs at the time of year corresponding to the shedding of the inner coat in animals where this is the rule. It has also been shown that cotting is, to some extent, a constitutional characteristic of individual sheep, and that this tendency increases with increasing age. It varies to some extent in a given flock from season to season. The case is of great interest because it illustrates the potency of external influences as well as of factors

peculiar to the sheep itself to produce an effect at a time when the fleece is showing the remnants of a process once normal and universal. The whole question of the shedding of wool fibres is another field most favourable for the study of the effect of environmental factors.

Variations in Pigmentation.

The case of the sheep, all of whose fleece is coloured or which shows a definite pattern, is a special one. It may be a question of economic importance in cases where naturally coloured wools are being produced, and it is of the greatest economic importance in the case of the fur sheep, such as Persian lambs, which are bred for their skins. In the case, however, of the bulk of the sheep population, the main interest is confined to the avoidance of coloured lambs.

Scattered coloured fibres, however, occurring in the white fleece are of the very greatest economic importance. There are few defects in wool that are more serious from the point of view of the manufacturer. The simplest and most obvious way to avoid coloured fibres in the fleece is to select against colour wherever it is found, and in whatever form. This is what is done in the case of the Merino. In the case of some breeds, notably the English Down breeds, this course cannot be followed, and there is no doubt that it is almost impossible to secure a sheep with a coloured face and legs whose fleece will be absolutely free from coloured fibres.

It was stated above that there was a general tendency for the outer coat and its derivatives to show more pigment than the inner coat, and the Suffolk sheep was quoted as an example. Scattered coloured fibres in the fleece are frequently of a kempy nature, so that to a large extent variations in the amount of coloured fibres in sheep where this is to be expected, depends upon variations in the amount of kemp. In Suffolks, for example, it is found that sheep with identical faces and legs may show a variation in the amount of coloured fibres in given areas of 1,600 : 1. It is true that new wool fibres may have pigmented tips, but the contribution of the pigment carried in the wool fibres to the total amount of colour present is trifling. There is evidence that the production of colour in certain cases varies with temperature conditions. This last observation, though perhaps of no very direct economic importance, opens up a very interesting field.

Variations in Total Amount of Fleece.

The weight of the individual fleece is a matter of great importance to the sheepbreeder, and it is well known that wide variations are found in different classes of sheep. It is also found that considerable variations exist as between individuals of the same breed and type and even of approximately the same body weight. Studies have revealed the fact that the tendency to produce a fleece of a certain weight is, to some extent, an individual characteristic. It has also been found that fleece weight varies with the age of the sheep and in the same flock the average fleece weight varies from season to season.

A more precise analysis would aim at classifying sheep not on the basis of total fleece weight, but on weight of wool produced per unit area. Little has been done up to the present on these lines owing to difficulties of measurement, and it is only very recently that this procedure has become possible at all. Weight per unit area is likely to become one of the most valuable criteria in wool experiments. One of the factors that enters into fleece weight is the number of fibres per unit area. Until very recently this, too, was a measurement that presented considerable difficulty.

Total fleece weight has formed the subject of several experiments designed to show an influence on the fleece by certain environmental conditions. That variations are caused in this way will be doubted by few. In one set of experiments a considerable increase in fleece weight was claimed as the result of a calcium supplement to the diet. Whether the controls had been fed on a calcium deficient diet is not quite clear. In these experiments, however, the results have not the definiteness they should have because of the lack of an adequate system of fleece analysis. There is no question, however, that along these lines much fruitful information is to be expected in the future. It is known that many parts of Australia are deficient in phosphate, and it is considered that this may be a limiting factor as regards total fleece weight. It is characteristic of hair and wool that they have a high sulphur content. This sulphur, apparently mainly or entirely in the form of the amino acid cystine, must be obtained by the sheep from its pasture. Whether the amount of cystine in the pasture or the capacity of the animal for its utilization may be a limiting factor in wool production is not yet known.

In all such investigations, a question of the utmost importance is precisely how variation in total fleece weight is brought about. If the weight of the fleece can be increased, is this due to the appearance

of a larger number of fibres, which is perhaps improbable ; is it due to a more rapid growth rate leading to a longer fibre ; is it due to an increase in thickness leading to a heavier fibre ; or is it due to a combination of all these ? The answer cannot be given as yet, but there is no doubt that it will soon be forthcoming. In the meantime, the Australian sheepbreeder dare not attempt to increase fleece weight, or what is even more important, in all probability improve the general health and vigour of his sheep by making good the phosphate deficiency, until he is certain that such procedure will not make his wool coarser.

It has been claimed that the fleece of the ram can be improved in quantity, and in quality, by testis grafts. This is now being examined. It is thought that the activity of the thyroid gland may be of importance, though as yet information is not of a definite character.

Allied to the question of total fleece weight is that of "shrinkage," which is the technical term defining the relationship between total crude fleece weight and the percentage of clean wool. The difference is made up of wool grease and foreign matter. Wool grease is of importance biologically ; it has a profound significance in the make-up of the fleece and the general economy of the animal, and is undoubtedly closely associated, as regards the amount in which it occurs, with characteristics of the fleece that are valuable or the reverse.

The arrangement of fibres on the skin has attracted a good deal of attention, though mainly in animals other than the sheep. It is likely to prove an important subject.

Variations in Group Characteristics of Fibres.

Groups of fibres considered together fall into a definite arrangement in many cases. Locks are to be distinguished that have in a sense an individuality of their own that cannot be expressed or at least cannot be simply expressed in terms of the individual characteristics of the fibres composing the lock. Such questions as curl, crimp, and general arrangement of fibres, the ease with which the wool parts into locks, and the variations between neighbouring complete locks are all of importance.

The Interrelationship of Fleece Characteristics.

For purposes of simplification, certain fleece characteristics have been separately treated up to the present, but, of course, there is intimate connection between them in many cases. For example,

there is a correlation, by no means perfect, but nevertheless large, between length and thickness, another between thickness and total fleece weight. In fact, it would be true to say that in many cases it would be impossible to consider any single fleece characteristic without also taking others into account. Variation of one will lead automatically to variation in the case of others, and a study of these correlations is one of the most important subjects for wool research. Some characteristics have little significance on their own account in manufacturing processes, but are correlated with characteristics of great importance; for example, crimp as crimp is not supposed to be a factor of great moment in the spinning of wool, yet it is nevertheless in some directions and with some reservations an undoubted index of characteristics that do affect spinning. A good example of the importance of the associations of fleece characters was made clear in the case of the Welsh Mountain sheep. In this breed the outstanding defect is kemp, and it was desired to discover how far kemp was associated with other fleece characters. It was found that kemp was not appreciably associated with fineness, length, density of fleece or lock formation, but on the other hand, these four other characteristics did tend to vary together. A kempy sheep, therefore, may have fine or coarse wool, a non-kempy sheep equally may have fine or coarse wool. This conclusion, that in all probability applies to any breed, is of great importance. Selection or other appropriate breeding procedure designed to vary the proportion of kemp will not automatically affect the quantitative characteristics of the remainder of the fibres. If fibres other than kemp are considered too coarse, selection to eliminate this undesirable characteristic must be practised in addition. In the same breed (the Welsh Mountain) it was found that the occurrence of kemp was, moreover, closely associated with the nature of the birth coat of the lamb. It was found that those lambs that possessed thick hairy birth coats had, on the average, the most kemp in the adult fleece, and from the results with this breed certain facts of general importance may be deduced. In the first place, kemp does not occur in any quantity unless the lamb possesses at birth a hairy birth coat. If the lamb does possess a hairy birth coat, kemp may or may not be present in appreciable quantity when the fleece has matured. It is thought that the tendency of the thick birth coat to regenerate in the form of kemp is related to the rate of shedding of that birth coat. If it is quickly shed, little kemp will regenerate, and *vice versa*. In some breeds kept under comparatively easy conditions, the birth coat of the lamb is of little importance, and

selection of those lambs which tend to have few or practically no coarse hairy fibres at birth will be of immediate assistance in reducing kemp. But in many mountain breeds the hairy coat is considered to be a factor of great importance conducing to the hardiness of the lamb during the first few hours of its life if conditions are adverse. In such a case it is necessary to select against kemp whilst at the same time preserving the hairy birth coat. The facts mentioned relative to shedding are likely to be of material assistance in this task.

The same consideration relative to the rate of shedding of the birth coat applies in the case of an attempt to reduce the proportion of coloured fibres in the fleece. In this case, the rate of shedding of the lamb's coat can be readily noted by the eye as a rate of change of colour. Suffolk lambs that rapidly lose their dark colour are likely to be far more free from dark fibres as regards the adult fleece than are Suffolk lambs in which the rate of change of colour is relatively more slow.

Associations between fleece characters and the general hardiness of the sheep, *i.e.*, the ability to live and thrive under any particular set of environmental conditions, is no less important. It is generally accepted that the highest development of wool and of mutton cannot be obtained in the same individual, and there seems to be little doubt that mutton qualities and fleece qualities are associated in some way. Very little is known on this subject as yet, but it is one that requires thorough study if useful schemes of wool improvement are to be elaborated.

Conclusion.

The ultimate structure of wool and of hair, the development of the fibre from its beginning until it is complete, lie at the basis of all wool research. Variations both qualitative and quantitative in the composition of the fleece are the material upon which is based the work of the sheepbreeder and of the biologist. In many cases a thorough study of the fleece, a definition of its characteristics and of their variability, an appreciation of their interrelationships and of their association with other characteristics of the sheep, and finally a harmonisation of the requirements of the sheepbreeder and manufacturer meeting upon a common and scientific ground, are sufficient to define standards for a breed that will secure by the known methods of selection an improvement from the point of view of both interests. Practically, it is not so much a question of evolving something new

and better that does not at present exist in a breed—it is a question of deciding after full examination of all relevant considerations, what is the best type already existing in a breed. The breeder, following his traditional method of selection and, it is to be hoped, assisted by scientific discovery, can then secure rapid improvement by bringing the average nearer to the best.

Whilst this alone can produce great improvement, the biologist must go further. It is necessary to define the heritability of fleece characters, and no less necessary to define the variations that can be produced by a varying environment, varying climatic conditions, varying food, and varying treatment. In this way the biologist may hope not only to clarify the breeder's conception of the make-up of the fleece, but state its variations in terms that can be related to commercial utilization, and eventually assist him to control his material in the most rapid fashion possible, and to produce what is found to be economically desirable.

CHEMISTRY OF WOOL.

General.

A discussion of the chemistry of wool falls under two headings; the chemical problems that arise during the production and manufacturing treatment of wool, and the problem of the determination and investigation of the chemical nature of wool fibre itself. Under the first heading appear such problems as the following :—

- (a) Chemistry of sheep dips, sheep marking material, and wool grease, an important but little exploited by-product.
- (b) Chemical changes in wool subsequent to shearing, for example in storage. Treatment up to the spinning stage, the ideal being to preserve the natural properties to the utmost.
- (c) Chemical effects deliberately sought after to modify or obliterate certain natural properties in order to render the wool more suitable for such processes as bleaching, milling, felting and rendering unshrinkable or to modify the dyeing affinity and lustre, or increase the resistance to various forms of decay.

(a) and (b) are very obviously associated with wool production. The main qualities of a wool only become fully revealed at the spinning stage, and the relative resistance of various wools to the conditions leading up to that stage is an important factor from the

wool growing standpoint. The relation of (c) is more distant but still real, since the relative amenability of different wools to such processes must reflect back upon their production.

Under the second heading comes a survey of the chemistry of the substance of which wool fibre is found to be substantially composed, namely, wool keratin. Investigations are being carried out to ascertain the chemical constitution of keratin and the biochemical basis of its formation. Further studies include the variation of its composition with different wools and with changes during growth caused by such variables as weathering, environment, nutrition, etc. Naturally the wider aspects of the chemistry of wool mentioned above are closely related to this more particular study of the nature of keratin itself, for the practical success of chemical processing of wool for specific effects necessitates knowledge of the underlying chemical changes in the keratin, the elucidation of which should give us more efficient control of such processes, and render possible the use of new processing reagents and effects.

A comparison of the chemistry of wool with that of the other textile fibres shows that whereas the constitution of cotton, flax and the synthetic fibres is relatively well established, that of wool is ill-defined. The two chief reasons for this are as follows :—

First, wool is a natural product requiring only removal of dirt and grease to make it at once available for manufacture. Other fibres require direct chemical processing to bring them into a manufacturing condition, such as retting in the case of flax, and various synthetic operations for the production of artificial silk fibres. Especially with the latter a thorough knowledge of chemical constitution and properties is a necessary antecedent to manufacture, whereas with wool, formerly this has been less imperative and the subject has been consequently somewhat neglected. However, it is now being realized that the more completely the chemical character of wool is understood the greater will be the possibility of variety of effects produced in fabric form, which should popularize and increase the demand for woollen textiles. An interesting example of industrial expansion incident upon new possession of chemical knowledge is afforded by the rubber industry. Within recent years the commercial use of rubber has expanded tremendously, consequent upon the determination of the effect of vulcanization (the amount of sulphur incorporated) upon its durability and elasticity. It is a stimulating view to regard sulphur as the constituent conferring hardness and elasticity to wool substance, reference to which will be made later.

Secondly, the keratins are the most complex of those products of animal metabolism known as proteins, our understanding of which, even in the simpler members, is still incomplete. In attempting to determine the chemical nature of the material which feeds the woollen industry, the chemist is therefore confronted with one of the most complicated materials in the whole field of organic products, and progress is correspondingly difficult and slow. In spite of difficulties, however, valuable progress towards the eventual solution has already been made through chemical and biochemical work upon the constituent units into which wool can be broken up by hydrolysis. These are for the most part amino acids.

The Nature of Wool Keratin.

It is a coincidence of the happiest kind, as was first pointed out by Drechsel (*Ber. Sächs. Akad. Wiss.*, 1889, **41**, 117), that hydrolysis, brought about by acids or alkalis, under laboratory conditions, seems to follow a very similar course to that which occurs in the physiological environment when digestive enzymes attack the natural proteins taken in as food. Certainly the end products are the same, and hence the biochemist is able to make quantitative analyses of his material with the knowledge that the substances he weighs are the true building stones or unit structures which form, when united, the parent protein, and are not artifacts produced during the chemical manipulations unavoidable during the course of the analysis. This point is one of some importance and worthy of more attention than it often receives. But although it is quite certain that amino acid anhydrides (or diketopiperazines) are to be found amongst the products of protein hydrolysis, it is unsafe to conclude that these structures exist as such in the natural protein. An argument strongly militating against such a view is the experimental observation that diketopiperazines are completely resistant towards proteolytic enzymes, whereas proteins are digested by them with ease.

In all, some twenty of these constituent units have been isolated from proteins and identified. They are all α -amino acids, with the exception of proline and oxy-proline, both of which contain the pyrrole ring. Although similar in this respect they may nevertheless be grouped according to the characteristics which they show as a result of the rest of their molecular constitution. Thus, arginine, histidine and lysine are predominantly basic in character, whilst aspartic and glutamic acids, each of which belong to the class of dicarboxylic acids, show predominantly acid characteristics. Most proteins yield, upon hydrolysis, a large variety of these amino acids in varying proportions, but in some, one or other may be absent.

Wool substance, apart from grease and moisture, is almost entirely protein in nature. Its characteristics entitle it to be classified as one of the group of keratins—proteins distinguished by their insolubility and comparative resistance to enzyme hydrolysis and also by their relatively great sulphur content. Analyses of wool keratin have been carried out, and, as in the case of other proteins, a mixture of the known amino acids has been obtained. The accompanying figure (Fig. 1) illustrates the yields obtained of each, and hence their relative importance in the complete wool structure.

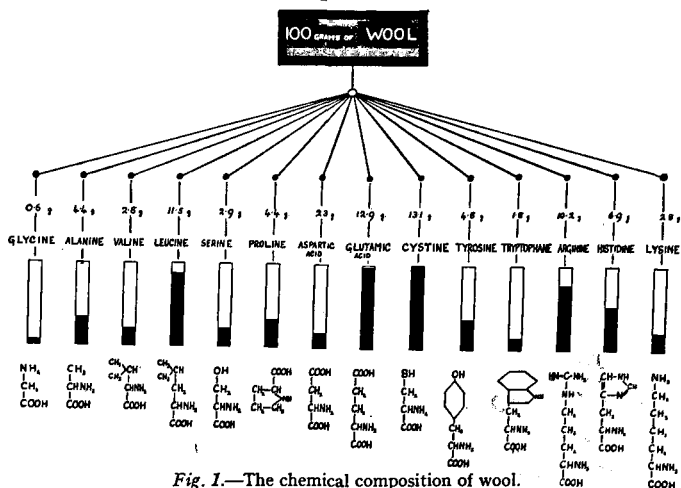


Fig. 1.—The chemical composition of wool.

It will be seen that *cystine* constitutes the largest portion, amounting to 13.1 per cent. of the wool keratin. This is the figure recently established by Rimington (*Biochem. J.*, 1929, 23, 41). The greatest interest attaches to this amino acid, since it is the only one (with the exception of the recently discovered* methionine (Barger and Coyne, *Biochem. J.*, 1928, 22, 1417), which contains the element sulphur. Wool is characterized by its high sulphur content, and it has been found that there is a direct correlation between sulphur content and spinning quality.

* Isolated in traces only from gelatin and egg albumin.

Up to the time of Rimington's work only about 60 per cent. of the total sulphur present in wool could be accounted for as cystine (Barritt, *J. Soc. Chem. Ind.*, 1927, **46**, T 338-41) and it was left as a matter of uncertainty whether the remaining 40 per cent. represented some hitherto undiscovered compound, or whether the discrepancy was due merely to the losses incidental to the methods employed. This important question was solved by the use of the new technique which Rimington employed in his investigations, and 99.5 per cent. of the sulphur was accounted for as cystine.

A table of some of the results obtained with wools of different sulphur contents and with animal hairs is reproduced below (Table I).

In this table the cystine content in the acid hydrolysate found by (1) Sullivan's method and (2) Folin and Looney's method is compared with the cystine content calculated by assuming all the sulphur to be present in that form. The difference between the figure obtained by Sullivan's method and the calculated cystine content is also shown, being expressed as a percentage of the latter.

TABLE I.

Wool.	Total S per cent. dry wt.	Cystine in Hydrolysate.		Total S of Hydro- lysate (as cystine). g.	Ratio.*
		By Sullivan's Method (max. value). g.	By Folin and Looney's Method. g.		
Crossbred 50s I	3.46	0.3780	—	0.3602	-4.94
" 50s II	3.47	0.5700	0.5950	0.5815	+1.99
" 50s III	3.54	0.5575	0.5673	0.5589	+0.25
Devon lamb	3.34	0.5755	0.5825	0.6001	+4.10
Welsh mountain	4.08	0.6300	0.6400	0.6277	-0.37
Turkey mohair (coarse) ..	3.02	0.5978	0.6080	0.5948	-0.50
Turkey mohair (fine) ..	3.18	0.5405	0.5564	0.5393	-0.22
Cape merino	3.67	0.5875	0.5863	0.5887	+0.02
White Samoyed dog hair ..	5.07	1.0400	1.0080	1.0265	-1.31

* $\frac{\text{Total S (hydrolysate)} - \text{cystine (Sullivan)}}{\text{Total S}} \times 100.$

Referring once more to the figure (1) there are further peculiarities in the chemical composition of wool which are well worth discussion. The high glutamic acid content (12.9 per cent.), would lead one to expect at first sight that wool should be a substance pronouncedly acid in character and having an affinity for basic dyes. It is well known that, in reality, the reverse is the case, and looking once more at the chart this is seen to be due to the unusually large proportion of basic amino acids—arginine, histidine and lysine—which in the aggregate amount to nearly 20 per cent. of the whole protein. The total dicarboxylic acid content, that is, aspartic and glutamic acids together, reaches only 15.2 per cent., thus leaving about 4.8 per cent. of strongly basic material which undoubtedly confers upon wool its affinity for acid dyestuffs. The isoelectric point of wool is given as pH 3.4 by Marston (1928) and as pH 3.6—3.8 by Meunier and Rey (1928), whilst the earlier work of Speakman (1925) gave a value of pH 4.8.

Passing to the consideration of the rest of the chart, there are only two other features calling for special comment—the remarkably high leucine content and the proline content which is slightly greater than that usually found in proteins, although keratins and plant proteins appear as a general rule to be richer in proline than animal proteins. The high leucine content is interesting in view of the fact that its parent substance—isobutylic acid—is a branched chain fatty acid, a type not very frequently encountered in natural materials.

Wool Grease.

The characteristics of wool grease vary with the source of supply ; thus fat from Merino wool is softer than that obtained from coarser wools. Its chemical constitution is complex, and our knowledge of the different constituents and their composition is not complete. The work of Drummond has shown that the bulk of the mixture comprising wool fat consists of esters of stearic, palmitic and cerotic acids with the higher alcohols. Only about 4 per cent. of free fatty acid is present and about 4 per cent. of free cholesterol. The unsaponifiable portion consists largely of cholesterol and iso-cholesterol, the alcohol present in greatest amount being cetyl alcohol. Rather remarkable, is the complete absence of ergosterol, the precursor of the anti-rachitic vitamin D. The fact that no glycerides are found in wool fat, classes the substance, strictly speaking, as a wax and not a fat.

Wool fat is used in the manufacture of pharmaceutical preparations, soap and candles, oils and lubricants, printing inks, shoe polishes and varnishes, illuminating gas ; it is also used in such industries as the rubber, textile, and leather industries, and in the manufacture of paving materials. The use of wool grease in the commercial world is steadily increasing, new uses are being found both for it in the crude state, and for the products arising from it. There is scope for a great deal of work on the chemical problems concerning methods of separating its constituents and the application of those methods and the products arising therefrom, to industry.

It must be emphasized that a complete analysis of wool, such as that represented, is of the utmost importance since all chemical operations refer ultimately to the composition of the material which is being dealt with. An analysis, however, is able to solve only one-half of the whole problem, the other aspect presenting itself for solution is the manner in which these units are connected to each other and organized to complete the whole structure as we know it in its familiar form. So far, however, our knowledge is not sufficiently quantitative even to speculate on the disposition of the various constituents within the keratin complex. (See Appendix, page 156.) Even so, the lack of such knowledge is by no means a complete barrier to a satisfactory understanding of the chemistry of keratin, for although we may not know exactly where each structural unit fits, the behaviour of the complete complex will necessarily be better interpreted as the constitution and properties of its constituent units are more precisely determined.

As has been mentioned above, preliminary work by Barritt (*loc. cit.*) has culminated in its having been shown by Rimington that the whole of the sulphur in wool is present as cystine. This is a measurable step towards elucidating the structure of wool keratin, and incidentally is a valuable contribution to biology. Not only does it simplify all problems in hand involving sulphur content, including the general chemical behaviour of cystine as reflecting changes occurring in wool substance, but it provides a working hypothesis of the biological process of keratinisation. Histology of the wool fibre shows that the cells of the wool substance are developed from the cells of the basal layer of the epidermis. (Duerden, *J. Text. Inst.*, 1926, 17, T270.) The work of Barritt and King (*J. Text. Inst.*, 1925, 17, T394) on sulphur content of wool, showed the percentage of sulphur to be least in coarse kempy fibres, and again Barker and King (*J. Text. Inst.*, 1925, 17, T68) found that coarse kempy fibres contained the

largest proportion of medulla substance. According to King, it would therefore appear that in all probability medulla cells, like the epidermal cells from which they are derived, are substantially devoid of sulphur. Keratinisation, or the formation of real wool as opposed to kemp, possibly results from the incorporation of sulphur into the plasmic material of the cells of the basal layers. Compact cortex and scale cells typical of a wool fibre then result. On the other hand, if the plasmic material fails to become keratinised the resulting cells are protruded upwards into the shaft of the fibre, where they dry up and shrink, forming the honeycomb structure known as medulla. The "sulphur stimulus" is evidently the cystine nucleus.

The biological significance of these observations is clearly indicated for they suggest that deficiency in sulphur content favours medulla formation.

The realization that sulphur content does vary with different wools is quite recent, and indeed no practical significance at all was formerly attached to the presence of sulphur in wool. Trotman and Bell in 1926 (*J. Soc. Chem. Ind.*, 1926, 45, T12) published a summary of the previous work on the subject, and were unable to confirm the various percentages found by previous workers. Their conclusion was therefore as follows: "Consideration of the above results indicates that there is very little variation in the percentage of sulphur in purified wool, and that 3.4 per cent. is probably the maximum value." The results of Barritt and King, however, have proved that the sulphur stimulus must be variable, for the sulphur content of the different kinds of wool examined showed an appreciable variability, as is shown in the following table of typical results, and the accompanying figure 2.

TABLE II.
Sulphur Content of Wools of various origin.

Type of Wool.	Per cent. Sulphur on dry wt.	Type of Wool.	Per cent. Sulphur on dry wt.
Cape Merino (Kaffrarian) ..	4.00	Turkey mohair (fine) ..	3.36
Welsh mountain P.64 ..	3.97	Fine Ripon fleece ..	3.34
Blackface (fine) ..	3.82	Blackface (coarse) ..	3.33
Australian merino, 100s ..	3.76	Blackface (kempey) ..	3.24
Peruvian (1924) ..	3.75	Lincoln (white) ..	3.10
Lamb's wool merino ..	3.83	Turkey mohair (coarse) ..	3.03

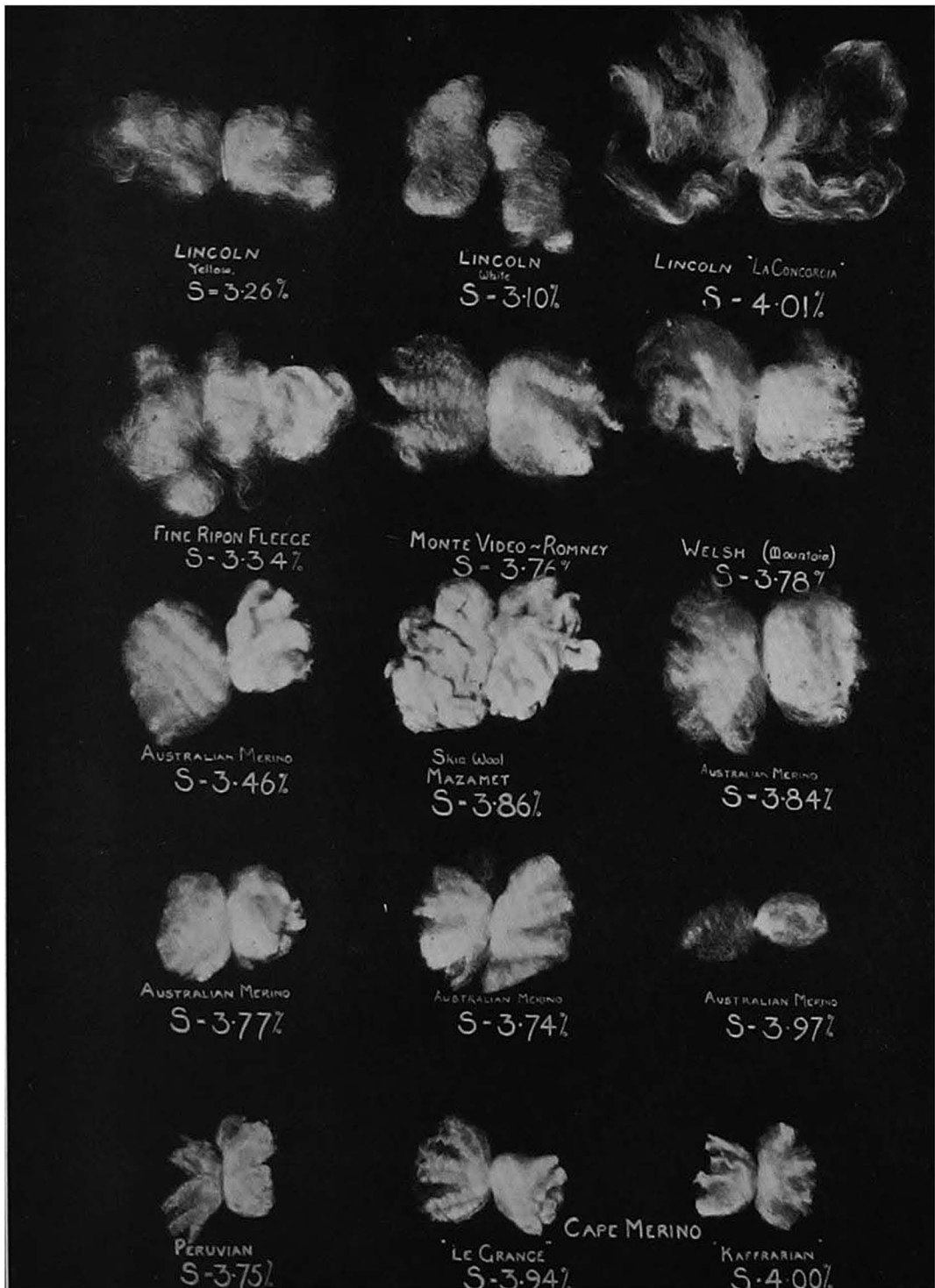


Fig. 2.—Sulphur content of various wool.

Further work (Barritt and King, "The Sulphur Content of Wool, Part II," *J. Text. Inst.*, 1929) showed that not only did the sulphur content of different specimens of wool vary, but also that the amount of sulphur present was not constant in different regions of the same fibre. In almost every case examined it was found that on analysis of a different region of the same lock for sulphur content, the tip was richer in sulphur than the rest of the lock. An explanation of this result was sought in the consideration of the external conditions to which the fibre may be exposed and which would naturally be expected to exert a greater influence on the tip of the fibre which is the most exposed portion. The effect of dipping was first investigated. Wool was treated in the laboratory with a typical sheep dip containing free sulphur and the wool specimen carefully analysed for sulphur content before and after treatment. The result obtained was a sulphur content of 3.78 per cent. of the dry weight before dipping and 3.75 per cent. afterwards. Sulphur dips do not, therefore, add to the sulphur content of wool; that is to say, the sulphur of the dip is not retained by the wool and there is no reason to suppose that it causes any alteration in regain or capillary structure. Secondly, the effect of weathering was considered. It was shown that exposure to ultraviolet light causes a modification of the cystine region of the keratin molecule; sulphur dioxide is formed, part of which escapes as such and part is changed to sulphuric acid, the total sulphur content thus being diminished. With this loss of sulphur the wool shows a modified affinity for stains and dyes and a diminution of strength. The climatic conditions which favour low sulphur content are, therefore, exposure to sun and rain, and it is found that when the wool fibre is not well protected by the natural grease undesirable "tippy" wools result. The effect of weathering is, therefore, in the wrong direction to explain the greater sulphur content in the tip region of fibres, and we are at liberty to conclude that wool which has not been greatly weathered would exhibit the phenomenon of excess sulphur at the tip of the lock to an even greater extent.

Variation of sulphur content with colour was also investigated and the general rule obtained, using samples of wool from Jacob's flock and Badger face sheep, Alpaca and rabbit wool, was that the less the amount of pigment the greater the sulphur content, and further, that the higher the sulphur content the lower the regain of the wool.

An investigation (Barritt and King, *J. Text. Inst.*, 1929, June) of the effect of commercial processes on sulphur content of wool showed that normal processing has little effect, and it is, therefore,

evident that changes in physical properties accompanying such processing as normal chlorination, are out of all proportion to the actual changes in chemical composition, at any rate as far as the sulphur content is concerned. Increasing the concentration of alkali in a normal commercial scouring solution of soap and alkali and also increasing the time of treatment caused a progressive diminution in the sulphur content of a sample of wool with a corresponding yellowing and loss of "handle." Treatment of a sample of Australian crossbred wool with saturated lime water caused a decrease in sulphur content from 3.66 per cent. to 2.10 per cent. of the dry weight after 250 hours' contact with the solution. The effect of chlorine water of various concentration again showed that normal treatment causes only slight loss of sulphur, but that intensifying the chlorination to as much as 31 per cent. on the weight of the cloth gives rise to a diminution in sulphur amounting to nearly 1 per cent. of the dry weight. Regain decreases with increase of chlorination and decrease of sulphur content.

To find all the factors affecting the variation of sulphur content of wool, and thus ultimately to control the amount of sulphur present, is the ultimate goal of this investigation. Breeding, environment and the pathological condition of the sheep will almost certainly play an important part.

Hopkins (1921) has identified a derivative of cystine—glutamyl cystine, a dipeptide of cystine and glutamic acid—present in low concentrations in many animal tissues. This substance plays an important physiological rôle in living matter, fulfilling the function of an oxidation catalyst. Wool is comparatively rich in both glutamic acid and cystine, these amino acids being present in almost exactly equal quantities (12.9 per cent. and 13.1 per cent. respectively), and it is not without interest to speculate upon the possibility—assuming that the molecules of each are associated in peptide linkage—of the union conferring upon wool some of its peculiar properties such as its chemical stability and resistance.

Much of this section of wool chemistry may be well summed up in the question, "Is high sulphur content desirable and can this factor be brought within the breeder's control?" The full answer has yet to be given.

An investigation to determine the nitrogen content of wools of various origin (Barritt, *J. Soc. Chem. Ind.*, 1928, 47, T69) gave results which show that the variation in nitrogen content appears to

be very small, the extreme values found for unpigmented sheep's wool being 16·50 per cent. and 17·07 per cent. of the dry weight respectively, as is seen from the table below.

TABLE III.
Nitrogen Content of Wools of various origin.

Type of Wool.	Per cent. Nitrogen on dry wt.	Type of Wool.	Per cent. Nitrogen on dry wt.
Alpaca black, No. 1	15·85	Mazamet	16·71
" " No. 2	15·88	Devon lamb	16·71
Jacob black	16·16	Fine Ripon fleece	16·72
Peruvian merino	16·50	Rabbit wool	16·72
Jacob white	16·52	Australian merino lamb, No. 1	16·73
Welsh mountain, S.10 ..	16·54	Scotch blackface (medium) ..	16·74
Australian merino, 60's, C.22..	16·57	Australian merino, 64's, F.87	16·76
Welsh mountain, P.5 ..	16·60	" " 60's, A.4 ..	16·78
La Condordia Lincoln ..	16·61	" " 60's, F.86 ..	16·79
Lincoln yellow	16·62	Lincoln white	16·80
New Zealand matchings, 50's	16·62	Australian merino, 64's, F.85	16·82
Scotch blackface (fine) ..	16·63	Mohair (fine)	16·83
Australian merino, 64's, A.6 ..	16·63	Australian merino, 60's, E.64	16·86
" " 58's, A.3 ..	16·63	Alpaca (white)	17·00
Alpaca (brown)	16·66	Australian merino, 64's, E.76	17·01
Mohair (coarse)	16·70	Monte Video	17·07

The average value of the nitrogen content of the samples in the table is 16·72 per cent. (excluding coloured wools, and rabbit wool). It is obvious that there is no characteristic variation in nitrogen content such as is shown in the sulphur content of wool.

The results for coloured wools are interesting. The Jacob's flock samples (piebald sheep) were taken from the same animal and the difference between the white and black (16·52 per cent. and 16·16 per cent. respectively) is much more than can be ascribed to experimental error. The coloured samples of Lincoln and of Alpaca are also seen to give lower nitrogen contents than uncoloured samples of the same kind of wool. This result has also been obtained by Gortner (*J. Amer. Chem. Soc.*, 1913, 35, 1262) who determined the distribution of nitrogen in black and white wool from the same animal. His results were 16·27 per cent. of nitrogen for the white

and 15.11 per cent. for the black wool. This shows an even greater difference than that obtained with the samples from the Jacob's flock. The difference in nitrogen content obtained with increasing colour contrast suggests that the coloured samples contain a pigment of lower nitrogen content than that of normal wool. The effect on the nitrogen content of wool of scouring, carbonising and chlorination were also studied and the results appear in Barritt's paper (*loc. cit.*).

In conclusion it is obvious that elucidation of such a fundamental property as chemical composition could not fail to supply us with knowledge that should make for the attainment of the best result, not only in wool production, but also in processes of manufacture.

THE PHYSICAL CHARACTERISTICS OF WOOL.

The physical nature of wool may conveniently be discussed from two different aspects, namely :—

- (1) The inherent physical properties of the fibre itself.
- (2) The measurement and assessment of importance of dimensional characteristics.

In the first place there are properties of a purely physical nature which have to be considered, such as, *e.g.* :—

- (a) Hygroscopic nature : Phenomena of moisture absorption ; heat of wetting ; commercial regain ; X-ray analysis.
- (b) Elasticity.
- (c) Plasticity.
- (d) Rigidity.
- (e) Thermal conductivity.
- (f) Durability.
- (g) Electrical properties.
- (h) Ultraviolet transparency.

In consideration of the second we have to regard the fibre as a separate entity, measuring individually its dimensional attributes.

- (a) Fibre length.
- (b) Contour or cross-sectional area.
- (c) Crimp or waviness.
- (d) Evenness or soundness along the length of the fibre.
- (e) Scaliness.
- (f) Rate of growth, etc.

These characteristics are common to every fibre, and their measurement is of primary importance.

Finally, in the light of the results obtained by a consideration of the foregoing data, we might be able to consider something of the internal structure of the fibre itself. Arising out of the whole discussion comes the crux of the whole problem, what influence (and in what relative proportion is this influence exerted) have these physical characteristics, both individually and collectively, on the determination of fibre quality and its relationship to spinning power or other factors desirable for manufacturing purposes? Can these characteristics be modified, enhanced, or cultivated by suitable adaptation of methods of breeding and production? These questions of paramount importance can only be answered by thorough research, and primarily in this research must be the design of proper means of measurement, and assessment of the accurate value of each attribute of the wool fibre individually, whilst simultaneously attempting to show the close inter-relationship between them.

The Hygroscopic Nature of Wool.

The factors affecting the moisture content of wool may be grouped into two distinct classes :

(1) External conditions—such as the temperature, relative humidity and effective velocity of the air surrounding the material. These are termed “drying conditions” and can be more or less readily understood.

(2) Internal conditions—such as the chemical and physical properties of the material under test, and the changes in these properties during drying.

Further, moisture can be present in two forms :

- (a) Water mechanically adhering to the material, with a vapour pressure equal to that of water in bulk.
- (b) “Sorbéd” moisture, the vapour pressure of which is less than that of water in bulk.

The rate of evaporation of water from wool is directly proportional to the difference between the vapour pressure of the evaporating water and that of the moisture in the surrounding atmosphere, and can be expressed by the equation :

$$-\frac{dw}{dt} = k(\phi_0 - \phi_1).$$

According to Fisher, the curve for rate of evaporation falls into four distinct sections in the case of wool, viz. :—

(1) Where the rate of evaporation is constant. This occurs with a moisture content of 31 per cent. to 33 per cent. approximately, and is due to the evaporation of the water mechanically adhering to the material. It is obvious that here drying depends only on the vapour pressure of the surrounding atmosphere ; in short, it is plain, straightforward evaporation.

(2) A second portion of the curve between 31 per cent. and 11 per cent. moisture content. Over this portion the evaporation is approximately proportional to the moisture content of the fabric.

(3) The region below 11 per cent. to about 5 per cent., where the proportionality to regain is not direct but can be represented by regain plus a constant.

(4) The portion below 5 per cent. moisture content in which the rate of evaporation is extremely slow, the last 2 per cent. of moisture being very difficult to remove. It appears that the water represented in this portion of the curve is held by different forces from those operative earlier in the drying process. The difficulty of its removal suggests that it may be chemically combined.

In the light of further work it seems probable that the rate-of-evaporation-moisture-content curve for wool, which is sigmoid in character, falls into only three sections and not four as indicated above.

As early as 1893 Schloesing attempted to express the variation of moisture content or " regain " of textile fabrics with changes in the two postulated variables :—

(a) The relative humidity of the atmosphere surrounding the fabrics.

(b) The temperature to which the fabric is exposed.

He plotted the " regains " of various textile materials for relative humidities of 1 to 100 at a temperature of 24° and later compared these curves with similar ones obtained at 12° and 35° C. He concluded that the rise in temperature from 12° to 35° C. decreased the regain by about 2 per cent. only. He, therefore, assumed that the effect of his second variable (temperature) was slight, but subsequent work has shown that actually its effect is appreciable. Hedges,

working in our laboratories, on heat of wetting of wool, incidentally measured its moisture content at various humidities for temperatures of 17° and 29° respectively. The curves show that between these two temperatures there is a difference in moisture content of nearly 1 per cent. for low humidities, and for high humidities (80 per cent.) as

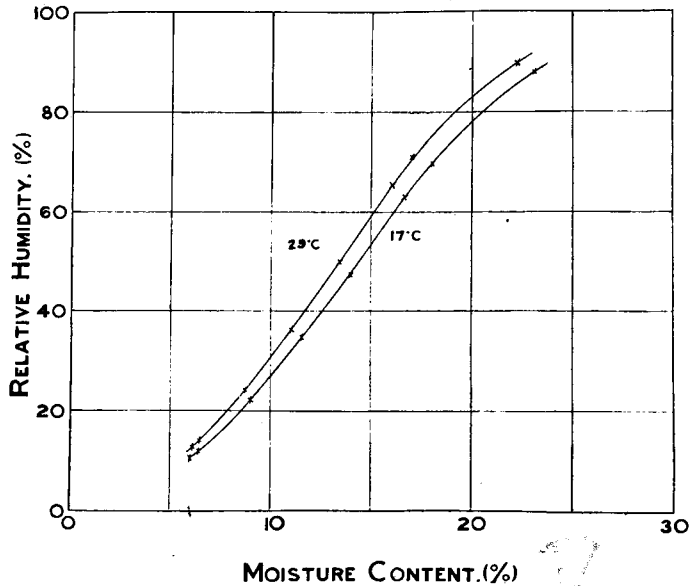


Fig. 3.—Change of moisture content with rise of temperature.

much as 1.7 per cent., although the difference in temperature (17° to 29°) was only about half that used by Schloesing (12° to 35°). See figure 3.

Let us examine how moisture is held in the wool and how that moisture can be removed without injury to the wool itself. Hedges has thrown considerable light on the first of these points by his study of the heat of wetting of wool. He showed that what is universally

known as the dry weight is not the weight of really dry wool, but that a residue of water is always present which it is most difficult to remove. He further showed that the heat of wetting of perfectly dry wool is very considerable, but that it rapidly diminishes as high regains are approached. In his discussion of the mechanism of moisture absorption in wool, Hedges reviews the situation from a historical standpoint. He suggests that the process of water absorption from dryness to

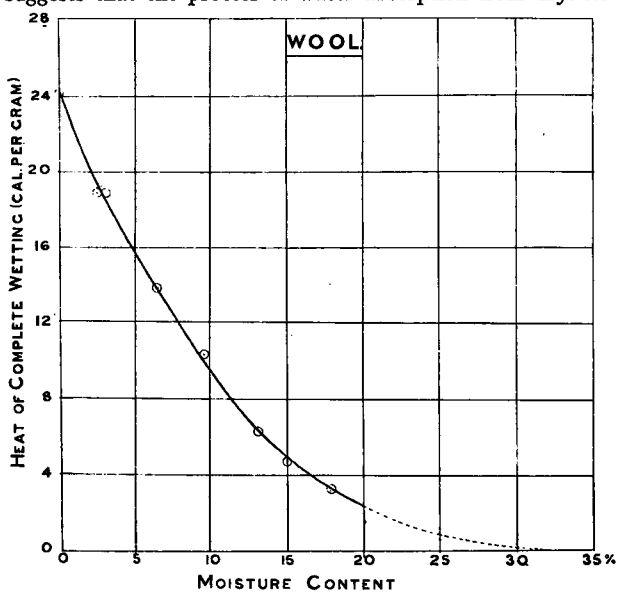


Fig. 4.—Heat of wetting of wool.

saturation falls into three stages, with no sharp line of demarcation between them. The first stage, where the wool is relatively dry, is marked by its great affinity for water, accompanied by large heat of absorption; whereas, at the other end of the scale, where saturation is approached (at about 33 per cent. moisture content) the heat of absorption becomes very small. (See figure 4.) Assuming the wool

to have a capillary structure—that is, to possess pores—Hedges attributes the phenomena exhibited during the first stage, to adsorption of water on the large surface presented inside the fibres, due to the presence of the pores. A molecular layer is apparently first formed, followed by the filling up of the pores. As the pores are filled the water surface decreases considerably and consequently energy is released. It thus follows that the amount of energy will decrease as the moisture content of the wool increases. During the later stages water appears to be taken up in a manner resembling an osmotic process. Probably a small amount of chemical reaction takes place, so that a fraction of the water is held by forces comparable in magnitude with those of real chemical combination. It is conceivable that this water would not be removed by ordinary methods of drying while its removal by heating to a higher temperature would most certainly be accompanied by change in the physical properties of the wool.

In a recent paper on the regain of stretched fibres and the porous structure of wool, A. T. King further developed the pore hypothesis. In discussing the question he remarks :—

“ On the capillary hypothesis it is the pores, of effective size (a few $\mu\mu$ in diameter, as computed by various workers) which determine regain phenomena so far as ordinary humidities are concerned. If this is so, alteration of the size of pores should alter the regain at ordinary humidities.

“ There is microscopic evidence of the actual existence of pores in wool as well as in cotton and flax. Unscaled wool fibres show their presence clearly. These pores are of varying size from a diameter of 2μ downwards, and visible pores of such dimensions cannot be responsible for regain phenomena at ordinary humidities. Their presence may, however, be taken as presumptive evidence that smaller pores of effective size also exist.”

The vapour pressure, and hence, the regain, is determined by the dimensions of the pores which are filled with water, and the dimensions operative at a given moisture content can be calculated.

The smallest will fill first, and the larger ones will come into operation as the humidity of the surrounding atmosphere is progressively increased. Thus at a given humidity only those pores below a certain size will fill. If this theory is correct, then alteration of the size of pores should alter the regain.

Microscopic examination of stretched fibres showed evidence after removal of the scales, of elongation of the visible pores, which is presumably true also of the effective pores which are too small to be so observed. Fibres steamed in stretched condition (permanently set) showed evidence of a sealing up and disappearance of the pores.

“Distortion of the pores should, if Fisher’s theory referred to above is correct, increase the amount of water capable of being held at a given humidity, both by reduction in volume of the pores which will bring an increased number within the effective range, and by reduction of the distance between the capillary walls, which will favour coalescence of the water films on these walls, with consequent filling up of the capillaries.

“On the other hand collapse of the pores may be expected to result in diminished regain compared with that of normal fibres.”

Experimental evidence supporting these hypotheses has been obtained by weighing single fibres with a specially designed micro-balance, under carefully controlled conditions, and it has been found that dry stretching produces an *increase* in weight. This is explained as due to distortion of the pores, which decreases their volume and thus brings a greater number within the effective size for a given humidity, and also, by reducing the distance between the capillary walls, increases the tendency of the water films on these walls to coalesce, with consequent filling of the capillaries. Permanently set fibres, on the other hand, showed a *decrease* in weight, which is presumably due to a diminished porosity and consequent decrease in water-holding capacity.

The second point with which we are concerned, namely, how to remove moisture from the wool, has been discussed by several investigators. Shorter, in a paper on the moisture content of wool, makes some pertinent remarks regarding the removal of moisture from wool, particularly from the point of view of testing. He criticises the commercial method of finding the dry weight of wool, by heating at 240° F. His first objection is that the air in which the fabric is being dried has a presumably small moisture content at 240° F., but which, from a strictly scientific point of view, is by no means negligible. In the second place, Shorter points out that in drying to absolute dryness, the later portions of moisture come off at a rate relative to the total amount of moisture present and, therefore, drying is much slower than with the earlier portions, and prolonged heating would cause

an unexpectedly large amount of further moisture to come off. Thirdly, he points out that a certain amount of moisture may never come off at all until the temperature is raised above a certain point, and, therefore, the "dry weight" obtained may depend upon the method of drying.

Commenting on the curves of Schloesing regarding regain and percentage humidity at different temperatures, Shorter remarks that :

"The general shape of the curves is significant. They are steepest in the middle and tend to become flat as saturation is approached. We may regard the ordinates of the curves as the vapour pressure of the water in the wool (expressed as a percentage of the vapour pressure of pure water). When the regain is small, the vapour pressure is small, indicating that the water is distributed in the wool in a molecular degree of fineness. As the regain increases the vapour pressure increases, not merely absolutely but also relatively to the amount of water present. At a regain far removed from saturation the vapour pressure becomes nearly equal to that of pure water. From this point onwards the vapour pressure increases more and more slowly as saturation is approached. This part of the curve is quite different from the corresponding part of the vapour pressure curve of, say, water in ether. The latter curve would show no special flattening in the neighbourhood of saturation, but would pass with perfect continuity of slope into a portion corresponding to supersaturation. The last portion of the water-in-wool vapour pressure curve denotes a change in the nature of the process of absorption. As the wool approaches saturation the process is approximating to a simple coarse-grained soaking up of water, such as occurs with a sponge. The vapour pressure of the water in a wet sponge is equal to that of pure water whatever the water content, so that the vapour pressure "curve" is the 100 per cent. humidity line—to which form the water-in-wool vapour pressure curve gradually approximates."

Three years after Shorter's paper appeared, Barker and Hedges published results of a comparison between the "commercial regain" or moisture content of wool, as determined by an ordinary conditioning oven or by the various conditioning houses, and the actual moisture content, which they referred to as the "true regain." They found that the commercial regain as determined by the Bradford Conditioning House, is about $\frac{1}{2}$ per cent. lower than the true regain,

while regains determined by ordinary commercial gas or electric ovens are as much as 1 per cent. too low. The values obtained by the Bradford Conditioning House are as near the true regain as is practicable, unless the air be dried by special means, and is, therefore, satisfactory as a commercial standard. For scientific purposes, however, it is often necessary to determine absolutely the amount of moisture in wool. The method we have found most satisfactory has been used successfully by King, Barritt and Hedges in connection with work on specific gravity, sulphur content and heat of wetting of wool. The method can be readily adapted for ordinary determination and should be useful to wool workers. The wool is contained in a glass weighing bottle fitted with a ground stopper, also inlet and outlet tubes, each with a tap. The bottle is supported in an electric oven of such capacity that in the space occupied by the bottle there is no sensible temperature gradient. Direct heat from the heating element is prevented from falling on the bottle by a system of baffles. A stream of air is drawn slowly through the wool by means of a filter pump. The air is bubbled through concentrated sulphuric acid and passed over calcium chloride before entering the bottle. Another tube of calcium chloride is included between the bottle and the pump to prevent any diffusion of moisture back into the wool. The oven temperature is kept constant at 105° to 106° C. (approximately 220° F) The bottle is removed from time to time, allowed to cool in an enclosure over calcium chloride, and then weighed. The process is continued until there is no further loss in weight. The final weight, less the weight of the bottle when empty, is then taken as the true, dry weight. If the sulphuric acid and calcium chloride tubes are omitted and ordinary air is drawn through instead, the commercial regain is readily obtained. The apparatus can easily be made and costs little.

In applying knowledge gained in the laboratory to actual practice of conditioning and drying, we have to remember that *rate* of absorption and *rate* of drying are perhaps even more important than the final equilibrium we wish to attain. Given time, a wool placed in an atmosphere of known relative humidity at a low temperature will attain equilibrium with that atmosphere and will then contain a definite amount of moisture. If the temperature be raised and the relative humidity remains the same, the *equilibrium* moisture content of the fabric will be slightly lower, but the rate at which this equilibrium is attained will be very much greater and until equilibrium is actually attained the moisture content of the fabric will be greater at the higher than at the lower temperature for a

corresponding time of exposure. The reason for this is that for air at two different temperatures and the same relative humidity the air at the higher temperature has a higher absolute humidity. In other words it contains more water vapour per cubic centimetre. The fabric therefore takes up moisture from it much more readily and equilibrium is more quickly attained. The same principle will obviously apply to drying processes. Perfectly dry air at a low temperature will not dry wool quickly because it is capable of taking up so little moisture that a very large volume of air will have to come in contact with the wool before drying is complete. In practice, therefore, it obviously saves much time to use air at a fairly high temperature for both conditioning and drying, although the equilibrium moisture content of the fabric varies but little with temperature.

The changes in physical properties which accompany changes in moisture content of textile fibres are perhaps more marked in the case of wool than of any other fibre. Thus electrical conductivity is shown to be *nil* in a perfectly dry wool fibre, whereas moist fibres conduct electricity. The shape of a dry wool fibre is usually not cylindrical but flattened to a more or less elliptical shape; as it absorbs moisture it swells and probably at the same time becomes more circular. Heat of wetting will be shown to vary very much with moisture content. Elasticity and tensile strength vary with moisture content and Speakman has shown that saturated wool fibres are plastic in water; they have a true yield point, but yet show perfect elasticity in that they return to their original length when stress is removed. Wool fibre, therefore, is not the imperfectly elastic material which it is often supposed to be. Large extensions can be imposed without appreciable permanent extension, and further, the wool fibre cannot assume a permanent strain at ordinary temperatures. This point is stressed by Shorter, who remarks that wool fibre gives a perfect recovery up to the breaking point. The property of perfect elasticity makes wool the valuable material which it is.

Density of wool varies with moisture content, and it has been shown by King that it was because experimenters ignored the fact that wool sorbs water, and indeed many organic solvents too, that the values for its specific gravity as determined by different investigators, vary so widely. The variation of apparent density of wool with change in regain is well illustrated by the following table due to King.

TABLE IV.
Determination of densities of wool of differing regain using benzene.

Regain per cent.	Actual wt. of Sample.	Wt. of Benzene displaced.	Sp. Gr. of Benzene.*	Sp. Gr. of Wool.*	Apparent Densities in Water at 25° C.
Zero	1.5936	1.0695	0.8752	1.304	1.396
2.0	2.5838	1.7312	0.8752	1.307	1.386
3.75	1.6047	1.0704	0.8754	1.314	1.377
5.9	1.6383	1.0965	0.8753	1.314	1.366
7.5	1.6625	1.1093	0.8754	1.312	1.359
12.0	2.1425	1.4276	0.8748	1.313	1.339
17.0	4.4977	3.0001	0.8754	1.312	1.320
17.3	1.3532	0.9436	0.9123 (olive oil)	1.308	1.319
20.0	2.5256	1.6949	0.8755	1.304	1.310
22.85	2.0682	1.3954	0.8756	1.297	1.300
30.2	2.2864	1.5666	0.8756	1.277	1.278
33.0	1.7231	1.1909	0.8755	1.267	1.271
33.0	1.6868	1.2163	0.9123 (olive oil)	1.265	1.271

* Compared with water at 25° C.

It was further shown by King that determination of "apparent density" and comparison with the true density value, furnishes a good method of estimating the amount of liquid sorbed by the wool. The results thus calculated were in good agreement with those published from actual measurements of swelling.

With regard to actual capacity for absorbing moisture, wool is in advance of other textile materials. The following figures compare the amount of moisture taken up by wool at 60 per cent. and 70 per cent. humidity, respectively, with that taken up by cotton and various artificial silks :

Material.	At 60 per cent. Humidity.	At 70 per cent. Humidity.
Wool	14.5	16.0
Silk (natural)	9.5	11.0
Cotton	7.5	8.8
Viscose Silk	14.7	16.0
Acetate silk	6.0	7.6
Nitro silk	—	15.5
Cuprammonium silk	—	13.9

At complete saturation the regains of wool, natural silk and cotton are not very different, being all in the neighbourhood of 33 per cent., but in atmospheres a little short of saturation there is a very wide difference. For example, at 95 per cent. humidity wool holds 25 per cent. of added moisture, whereas silk takes up 21·5 per cent. and cotton only 18 per cent.

There is an aspect of general interest here with regard to wool clothing. In the case of other fabrics, cotton in particular, the wide range in moisture-retaining power in a nearly saturated atmosphere produces a marked tendency to condensation with very slight changes in temperature. Consequently, the absorption and dissipation of moisture from the human skin tends to be accompanied by a clamminess in cotton garments from which wool is comparatively free. Also the rate at which wool absorbs or yields up atmospheric moisture is much slower than that of other textile fibres, and it is probably as much due to this fact as to the difference in conductivity for heat, that wool maintains a more equable temperature next to the skin. The following table shows the moisture content of wool at various humidities.

The moisture content of wool is of the highest importance in every branch of commercial practice, and although it is not the intention, in this paper to discuss matters relative to commercial standards of regain, yet, possibly, a few observations on the regain of wool, set out in tabular form, may be of interest. In general the characteristics of regain can be expressed as follows :—

(1) In a given mass of material in hygroscopic equilibrium with the atmosphere to which it is exposed, the regain depends upon the humidity and the temperature.

(2) The regain acquired at equilibrium under specified conditions of temperature and humidity differs with different materials and different grades of the same material. Exposure to high temperature, chemical decomposition, excessive presence of foreign matter, oil, etc., all vary the regain.

(3) The rate at which any textile material undergoes a change in moisture content in response to changes in humidity and temperature is dependent upon such variable factors as previous moisture condition of material, rate and magnitude of change in atmospheric conditions, size, shape, density and exposed area of the material, total quantity and rate or intensity of air circulation.

(4) At a given relative humidity, regain is less at high temperatures than at low.

TABLE V.

The Moisture Content of Wool with varying humidity at 72° F.

Relative Humidity of Atmosphere per cent.		43·3	55·4	62·3	74·6	81·5	86·2	90·0
		regain	regain	regain	regain	regain	regain	regain
Scoured wool	80's Botany ..	12·13	14·30	15·58	16·45	17·86	19·58	21·20
	56's Sydney ..	12·27	14·43	15·85	16·87	18·10	20·10	21·77
	Yks. Hog wool	12·00	14·10	15·50	16·60	18·00	19·70	21·30
	Cape wool ..	12·24	14·37	15·62	16·50	17·80	19·40	20·80
	Mohair ..	11·77	13·90	15·00	16·32	17·53	19·25	20·80
	Mean ..	12·08	14·22	15·51	16·55	17·86	19·61	21·17
Card ball ..	Botany ..	12·20	14·36	15·50	16·94	18·60	20·70	22·55
	Sydney ..	12·10	14·30	15·57	17·12	19·00	21·00	23·00
	Cape wool ..	12·10	14·40	15·49	17·00	18·60	20·70	22·40
	Mean ..	12·13	14·35	15·52	17·02	18·73	20·86	22·65
Backwash ball	Botany ..	12·05	14·30	15·42	16·88	18·54	20·60	22·40
	Sydney ..	12·10	14·37	15·45	17·20	18·96	21·10	23·05
	Cape wool ..	11·60	13·90	15·00	16·50	18·52	20·58	22·38
	Mean ..	11·92	14·19	15·29	16·86	18·52	20·58	22·38
Noil	Botany ..	11·90	13·66	14·92	15·75	17·10	18·80	20·30
	Sydney ..	11·74	13·80	15·18	16·10	17·60	19·40	31·18
	Hog wool ..	10·95	12·75	14·07	15·27	16·66	18·47	20·20
	Cape wool ..	11·93	13·95	15·41	16·06	17·40	19·00	20·15
	Mohair ..	11·80	13·82	15·05	15·75	17·10	18·80	20·30
	Mean ..	11·66	13·59	14·93	15·79	17·17	18·89	20·43
Top	Botany ..	11·85	14·06	15·10	16·68	18·28	20·40	22·25
	Sydney ..	11·90	14·10	15·36	16·84	18·30	20·40	22·14
	Hog wool ..	11·63	13·75	14·88	16·35	17·93	20·10	21·90
	Cape wool ..	11·35	13·50	14·57	16·18	17·70	19·60	21·30
	Mohair ..	12·14	14·30	15·45	16·78	18·38	20·25	22·00
	Mean ..	11·77	13·94	15·07	16·56	18·12	20·15	21·92
Yarn ..	Sydney ..	12·25	14·36	15·36	16·90	18·70	20·55	22·20
	Mohair ..	12·20	14·35	15·35	16·82	18·30	20·08	21·75
	Mean ..	12·22	14·36	15·36	16·86	18·50	20·31	21·97
	Schloesing ..	12·5	14·2	15·0	17·5	19·4	21·5	24·0
	Hartshorne ..	11·6	14·0	15·5	18·5	20·4	22·1	23·6

According to Hartshorne the regain for wool varies inversely as the three halves power of the absolute temperature, *i.e.* :

$$T^{-\frac{3}{2}}$$

To maintain a constant regain, increase of temperature should be accompanied by increase of relative humidity and conversely.

Thermodynamic Considerations regarding Moisture Absorption.

The thermodynamical treatment of water absorption in wool was first attempted by Trouton, who showed that if the latent heat of evaporation of water from the material is equal to the latent heat of evaporation of water in bulk, then the moisture content of the material depends only on the relative humidity of the atmosphere with which it is in equilibrium. Shorter showed that Trouton's conclusions were far from true in the case of textile materials, and that Schloessing's results showed that their regain in equilibrium depends upon temperature as well as humidity. Hedges subsequently showed experimentally that Shorter's work was correct, and that the relation between heat of absorption, regain, humidity and temperature was of the same nature as Kirchoff's equation for the heat of dilution of a solution. It is shown that when wool absorbs water there is an evolution of heat such that when one gram of water is absorbed into a large mass of wool material the heat liberated is given by the expression :-

$$Q = RT^2 \left(\frac{d \log H}{dT} \right) C.$$

Where H = Relative humidity.

C = Regain of wool at that humidity.

R = Gas constant.

Hedges has measured the heat of wetting experimentally, and there is close agreement between his results and those calculated by Shorter from Schloessing's data.

His paper shows the relationship between the heat evolved when wool is completely wetted and the regain, relative humidity and temperature.

The fact that freshly dried wool becomes warm when it is wetted is quite familiar. During the absorption of moisture from the atmosphere there is an additional heating due to the heat evolved

during the change from the vapour to the liquid state (latent heat). The heat of wetting is defined as the number of calories per gram of dry wool that are given out on complete wetting, and this quantity has been determined for wool with various initial regains. By complete wetting is meant the attainment of saturation, and in these determinations this state is brought about by immersion and soaking in water. (The above latent heat does not enter.) It is found that when dry wool is immersed in water—it would be the same if completely wetted by any other method, *e.g.*, spraying—that for each gram of material 24·1 calories of heat are liberated. For an initial absolute or true regain of 10 per cent. this value drops to 9·4 calories per gram, and at 18 per cent. it is only about 3 calories per gram. It is thus seen that the largest evolution of heat takes place during the absorption of the first few percentages of water, and that the value becomes considerably smaller in the region of normal regains. A table is appended in which the figures refer to a weight of 1 lb. at the specified regain previous to wetting. In addition, the figures are rendered in a more familiar form by taking as the unit of heat the amount of heat which is required to raise the temperature of 1 lb. of water by 1° F. (*i.e.*, the British Thermal Unit, B.Th.U.).

Regain R per cent.	Heat of Wetting B. Th. U. per 1 lb. Wool at Regain R.
0	43
5	27
10	15
15	7·8
20	3·6

An idea of the magnitude of the heat evolved when 1 lb. of dry wool is completely wetted is given by the fact that it is sufficient to raise the temperature of 1 lb. of water by 43° F.

As the result of experiments in which air saturated with moisture was passed through initially dry textile materials, and the temperature rise recorded, Obermiller (*Textilberichte*, Jan., 1926) came to the conclusion that if these materials were closely stored in a very dry condition, spontaneous combustion could easily take place. The results of the present paper show that the heat given out when

1 gram of water is absorbed (*i.e.*, the heat of absorption) is exceedingly large in the region of zero regain, but it decreases very rapidly as the regain increases. Unless, therefore, the material is exceptionally well dried (*e.g.*, overheated in a tenter or wool-drying machine) the heat evolved due to absorption of moisture by exposure to the air could not be dangerous, as under normal air conditions the absorption takes place too slowly. At the same time, this heat is by no means negligible; for instance, if freshly tentered cloth is water-sprayed and cuttled, it soon becomes quite warm. Such conditions may very easily lead to mildew, and it is even possible that fires might occasionally be traced to this cause; thus, if scoured wool be made very dry and then oiled and put out in the yard, there is undoubtedly some evolution of heat, and unless the oil be a thoroughly "safe" one, it may oxidise and cause further heating.

It is not suggested that this heat is a frequent cause of trouble, but it is an additional reason why overdrying should be avoided and the material be brought out as near the correct condition as possible—many firms already carefully regulate their machines to this end.

The practical results now obtained are found to be in agreement with the theoretical values calculated by Shorter on the theory of water absorption in textile materials. The results can be explained by considering the wool structure to be similar to that frequently attributed to other colloids.

Hedges has shown experimentally that the relation between heat of absorption, regain, humidity and temperature is of the same nature as Kirchoff's equation for the heat of dilution of a solution—a conclusion which had previously been suggested by Shorter.

The following table presents the experimental data:

TABLE VI.
Heat of wetting of Wool of different Moisture Contents at 22° C.

C	..	..	17.8	15.0	13.1	9.5	6.4	3.0	0
W	..	..	3.3	4.7	6.3	10.1	13.8	18.8	24.1

C = weight of water initially present in the wool expressed as a percentage of the dry weight of the wool.

W = calories evolved per gram of dry material in increasing the water content up to saturation.

The practical consequence of this evolution of heat, as already pointed out, may be serious, and recently two cases have been brought to our notice which can be almost directly attributed to this phenomenon.

Wool baled in California was found to be smoking in the ship's hold within twenty-four hours of loading. It was removed to the quay, and after a short time actually burst into flames. Tests on the wool for its moisture content previous to baling showed that it had actually been baled with a regain of less than 3.6 per cent. Prior to loading a downpour of rain had thoroughly wetted the outside of the bales, and as the water penetrated to the centre, heat had been generated by wetting, and since the outer part of the bales formed an effective insulator for heat transmission the interior of the bale gradually became hotter and hotter until actual combustion took place.

A similar incident occurred when a delivery of New Zealand wool was opened in this country last year. The interior of the bales was found to be yellowed and of charred appearance although very damp, whilst the outside portions were exceptionally dry and rendered brittle. Hence, it is evident that the correct moisture content of the wool previous to baling is of importance as a safety precaution.

On the other hand, this property of heat evolution is of great advantage to the wearer of woollen clothes. A freshly aired wool garment, when placed on the body, will absorb the perspiration and moisture from the skin. The first effect of moisture absorption is a rise of temperature of the wool itself which naturally causes a warm, comfortable glow on the body. This property, therefore, is a source of advantage to the wearer of wool next to the skin, in that the absorption of moisture from the body actually creates warmth and prevents cold or chill.

Swelling of Wool.

Yet another characteristic of moisture absorption by wool has to be studied, namely, the distension or swelling of wool.

Among the earlier workers, Höhnel gave 15 to 16 per cent. swelling in diameter for wool with medulla, and 10 to 11 per cent. for wool without medulla. His figures, however, are indefinite, as they represent the swelling in water as compared with air at an indefinite humidity.

The subject did not receive very great attention until studied by Hirst, who investigated the phenomenon for various types of wool, measuring the increase of cross sectional area of the fibre whilst in air at various humidities, immersed in water, solutions of alkalis, acids and several organic liquids. His measurements were carried out microscopically, the stage of the microscope being fitted with a Polikeit apparatus, by means of which the fibre could be held freely or under tension, immersed in liquid or otherwise, and capable of being turned through 90° so that the width could be measured in two directions at right angles coinciding with the major and minor axes of the ellipse of cross section. The fibre was examined in each case at different points along its length, and the same portions of a fibre could be studied when immersed successively in different liquids. The initial swelling during the first ten minutes of such immersion showed that before the fibre took up its final volume, oscillation occurred above and below the mean point of equilibrium. After twenty minutes the equilibrium was usually established, apparently an adjustment of the internal strains which exist in wool fibres and of the internal pressure having taken place. Hirst noted that during swelling there is a marked tendency for the initially elliptical fibres to assume a more circular contour. This tendency towards the circular has been further investigated by Barker and Norris. It is found that the maximum swelling corresponds to a point of minimum ellipticity, and further that as swelling proceeds there seems to be continuity of elongation of both major and minor axes up to a point, when the minor axis elongates at a much accelerated rate and the fibre becomes more circular. This discontinuity in swelling is now being investigated carefully in detail. Hirst found that the amount of swelling varies to some extent for different types of wool.

The following table gives the amount of swelling in water of thoroughly dry wool fibre, *i.e.* of wool measured first in glycerine and then in water.

The results for swelling of different kinds of wool, according to this table are not very variable, but results as low as 13.2 per cent. have been recorded. The effect of temperature on the amount of swelling was not very marked, the relative area of cross section at 16°C . being 105.6, whilst for the same fibre under like conditions at 60°C . in water the figure was only 109.8, an increase of about 4 per cent. In common with other physical phenomena concerning wool, it was only to be expected that humidity would have a noticeable

effect on the area of cross section of the fibre. This has been noted in the measurement of fibre cross-sectional areas, and again is a natural corollary to the variation of density already discussed.

TABLE VII.

Swelling of Wool Fibres in water at room temperature.

	Per cent. Swelling in Area due to Water compared with Glycerine.	Diameter of Swollen Fibre compared with Diameter in Glycerine as 10*.	Per cent. Swelling in Diameter (mean).
Lincoln average of 5 fibres	36.0	11.66	16.6
46's New Zealand average of 3 fibres . .	36.9	11.7	17.0
56's English average of 15 fibres . . .	34.6	11.6	16.0
56's English neglecting extreme values . .	35.8	11.65	16.5
60's Sydney average of 2 fibres	35.7	11.65	16.5

* Dry wool is taken as area 100. The square root of the swollen area, viz., $\sqrt{100 + \text{per cent. increase}}$, gives a figure which is in proportion to the new diameter, with dry wool represented as 10.

Hirst observed the amounts of swelling at various humidities, and his results are in agreement with relevant physical data. In tabular form they may be summarized as below, for a 56's quality English wool fibre.

TABLE VIII.

Swelling of Wool Fibres in air at various humidities.

Hygrometric Condition.	Relative Areas.	Per cent. Increase in Diameter from Dry Wool.
Dry air	81.0	100.0
63 per cent. relative humidity	86.75	103.4
74 " " " "	91.0	106.0
78 " " " "	92.0	106.5
84 " " " "	95.5	108.3
Water (100 per cent.) " "	106.8	114.8

From direct observation it is found that the swelling in moisture-saturated air is the same as that in water. No perceptible increase in the length of the fibre was found during the conditions of swelling. The hair hygrometer would suggest that there should be some linear distension, but it must be remembered that in that instrument the hair is under tension, and the change in length is due to the amount of stretch. In the case of thin sections of wool cut with a microtome, there is evidence of longitudinal swelling. In this case the length of the sample is comparable with the diameter, and different conditions of a dimensional nature prevail, therefore, compared with those in the fibre as a whole. It is worthy of note that, as will be shown later, Hirst's results have in part been confirmed by Speakman, an entirely different method being employed.

An interesting development of Hirst's work was the measurement of the swelling in various liquids, and with solutions showing differing degrees of alkalinity or acidity.

A comparison of the figures obtained by Hirst with those recently published by Meunier and Rey (*Journal of the Society of Leather Trades' Chemists*, 11, No. 12, p. 508, 1927) shows an interesting similarity in the type of curve obtained. Employing an entirely different method, they have measured the swelling of wool in solutions of varying degrees of alkalinity and acidity over a range of pH values from -0.5 to 10 , using hydrochloric acid and sodium hydroxide. The acid portion of their curve shows a minimum value for the swelling at pH 0.1 , a maximum swelling at pH 1.25 , and another flat minimum at pH 4 to 4.5 . This latter point is the isoelectric point corresponding to that for gelatine as found by Loeb (4.7). Proctor and Wilson also found a maximum value for gelatine at pH 2.4 , which would seem to correspond with that of wool at pH 1.25 . With regard to the minimum at pH 0.1 , the authors state that only in the case of one other protein has a similar minimum been noticed, namely, that by Pawelow (1926) for skin. Very little work of any sort has been done on this point, however. The range of pH values utilized by Meunier and Rey finishes at pH 10 , and it is to be regretted that they did not pursue their work further. It is believed that the effect of the acidity or alkalinity of the milling liquor has a great effect upon the facility of wool fibres to respond to the mechanical action of milling. Since the pH of alkaline milling liquors is frequently above 10 , further work is obviously necessary.

The swelling of wool is attributed by the authors to the formation of ionisable salts between the acids or the bases which exert in the interior of the fibre gel an osmotic pressure greater than the external

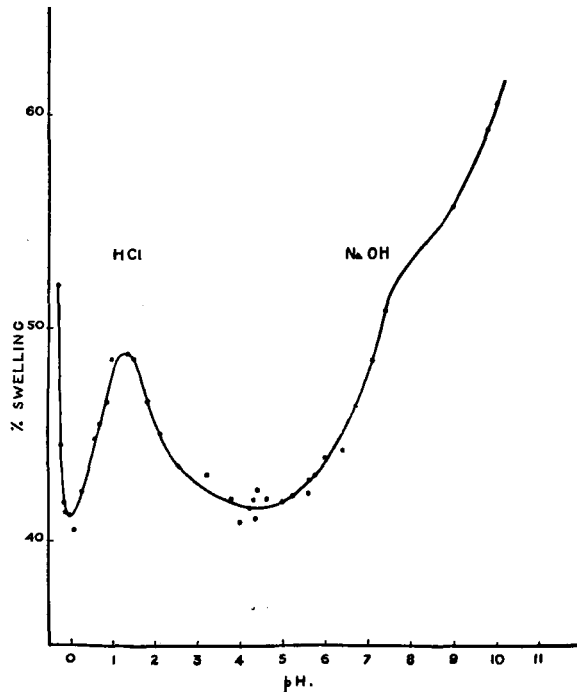


Fig. 5.—Swelling of wool.

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osmotic pressure. It has been shown that if the basic character of the wool is diminished in any way, then the formation of ionisable salts, and in consequence the amount of swelling, is also diminished. The curve of Meunier and Rey is reproduced in figure 5.

It is impossible to pursue the question of the swelling of wool further without intimate knowledge of the structure of the fibre as also its chemical nature, and in this field alone there is ample scope for research in many directions. The alkalinity of the liquor is a great factor in scouring and milling, and until the precise nature of the action of acid and alkali on the fibre itself is known in these important manufacturing processes, the attributes of the fibre conducive to the best results in this direction must remain unknown to the producer of wool. The question therefore arises as to what type of wool responds best to these processes and what natural attributes of the fibre should be encouraged to facilitate such handling in manufacturing practice. Fundamental research alone can supply the answer.

The consequences of the sorptive properties of wool are manifold, and are of influence in dyeing and various other manufacturing processes. The moisture content is a potent factor at every stage of wool manufacture, and as will be shown later, has a profound influence on the elasticity, plasticity and rigidity of the fibre. The exact nature of the mechanism of moisture absorption is as yet indefinite, but considerable light is being thrown upon it by scientific research. Patrick considers that there are three types of absorption, (1) chemical, (2) the formation of a molecular layer, and (3) capillary absorption. In the case of wool, Hedges remarks that (2) and (3) appear to be present, but on nearing saturation the water is taken up in a manner resembling an osmotic process. There may also be chemical absorption in which a small amount of water is held by forces comparable in magnitude with that of real chemical attractive force. Water held in this way would not be easily removable by ordinary methods of heating in a current of dry air at 105° C. Its removal would probably cause the disintegration of the wool itself. King and Barritt have found in recent work on the sulphur content of wool that wools with high sulphur contents in general show lower regain. This fact they regard as a chemical rather than a physical factor, in line with Speakman's suggestion that the hygroscopic property of wool is due at least in part to the presence of imino groups which undergo molecular hydration. He regards the action of formaldehyde, for example, which causes a marked lowering of moisture absorptive powers, as converting these groups into a form incapable of molecular hydration, with accompanying strengthening of molecular structure and consequent resistance to hydrolytic action. King remarks that these effects may be regarded as primarily

produced by the cystine nucleus, in varying degree according to the proportion present. Thus all three types of absorption may exist in wool.

The whole question of moisture absorption, therefore, is a matter of vital interest, and until considerable further research of a fundamental character has been done the elucidation of its mechanism, as also of the structure of the fibre itself, cannot be definitely pronounced.

To turn to a further aspect of the wool fibre, let us now consider its elastic properties and their relation to the structure and physical attributes of the fibre.

Elasticity.

Wool is an amphoteric colloid and in physical characteristics presents many of the well-known colloidal relationships and qualities.

The study of the elastic properties of textile fibres has engaged the attention of many workers, and in the absence of colloidal theory, it is remarkable how closely their findings conform with modern knowledge. In 1835 Weber published a work on the recovery of silk fibres after extension and noted that after they had been kept in a strained state the fibres made an immediate partial recovery, followed by a slow further recovery. To this phenomenon of slow recovery he gave the designation "elastische Nachwirkung." The work of the early physicists was greatly hampered in that, being unacquainted with modern colloid theory, they were unable to analyse their results properly. Maxwell, however, made a very close analysis of the phenomenon, and in an article on the "Constitution of Bodies" in the Encyclopædia Britannica, published in 1877, he criticised Boltzman's mathematical theory and pointed out that it failed for substances like gelatine and rubber. He further suggested that the cause of the "elastische Nachwirkung" was due to a group of molecules in two different states, elastic and viscous. He refers to one group as forming a solid framework which cannot be permanently deformed except by a stress greater than a given amount. No reference, however, was made to colloidal structure. The two points to be reconciled in any theory of "elastic after-effect" are the time effect, dependent on essentially irreversible changes, and the process of elastic recovery, which is reversible. Maxwell avoided any explanation in terms of the characteristics of a single molecule,

but postulated an elastic structure giving reversibility and a viscous structure for the time effect. This explanation is exactly in accordance with modern colloid theory, and is a remarkable result when achieved at such an early date.

In 1894 (*Archiv. f. Mikr. Anat.*, 43, p. 148, 1894) Nathusius published a work on a study of the internal structure of fibre cells. He showed that the cells composing wool, hair and feathers can be separated from one another by treatment with dilute ammonia for an extended period at low temperatures. The cell walls were broken in certain cases and the contents were found to consist of long threads or fibrillæ about $1\ \mu$ in diameter, irrespective of source. Nathusius expressed his results in diagrams which suggested that the majority of the fibrillæ were parallel to the length of the fibre, whilst others were arranged in all directions. This will be referred to later.

In 1918 Harrison showed that :—

- (1) Wool fibres when dry exhibit a kind of plasticity in which strains produced remain in the fibre when the stress is removed ; these strains are accompanied by internal stresses.
- (2) Such strains are released when the fibre is placed in cold water.
- (3) Wet fibres are truly elastic.
- (4) In boiling water wool fibres are truly plastic.

In considering the elastic properties of fibres the difficulty has always been that the forces created when a fibre is deformed are not permanent, but change under certain conditions, more or less rapidly in the course of time.

In 1924 Shorter put forward a theory of elasticity for wool. He attributed to the fibre the characteristics of a two-phase system consisting of an elastic framework (the elastic phase), the interstices of which contain a viscous medium (the viscous phase), and described a mechanical model consisting of a heavy and light spring as an analogy. An extension of the fibre will produce a twofold effect : firstly, an extension of the elastic framework, and secondly a deformation of the viscous medium. The viscosity of the latter tends to impede the extension or recovery of the fibre and thus delay the attainment of complete equilibrium between the stretching force and the stresses on the elastic phase. The rate at which this equilibrium is attained depends on the viscosity of the viscous phase.

Such a system can be treated graphically. When a stretching force is applied to the fibre, the first effect would be an extension of the unimpeded elements followed by a slower movement of the impeded elements with the reverse effect when the stretching force is removed. The ultimate degree of recovery depends on the degree of perfection of the elasticity of the elastic phase. In the case of wool the fibre possesses an elastic phase which is perfectly elastic, and thus ultimate recovery from strain is complete. This in essence is the theory put forward by Shorter, and it bears a remarkable tribute to the foresight of Maxwell in being so close to the true explanation of "elastic after-effect," showing how nearly Maxwell predicted the colloidal explanation. In a recent paper Speakman states that the wool fibre possesses a true yield point, and after extension remains permanently more extensible at low tension. These observations would seem to entail fundamental changes in Shorter's theory on the internal mechanics of fibres. They are, however, not irreconcilable. Speakman puts forward the view that instead of possessing the usual two-phase structure of colloidal gels the wool fibre may consist of two gels arranged in parallel. The first of these he styled a "petrified gel" and hypothesises its constitution as an elastic cell enclosing a fibrillar structure which is not in physical equilibrium with a viscous phase. The second gel which fills the interstices of the first gel is gelatinous and capable of reversible solution in water as also deposition from water. Gelation occurs in water at 0° C., and at ordinary temperatures in unsaturated air. Under such conditions this medium possesses the usual two-phase structure of gels. The wool is, therefore, assumed by Speakman to possess three phases :—

- (1) An elastic wall enclosing
- (2) A fibrillar structure which is not in physical equilibrium with
- (3) A viscous medium of gelatinous character included in its interstices.

Recent work on wool seems to be in confirmation of the latter theory, although Shorter has pointed out that it is in no way in conflict with his own. There remains much to be done in this direction. The effect of moisture on the elastic properties of fibres could, according to Shorter, conceivably produce :—

- (1) A diminution of the viscosity of the viscous phase.

(2) An impairing of the elasticity of the elastic phase. It would be expected, however, that the portion where the molecular structure is looser, namely, the viscous phase, would be most readily affected, and in the ideal case, the absorption of moisture would merely affect the viscous phase and leave the elastic phase unaltered. It is found that the wool fibre is perfectly elastic in cold water and only at high temperatures can it be perfectly strained, thus conforming closely to the ideal colloidal fibre set out above. In the case of artificial silk, moisture affects both phases and the effects of viscosity and elasticity are not readily separable. Wool fibre, therefore, presents an excellent example of this theory of elasticity and it can be seen that variation of moisture content merely affects the internal viscosity and leaves the elastic phase unimpaired. The release of latent strain, being an equilibrium condition between a stress in the elastic phase, and an opposite stress in the viscous phase, is released by any diminution of internal viscosity. This is quickly realized by complete wetting out. A state of latent strain is easily set up by wetting a fibre, stretching it and allowing it to dry in the strained state. It is now obvious why a dry fibre breaks at smaller extension, since the total stretch is taken up unevenly, whilst in a wet fibre the local variations are less and the extension at rupture greater. In a wet fibre, at breaking point we really attain the actual extension of the elastic phase. In commercial testing of fibres and yarns, therefore, it is important to realize the effect of humidity and speed of stretching upon the tensile strength of fibres, and since ordinarily, dynamical methods of test are employed, the viscous phase contributes largely to the tensile strength. The effect of the viscous phase is greater in proportion to the increase of speed of stretch and the decrease of moisture content, *i.e.* the consequent increase of viscosity. The experimental work of Speakman on the slow stretching of wool fibres shows that the stress-strain curves obtained during a time interval of two weeks, all exhibit the same features—namely, a region of rapid extensibility, and finally a region of slower extensibility. This is adequately explained by the theories above. A great point in his results is that with slow application of load, the extensibility of wool fibres at breaking load is the same for all wool fibres of the same type. A table of results will illustrate his point. The extension at break was nearly 70 per cent. of the original length of the fibre.

TABLE IX.

Fibre No.	Percentage Extension.	Breaking load in Grams.
1	70·6	8·7
2	71·7	8·8
3	67·1	12·3
4	71·4	17·2
5	68·3	24·0

For Romney Marsh fibres a constant extension of 70 per cent. of their original length in air at 100 per cent. Relative Humidity and 16° C. was noted. It is thus seen that the extension at breaking load of wool fibres as measured under the particular conditions above, is a constant quantity and is invariable from fibre to fibre: a somewhat unique feature for the wool fibre. It is, of course, a natural sequence, since we have already hypothesised that we are thus measuring the actual extension at break of the elastic phase. It is probable that the latter has fairly regular physical properties and the irregularities exhibited are due to the viscous phase. If a wool fibre be taken and completely wetted, thus releasing all latent strains, or if placed in water and then in either case the fibre be stretched and then the stretching force be released, the fibre is found to make a perfect recovery even when the strain imposed has taken it almost to its breaking point. As an example of the recovery of a wool fibre an 8-inch long fibre of diameter 0·0051 cms. was stretched gradually for 24 hours. After that period its extension was 35 per cent. of its original length. The fibre was maintained wet throughout the whole time of the experiment. The load was then slowly released, allowing the fibre to recover from its strain. After a further period the fibre had almost recovered in 260 hours when a reverse was made and for the next 11 hours the load was again gradually increased. The load was then entirely removed and at the end of 50 hours more the recovery was complete. The residual extension was negligible, showing complete recovery was possible. It can thus be noted that the wool fibre is remarkably truly elastic. Large extensions can be imposed upon it without appreciable permanent extension, but further, the wool fibre cannot assume a permanent strain at ordinary temperatures.

Shorter stresses this point and remarks that wool fibre does not possess a definite elastic limit and that there is a perfect recovery up to the breaking point. The property of perfect elasticity makes wool the valuable material it is. A suit of clothes put away for a long rest comes out again refreshed since the stretched fibres have an opportunity to recover their original length. A tailor damps and presses a suit, the house-wife damps the dry clothes before ironing. The wetting releases the latent strains more readily, thus enabling the removal of the sagging effects of wear on the clothing. This elastic property, however, can also be a source of trouble, and, unless correct humidity control is observed, is a source of difficulty in the carding, combing, drawing and spinning processes. During these processes the fibres are liable to rupture or to be left with latent strains due to the tensions to which they are subjected. The same may apply to irregular tensions occurring during warping and weaving. All these latent strains can be released by wetting, but it is obvious that such a process gives rise to unevenness in the finished fabric. These are usually obviated by "crabbing" or treating the fabric with boiling water whilst stretched on a roller. This process eliminates the state of strain in the elastic phase and produces a permanent "set" in the material, after which scouring may take place in cold water. Finally, if at the end of the finishing processes, there is any latent extension in the piece, the cloth would shrink when wetted. The cloth is, therefore, wetted and dried without tension, thus releasing strain without imposing new strains. Such a process is known as "London Shrinking". It has been shown by Garrett that woollen fabrics which have been rendered unshrinkable by chemical means, *i.e.* chlorinated, absorb moisture to a degree which is very little different from that of untreated material, if subsequently treated in a very dilute bath of ammonia in water (0.5 per cent.) The importance of elasticity from the manufacturing point of view is paramount, and it is thus essential that the producer should duly recognize this factor in the production of his wools. It may be noted, however, that in considering the elastic properties of gelatin jellies, Poole has remarked that the load-strain curve for cellulose acetate jellies (artificial silk) bends continuously towards the load axis. This is taken as direct evidence of the existence of a fibrillar structure of the rigid material of the jelly. In the case of wool these fibrillar marks have also been observed by Mark, under high magnification, and recent work on the elasticity of wool seems to point to the establishment of their existence.

In a paper to the British Association (1927) on the "Intracellular Structure of the Wool Fibre", Speakman develops the fibrillar theory of wool structure still further. He recapitulates his previous theory that the elastic properties of the fibre as a whole are those of the single cell, the latter being assumed to consist of an elastic cell wall enclosing a fibrillar structure whose interstices are filled with a viscous medium, the fibrillæ showing a decided tendency to lie along the axis of the fibre.

Speakman considers the action of such a system under the effects of a stress, and states that under small loads extension will be considerably delayed by the friction within the cell. Up to 2 per cent. extension for different wools in water, and at various other points for different relative humidities in which the fibre is placed, Hooke's law can be applied. The length of the load extension curve obeying Hooke's law increases with decrease of humidity, on account of augmented internal friction. Speakman remarks that for the same wool in water at higher temperatures, the deviation begins from about 1.4 per cent. extension. If this critical extension is exceeded, then, according to Speakman's theory, the rotation of the fibrillæ creates a rapid extension, the rate of such extension being determined by the viscosity of the medium within the cell and the elastic constants of its framework. At high humidities the rate of extension is greatest, since both the viscosity of the medium and the elasticity of the fibrillar structure and cell wall decrease with water absorption. The impeding action of the medium creates one kind of plasticity observed in wool. During rapid extension actual rupture of the fibrillæ does not occur, but during slow loading plastic flow can occur within the fibrillæ themselves. This latter predominates at high humidities, and affords a second kind of plasticity found in wool. It is on account of this fibrillar plasticity that by slow loading of wool fibres in water the extension is greater than that observed during rapid loading. The effect of increasing temperature and humidity is to increase the fibrillar plasticity, and thus increase the extensibility of the fibre under these conditions.

Rapid loading eliminates fibrillar plasticity, and as a consequence more and more fibrillæ are broken as extension proceeds, until the whole fibre is ruptured.

At 18° C., in water, Speakman finds that part of the cell structure is incapable of plastic flow, and as the plastic and elastic elements are arranged in parallel, the fibre as a whole possesses a perfect elasticity of form. He finds that once—extended fibres are permanently more

extensible at low tension than fibres extended for the first time. He attributes this to actual breakage of fibrillæ during rapid extension and to the permanent set acquired by the plastic fibrillæ, in addition to actual breakage, when fibres are extended slowly. As the temperature is increased the plasticity in those portions of the cell structure in which it is not ordinarily found is considerably developed. Whether this is due to increasing solvation of the wool substance or simply to molecular agitation is a matter for investigation. Ultimately, however, all parts of the fibre become plastic, and at 100° C. extended fibres take a set which is permanent as regards subsequent immersion in cold water. Speakman attributes this permanent set to plastic flow within fibrillæ. This permanent set can be removed either partially or completely by exposure of the fibre to the same temperature and humidity conditions as originally imposed, in the absence of its retaining force. Different types of wool show this fibrillar plasticity to different degrees of intensity, and for ease of manufacture it is generally true that wool should be highly plastic. The ability of wool fibres to dissipate internal stress whilst the length remains constant is a desirable property in a textile fibre, and its possession in different degrees is one of the great reasons for the different behaviour of various wools during manufacture. Illustrative of this variation in plasticity, Speakman quotes the results for fibres which were taken through a cycle of extension and contraction twelve times in water at 18° C. Each cycle was of four hours' duration and 34 per cent. amplitude. The percentage reduction in energy necessary to extend the fibre by 37.5 per cent. was determined in each case and the results are shown in the Table X below.

TABLE X.

Kind of Fibre.	Percentage Reduction in Energy.
Australian Leicester	53.6 per cent.
Mohair	40.4 "
English Cotswold	36.4 "
Human hair	34.1 "
Diazotised Cotswold	7.7 "

The results serve to show the very different plasticity of wool and animal fibres. Merino wools appear to be highly plastic, whereas wools like English Cotswold possess this attribute to only a limited degree. The difficulties in manufacturing practice associated with

certain cross-bred wools may be ascribed to their limited plasticity, for when plasticity is well pronounced in a fibre, the strains imposed during manufacture are largely dissipated within the fibrillæ.

Speakman has followed this work on plasticity by a further paper in 1928, in the Proceedings of the Royal Society, in which he has shown that at humidities less than 100 per cent., wool is not markedly plastic, except at humidities approaching saturation. He showed that at 25 per cent. relative humidity the extension without rupture is roughly about 30 per cent. of its original length, and in an investigation on the influence of relative humidity on the elastic relaxation of extended wool fibres at various humidities (25, 50, 75 and 100 per cent.), he showed that a linear relation existed between the logarithm of the time and the tension, except at 100 per cent. relative humidity, where the rule was no longer valid.

An interesting table in Speakman's paper shows the time taken for the initial tension of a stretched fibre to decay to half its value after having been stretched to 40 per cent. of its length, and is appended herewith.

TABLE XI.

Kind of Fibre.	Extension.	Half-tension Time.
Human hair	39·5 per cent.	233 minutes
Mohair	39·6 "	156 "
Cotswold wool	40·0 "	114 "
Australian Leicester wool ..	39·8 "	88 "

Speakman summarizes the influence of chemical reagents on the fibrillar plasticity of wool, and placed in tabular form, they are as follows :—

TABLE XII.

Reagent used.	Effect on Plasticity.
N/10 and N/100 HCl	Less in acid solution than in water.
N/100 Na ₂ CO ₃	Greatly increased even in dilute alkali.
N/10 NaCl and satd. KCNS	No significant alteration detectable.
Dyed with tartrazine	Reduced, but results irregular.
Dyed with picric acid	Plasticity almost eliminated.
Formaldehyde	Plasticity disappears
Quinone	Plasticity disappears.
Nitrous acid	Marked reduction.

This phenomenon of plasticity is extremely important in manufacturing process, and its further study and elucidation is a matter for considerable research.

Rigidity of Wool.

With regard to the rigidity of wool fibres, in the Transactions of the Faraday Society, 1929, Speakman shows that the rigidity of wool and its dependence on humidity are of primary importance in the study of spinning processes, and secondly that the results obtained from rigidity determination throw further light on the probable molecular structure of wool itself. By determination of the time of vibration of a torsion bar of known moment of inertia, suspended from a fibre of known dimensions, under standard conditions, the rigidity of the wool fibre was determined in a large number of cases.

At the outset the results effected a confirmation of the work of H. R. Hirst on the swelling of the wool fibre at 100 per cent. relative humidity, and although Speakman's method differed entirely from that of Hirst, the value of 32 per cent. increase in the cross-sectional area of the wool fibre at 100 per cent. relative humidity for Cotswold wool was the same in both cases.

Speakman remarks on the hysteresis obtained by the absorption and desorption curves for wool over a large range of humidities, and in spite of the known heterogeneity of the wool fibre a relationship was sought for the rigidity of 55 single fibres in air dried by phosphorus pentoxide. The values obtained were surprisingly uniform. The following table shows typical figures :

TABLE XIII.

Fibre Diameter (cms.).	Rigidity (dynes/sq. cm. $\times 10^{-10}$).
0.00240	1.808
0.00266	1.665
0.00268	1.519
0.00283	1.728
0.00302	1.708
0.00309	1.769
0.00310	1.786
0.00315	1.849
0.00320	1.721
0.00323	1.773
0.00328	1.760
Mean	1.735

From the results with the 55 fibres it appeared that rigidity is at a maximum with fibres of intermediate diameter (0.00368 to 0.00382 cms.). No explanation of this can be attempted until a further knowledge of the proportions of cuticle and cortex in wool fibres is known.

The mean of the 55 values for the rigidity of dry wool is, therefore, stated as :

$$(1.76 \pm 0.012) \times 10^{10} \text{ dynes/sq. cm.}$$

The change of rigidity with variation of humidity was also investigated, and assuming the value at dryness to be unity, the table below is illustrative of the relationship between these two factors.

TABLE XIV.

Relative rigidity of Wool Fibres at various humidities.

% Rel. humidity	0	10	25	34.7	49.5	64.5	74.5	89.7	92.5	100
Mean rigidity.	1.000	0.981	0.921	0.859	0.726	0.570	0.445	0.204	0.145	0.062

The desorption data, corresponding to the preceding figures obtained under absorption conditions, were obtained with the four fibres whose rigidities had been measured at 89.7 per cent. humidity, by taking them from saturation to dryness in the same stages as before but in the reverse order. Within the limits of experimental error, the rigidities of the fibres at absolute dryness, determined at the completion of the cycle of observation, were in agreement with those found originally. When the results are plotted (relative rigidity against water adsorbed) it is found that the points for adsorption and desorption lie on a common curve, the shape of which is peculiar. The first amounts of water adsorbed by wool produce little change in rigidity, while subsequent amounts cause a linear fall up to 22 per cent. of water, after which the change in rigidity is small.

The relative rigidity of wool at any humidity between 23 per cent. and 87 per cent. can be expressed by the formula :

$$\text{Relative rigidity} = 1.255 - 0.047 A,$$

and the absolute rigidity by the formula :

$$\text{Rigidity} = 1.76 (1.255 - 0.074 A) \times 10^{10} \text{ dynes/sq. cm.}$$

where A is the amount of water adsorbed, expressed as a percentage of the dry weight.

On plotting the logarithm of the reduction in rigidity against the logarithm of the corresponding relative humidity, a linear relationship between the two is found to hold. The reduction in relative rigidity (R) with changing humidity (H) can, therefore, be expressed by the formula :

$$R = 2.57 \times 10^{-4}(H)^{1.78}$$

This equation is valid from 0 per cent. to 100 per cent. humidity under adsorption conditions. It is obviously of the same form as that for the adsorption isotherm :

$$A = kC^n$$

The parallelism suggests that the reduction in rigidity is caused by water adsorption on particular groups in the wool molecule, the simplicity of the rule being masked by the fact that water can be adsorbed by wool in two other ways in addition.

Finally, in dealing with the tensile strength of wool itself, it is remarkable that considered alongside the tensile strength of metals it has such a high value. Taking values obtained by various observers at ordinary humidities, a comparison of the tensile strength of a wool fibre with that of various metals per square inch, is illustrated in the table below :

TABLE XV.

Material.	Tensile Strength per square inch.
Wool	17 tons.
Copper wire, annealed	18 "
Gold wire	17 "
Aluminium wire	12 "
Silver wire	19 "

A comparison of the breaking strength of various wools is furnished by McMurtie, and is recorded in the International Critical Tables, v. 2, p. 232. This shows a marked difference between Cotswold on the one hand and Merino on the other.

R. O. Herzog, in a paper on "The Relation between the Structure of Organic Fibres and their Elastic Qualities," discusses the size of the fibrillæ in various vegetable and animal fibres, and states that they are, roughly, of a diameter of between 0.2 and 0.4 μ . He

considers them to be formed by directional coagulation from the fibre-forming gel, and that from an equation due to Becker, the elastic properties of the fibre may be derived.

Measurement of Elasticity.

A large variety of instruments for the direct observation of strength and elongation of fibres under increasing load are on the market, but at the outset it must be repeated that due cognisance of the inherent properties of the fibre must be taken into account in carrying out tests for comparative or other purposes. First of all, humidity conditions during test must be standardized, and secondly, in the case of wool the rate of loading is of supreme importance. The instruments for fibre testing may, roughly, be grouped into two classes—direct reading and autographic.

The well-known makers of testing apparatus for textile fibres have devised many forms of apparatus for testing strength and elongation of textile fibres and yarns, but from the scientifically accurate point of view, instruments specially designed to give automatic records and capable of great accuracy are of the greatest interest.

Electro-magnetic Fibre Balance.—In 1922 T. Barratt described an apparatus for the measurement of the breaking stress, extensibility, and recovery from strain of single textile fibres. This apparatus was primarily designed for cotton, but could easily be adapted for the longer and more extensible wool fibres. The instrument consisted of an ordinary Oertling balance with the pans removed. On the one side was a device for holding the fibre under test, and on the other a solid rod of iron acting as core to a solenoid. By variation of the electric current through the solenoid the load on the fibre attached to the other arm of the balance could be varied at will and using suitable rheostats, a cycle of extension and contraction could be imposed on the fibre. By means of an optical device of extreme simplicity the elongation could be measured magnified 120 times. This device, however, has not been further developed, since its function has been replaced by other types.

Shorter-Hall Autographic Tester.—In 1924 Shorter and Hall of the B.R.A.W.I. devised an instrument for the autographic recording of the elastic properties of yarns and fibres, which was a distinct advance on anything previously produced. A study of the dynamical

principles underlying the action of testing machines suggested the main outlines of an instrument in which the defects of previous machines were avoided, other methods used involved devices which introduced errors due to friction and inertia of the moving parts. In the Shorter-Hall machine the top end of the fibre is attached to a spring, and the bottom end to the stretching mechanism. The recording pen is attached to the spring and partakes of its vertical motion. The paper for record purposes is attached to a carriage, which by means of a simple mechanism is made to move horizontally at a rate equal to that of the vertical motion of the lower end of the fibre. As the paper moves to the right the pen moves over the paper to the left and downward. The vertical displacement of the pen point during test is equal to the extension, or sag, of the spring, and thus is proportional to the tension to which the fibre is subjected. The horizontal movement is equal to the sum of the depression of the spring (sag) and the extension of the fibre. We see, therefore, that both tension and extension of the fibre are recorded simultaneously in a fairly simple manner, though on a graph with axes of co-ordinates at an inclination of 45° to each other. A full description of the machine is given in the Research Association's Publication, No. 26.

Krais "Defordén" Apparatus.—P. Krais, in the *Textile Forschung*, 1927, Band 105, describes an instrument for the testing of fibres as used in the German Research Institute for the Textile Industry, Dresden. It consists of a scale beam, to one arm of which a clip for the material under examination is attached. The other arm supports a scale pan, upon the bottom of which a second clip for the attachment of fibres can be adjusted as required. The load is applied by allowing a measured quantity of water to flow into the pan. Krais demonstrated with this apparatus that the wool fibre was much stronger than previously anticipated, and that the increase of tension does not run parallel with the increase in load, but is threefold in that initially the tension increases slowly, then rapidly, and finally slowly once more. This apparatus is limited in utility and is not autographic.

The Cambridge Extensometer (British Wool Research Association Model).—In the *Transactions of the Faraday Society*, March 1929, S. G. Barker and N. Tunstall describe a new form of extensometer devised by the Research Association with the co-operation of the Cambridge Instrument Company. The authors have attempted to break away

from convention in the design of extensometers, and thus have eliminated any error due to friction and reduced the inertia error to a minimum.

The new principle involved consists in moving the ends of both spring and test piece in such a way as to keep their junction sensibly at rest. The spiral spring and fibre are supported horizontally, a light "float" at their junction being carried by fine spiral springs. This "float" is, therefore, free to move easily and almost without restraint in the direction of the lengths of both fibre and spring. The spring is extended at constant rate by means of an electric motor and screw; a separate motor provided for the fibre being controlled by special switches operated automatically by the action of the "float." During a loading operation the forward switch of the "fibre" motor is closed as the spring begins to extend. The first effect of extension of the fibre therefore is to open the switch. As the motor operating the spring continues to run, the opening and closing cycle of operations on the switch is repeated alternately until rupture of the fibre, or the movement is stopped or reversed by the operator. In the latter case an unloading diagram can be obtained. The rupture of the fibre is also signalized by a special cut-out motion in the electric circuit so that the apparatus ceases to function immediately the fibre is broken. At any moment during the operation of the machine the tension in the test fibre is sensibly equal to that in the spring, any errors in this regard being negligibly small. The "float" is practically at rest throughout the experiment, thus rendering any error due to inertia practically non-existent. The controls work in such a way that the gap in the silver contact switch on the float is never more than two or three-tenths of a millimeter wide. Correction for possible errors due to contact pressure is provided and the apparatus is capable of simple operation with great accuracy, tracing delicate and intimate phenomena during extension and relaxation of the fibre with greatest detail. It is by no means bulky, and can be fitted to a board 30 in. long and 24 in. wide. The electrical circuits work off a 12-volt battery or dry cell. The autographic record of the load and extension of the fibre under test is obtained on squared paper carried on a rotating drum. The axis of this drum is parallel to the travel of the pen which is carried with the moving end of the fibre, and by means of which the actual records are traced. The rotation of the drum carrying the squared paper is proportional to the tension of the spring during test and hence is proportional to the load upon the fibre. In this way the load-extension diagram traced

out is related to rectangular co-ordinates and direct reading is thus possible of the values of the various factors concerned. This instrument, therefore, fills the requirements of such a testing apparatus,

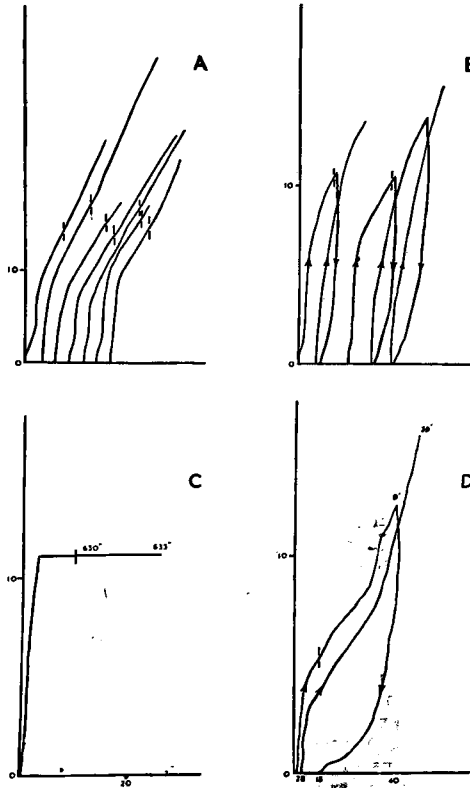


Fig. 6.—Autographically recorded elasticity curves of wool.
(Force in gms. is represented vertically and extension of the fibre horizontally.)

and illustrations of typical curves taken on wool fibres are of interest, in not only showing the efficiency of the apparatus, but in affording pictorial examples of the various factors previously discussed in connection with the elasticity and plasticity of wool fibres. Four typical diagrams, as obtained from the machine for wool fibres, are depicted in figure 6. Diagram (A) shows the behaviour of a wool fibre loaded to breaking point in air at 90 per cent. relative humidity. The fine line drawn across the records indicates a 10 per cent. extension for each fibre.

The curve traced for each individual fibre in the diagram shows the effect that at a certain load, a new extensibility is evinced, which is generally considered as being due to the slip in consequence of the plastic phase of the fibre.

Diagram (B) shows the effect of successive loading, unloading, and then reloading. The load was gradually applied up to a point, when no further increase was permitted. The fibre, although under a constant load, still continued to increase in length. A new effect is also noted in this diagram. Several fibres which have been treated as above, have extended under the constant load very slowly for a time, when suddenly a rapid increase in length was observed culminating in rupture of the fibre. The case illustrated in the diagram shows a fibre which elongated by 15 per cent. of its original length, during the first 10.5 minutes after the loading was arrested, followed by a further rapid 10 per cent. extension in the short period of three seconds, and then rupture. On the fibrillar theory this can be explained by the ultimate final slipping of the fibrillæ, which prior to the viscous flow were just held together end to end. The real reason is the matter of further research.

Diagram (D) differs from the others in that whilst they were taken in air at 90 per cent. relative humidity, this fibre was examined in air saturated with water vapour. The spring was slowly extended, the whole diagram taking 39 minutes to produce. The record bears all the characteristics of slow extension and plastic flow.

The whole subject of elasticity, with its attendant factors, rigidity and plasticity, is a vital factor in contributing to the manufacturing value of the fibre. It has been shown that the effects of environment, nutrition, breed, etc., have a profound effect on its elastic characteristics, and it is obvious that in the determination of the precise relationships and responses to diet, breed, environment and other influential factors in the life of the sheep, the effect of these factors on the elasticity of the wool is of equal, if not greater importance

than that of the fineness and dimensional attributes of the fibre itself. It has already been shown that sulphur content of wool, analogous to vulcanization in rubber, has a decided effect on its elastic and spinning properties, and hence the inherent chemical constitution of the fibre is a matter for fundamental research. Lastly, in considering the precise structure of the wool fibre the results of X-ray analysis of wool are of interest. Under the ægis of the Wool Research Association, Threadgold examined the fibre in both its normal and strained condition. His results were sufficient to show that there was a definite structure to be attributed to wool under X-ray analysis. With improved technique, Speakman and Ewles have examined a large number of different wools by means of X-rays, and by the courtesy of these workers a summary of their results is available and recorded below.

X-ray Analysis of Wool.

X-ray photographs were taken of three wools :—
Geelong 80's Merino wool,
Australian 64's Merino wool,
English Cotswold wool.

The greatest detail was shown by the latter, and in consequence Cotswold wool was used to study the changes in the X-ray fibre diagram produced by subjecting the wool to a variety of processes. The results will be discussed under headings as affording evidence of the previously discussed theories of wool fibre structure.

Cell Wall.—The characteristic features of the X-ray photograph of unstretched Cotswold wool are the two equatorial spots giving a spacing of 10·3 Å, the two sharp polar arcs giving a spacing of 5·15 Å, and the less defined equatorial arcs giving a mean spacing of 4·46 Å. The two equatorial spots are the only part of the pattern which is unaffected either by stretching the fibres, or by maintaining them stretched in water, or by immersing unstretched in water. In the light of the above-described work on the elastic properties of wool, there is, therefore, every justification for attributing the equatorial spots to the cell wall, which is known to undergo elastic relaxation in water at ordinary temperatures. In the case of the Australian 64's Merino, the equatorial spots are not very distinct, but are discernible as protuberances on the central spot, while in the case of Geelong 80's Merino, only a general scattering is observed instead of well-defined spots. In these two cases, therefore, the cell wall is probably much thinner than in the case of Cotswold wool.

Fibrillar Structure.—As already recorded, studies of the stress-strain diagrams for wool fibres have shown that an extension of 30 per cent. is sufficient to cause alignment of the fibrillæ enclosed by the cell wall. If the extension is carried out rapidly in water and the fibres dried immediately, the fibrillæ do not undergo plastic decay and comparison of the X-ray diagram for such stretched fibres with that for unstretched wool, should show the results merely of fibrillar rotation. In the photograph for stretched fibres, the well-defined polar arcs are absent, showing that these arcs are due to the fibrillæ. Analysis of the diagram shows that these are arranged in a cone or half angle 16° to 17° about the fibre axis. If fibres are held stretched in water at an extension of 30 per cent., the aligned fibrillæ undergo plastic flow. The photograph of such fibres confirms this observation in that a much greater and more general scattering is observed in the ring enclosing the two equatorial spots.

The fibre diagram for wool fibres immersed in water shows the same general features as that for air-dry wool with no change in their *relative* intensity. On this and other grounds it is concluded that no gelatinous medium exists within the cells of the fibre, and that the fibrillar structure does not dissolve. In the case of Geelong 80's Merino, the diagram for unstretched wool shows polar arcs of about the same length as in the case of Cotswold wool, indicating a similar arrangement of fibrillæ. The corresponding diagram for Australian 64's Merino, on the other hand, shows no polar arcs. There is, instead, merely a broad ring indicating that the periodicity along the fibrillæ is not continued far enough to give crystalline diffraction effects.

In conclusion, therefore, X-ray analysis of wool has up to the present confirmed the theory advanced on other grounds for the gel structure of the wool fibre.

In addition, differences in the nature of the cell wall and fibrillæ in different wools have been revealed. Figure 7 shows the X-ray photograph for Cotswold wool. From the foregoing discussions relative to fibre structures, elasticity, hygroscopic nature, etc., it is clear that our knowledge of the internal structure of the wool fibre has not yet passed far beyond the bounds of conjecture, and the field open for research on the very nature of the fibre itself is so vast, that intensified effort is essential if the improvement of wool is to be a reality. The relationship of fibre characteristics and of wool fibre structure and composition to biological, physiological, climatic and

local conditions of nutrition, etc., has yet to be determined, but a sound knowledge of the fundamentals is the one foundation on which this superstructure can be built. Intensified scientific research is the only key to unlock the door to the solution of the problems.

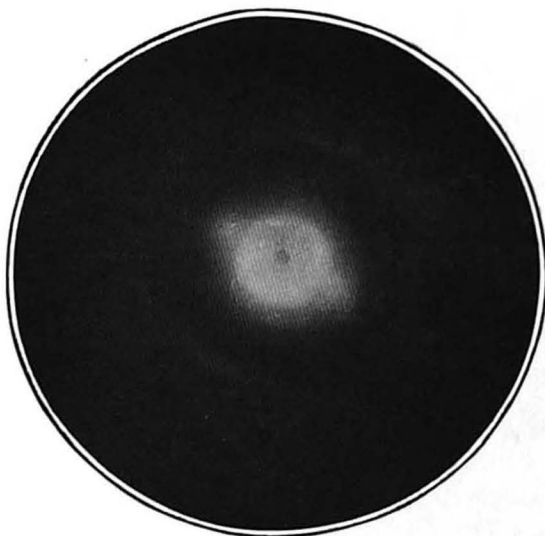


Fig. 7.—X-ray photograph of English Cotswold wool.

Various Physical Properties of Wool.

One or two points regarding physical properties of wool may be of interest, but they cannot strictly be included under the heading of the study of wool fibre. Since, however, these physical properties are inherent in the fibre themselves, and make wool clothing efficient for everyday wear, they may be outlined in brief.

It has already been mentioned under the heading of "Moisture Content of Wool" that the density of wool varies according to the moisture content. King's work showed that density measurements were an accurate measure of the regain of the fibre. It may be of interest, however, to append a further table of King's results, showing the difference in density between various types of wool. King showed that the mean value in benzene for the density, namely, 1.30 (reckoning water = 1), may be taken as the true specific gravity of wool. He found no appreciable variation in different samples of medulla-free wool, whether merino or crossbred. Lower values are, however, obtained as the tendency towards kempy nature increases, no doubt owing to the incomplete removal of the gaseous medium present in the medulla.

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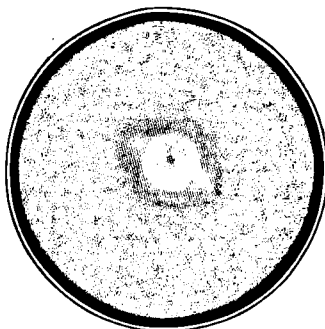


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King's table is appended herewith—

TABLE XVI.

Wool used.	Wt. of Dry Wool.	Wt. of Water displaced.	Apparent Density.
Sydney 60's	1·5466	1·1077	1·3964
Sydney 60's	2·0310	1·4534	1·3970
Sydney 80's	2·2616	1·6198	1·3962
Australian 50's	3·4225	2·4545	1·3943
English Skin 56's	1·5565	1·1147	1·3963
Santa Cruz 56's	1·6907	1·2105	1·3966
English 32-36's	2·8970	2·0727	1·3976
Blackface	2·1647	1·5539	1·3962

Thermal Conductivity of Wool.—One of the outstanding features of wool clothing is its ability to keep the body warm. This is, as has already been shown, partly due to its marvellous moisture absorptive capacity, but its low thermal conductivity augments the effect to a great extent. The actual thermal conductivity of wool has been the subject of investigation by many workers, but the difficulty in such measurements has always arisen from the fact that in any wool fabric there is an additional effect due to the insulating action of the air entrapped in the interstices or mesh of the weave, and also in the hairy beard, characteristic of the surface of such cloths.

The heat-retaining properties of a fabric, therefore, depend on the closeness of the texture of the weave, and also during actual wear, to wind proofness and the tension applied to the material. It is, therefore, obvious that when one speaks of the thermal conductivity of wool in the physical sense, the above effects must be eliminated, and standard conditions of humidity, tension weave, etc., imposed. From a commercial standpoint the thermal property of wool fabrics has been investigated with varying, and in many cases divergent results. Amongst the earlier workers on the subject the first measurements of importance were made by Nusselt, who, in 1909, gave the value for the thermal conductivity of wool at 0° C. as $0·92 \times 10^{-4}$ C.G.S. units, and at 100° on $1·39 \times 10^{-4}$ C.G.S.

Randolph, in 1912, put forward values obtained for wool packed at different bulk densities for wool fibres. An attempt was made by Bauer in 1915, to find a "heat protection number," and in 1917

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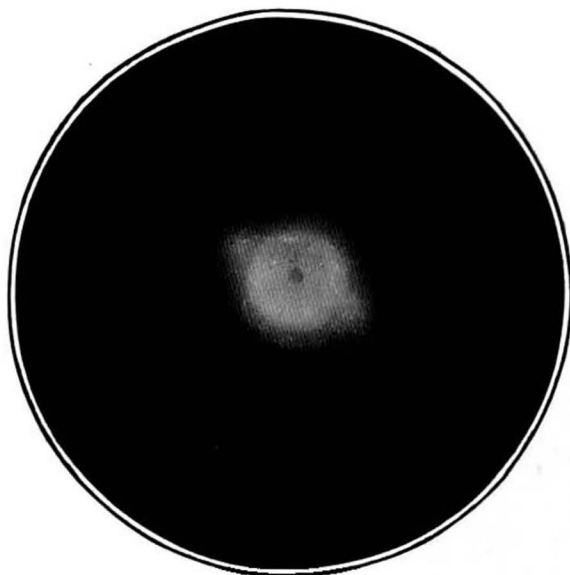


Fig. 7.—X-ray photograph of English Cotswold wool.

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the Bureau of Standards, America, issued a report on the thermal property of blankets. They stressed the importance of the enmeshed air in the beard and texture of the cloth. Colombo in 1920, and Priestman in 1921, also paid attention to the subject, whilst a paper by Rood in the same year, employing the Lees disc method of measurement, gave actual comparisons of various textile fabrics and concluded that, if equal weights of cloths be compared instead of equal thicknesses, looseness of texture played a most prominent part in the resulting values. In 1925 Staff, using the Lees disc method, conducted a long investigation into the relationship between thermal conductivity of wool and its moisture content. His results show a fairly linear relation between conductivity for heat and percentage of moisture absorbed. He estimated that the conductivity of the fabric increases approximately as the square of the relative humidity of the atmosphere in which it is placed. The values found for wool for the increase in conductivity of dry material for an increase in moisture content on 1 per cent. of the dry weight ranged from 1.7 to 2.0×10^{-6} C.G.S. units. This is a remarkable property of wool, for the increase in the thermal conductivity is very small for comparatively large increases of the moisture content.

Lastly, numerous workers have attempted the measurement of the thermal conductivity of wool in fibre form under various conditions of bulk density. Their results are set out in the table below.

TABLE XVII.
Thermal Conductivity.

	Bulk Density g/c.c.	t°C.	k.
Wool	0.09	0	0.37
	—	60	0.497
Pure wool	0.09	30	0.364
Pure wool, with loose packing	0.04	30	0.423
Slightly greasy	0.14	0	0.384
	—	50	0.488
	—	100	0.582
	0.08	75	0.77
Blankets	0.08	30	0.43
Air	0.00129	0	0.23

This table shows that the thermal conductivity of air is extremely low, being about one-half that of wool. Thus an open texture combined with the hairy nature of the surface of a wool fabric in which air is entrapped greatly enhances the heat retaining power of such cloths.

The heat *retaining power* of fabrics has hitherto, chiefly owing to difficulty, been little investigated, but the vagaries of fashion, having stressed the importance of light fabrics, have created a new demand for the work. Such investigations are actually being performed at the present time.

Electrical Conductivity of Wool.—In almost every process in wool manufacture there arises the question of its electrification. In woollen carding, when the humidity of the atmosphere is too low, electrification of the wool is the cause of serious trouble in its manipulation. In the worsted process electrification is known in drafting and drawing, and in all cases is often found during weaving.

It would appear, therefore, that wool had properties of electrical resistance which were fairly high. Actual measurements of the resistance of the wool fibre have not yet been prosecuted, except by Murphy and Walker in America. These workers examined both wool, cotton and silk fabrics, as well as the fibres and yarns, and their results confirmed what had previously been thought, namely, that wool has comparatively high electrical resistance properties. They were able to show that the electrical resistance of a textile sample is determined by its moisture content, according to a law in which the logarithm of the resistance is related to the logarithm of the moisture content by a straight line graph, whose slope is independent of the form of sample and is characteristic of the material tested. They give a table showing the insulation resistance of wool yarn at 25° C., in which they placed 100 threads in parallel and submitted it to various humidities. Their results are appended herewith:—

TABLE XVIII.

H.	M.	R.	H.	M.	R.
50.5	12.97	7.53×10^7	85.2	20.51	2.96×10^4
59.0	14.22	2.26×10^7	88.4	22.28	1.15×10^4
70.8	16.18	2.21×10^6	92.0	24.83	2.03×10^3
73.0	16.67	1.35×10^6	96.3	30.06	1.78×10^2
75.5	17.26	6.97×10^5	98.6	—	3.10×10
79.1	18.20	2.40×10^5	—	—	—

H is relative humidity in per cent. M is the moisture content of the wool in per cent. R is the resistance of a single 1.3 cm. length of yarn. Applied voltage 100.

These workers found that from these curves they were able to work out a characteristic equation for the electrical resistance of wool, which may be set out as follows :—

$$\begin{aligned} \text{For wool} \quad \dots \quad \text{Log. } R &= 16.4 \log. M + D, \text{ or} \\ R &= D'M^{-16.4} \end{aligned}$$

If 1.3 cm. is the length of the wool yarn, then $D = 26.0$.

From their results it is evident that a given quantity of moisture distributed in cotton creates in it a higher conductivity than the same quantity of moisture in silk, and further that a similar relationship holds between silk and wool. The difference, however, is smaller between silk and wool than between cotton and silk.

Discussing their results, they state that though the rate of change of resistivity with moisture content is much greater for silk and wool than for cotton, yet for a given moisture content the resistance of wool and silk is greater than that of cotton, in spite of their greater hygroscopic nature.

It is suggested by them that the effect of moisture is to create conducting water-paths in the textile, and that the hairy nature of a woollen fabric is such as to cause constrictions along the length of these aqueous filaments, and thus in the case of wool, partially owing to the hairy nature of the yarn, since the constricted paths of the filaments are smaller than those of other textiles the higher resistivity of these materials for a given moisture content is explained.

Experiments roughly performed on the leak of a gold leaf electro-scope show that perfectly dry wool, chemically treated so as to be pure, gives no leak, and even when raised to .70 per cent. relative humidity was still non-conducting.

The development of wool as an electrical insulator has not been exploited, but it is suggested that its properties should be tried, particularly since it is so durable, and thus a new outlet for wool may be created.

Transmission of Ultraviolet Radiation.—The therapeutic value of ultraviolet radiation has led to considerable discussion regarding the relative transmissive powers on various textile fabrics and fibres. Work done by Coblenz, Stair, and Schoffstall, the Bureau of Standards, America, has shown that after deducting, for the openness of texture between the threads, in all fabrics the transmission through the thread itself, especially when dyed, was only about 5 to 10 per cent. of the incident radiation.

When one considers that in a fabric the thread usually occupies about 95 per cent. of the total space, the transmission of only 10 per cent. of the total incident radiation is almost insignificant. After eliminating the light transmitted through the openness between the threads in a sample of cloth, Coblenz and his co-operators deduced that in the case of wool, for white, bleached, uncoloured fibres, between 5 and 15 per cent. of the incident radiation was transmitted by material itself.

Hirst, King and Lambert, in an exhaustive work on various types of fabrics, showed, as did the results obtained by the Bureau of Standards, that it seemed evident that the actual material composition of the fabric was over-estimated and that in order to obtain the most beneficial therapeutic results, an open weave fibre should be worn. In any case, wool does transmit the ultraviolet radiation, and further, keeps the body warm during the process of irradiation of the body.

Durability and Weathering (Action of Ultraviolet Radiation, etc.).— It has already been shown by King that the effect of ultraviolet radiation on wool would seem to cause a loss of elasticity together with an action upon the sulphur content of the fibre.

In 1926, Meunier and Rey, pointed out that the acidity of wool was increased after ultraviolet irradiation due to the oxidation of the inherent sulphur of the fibre into sulphur di-oxide, and stated that simple washing in water destroyed the effect. Following up this work in 1927, the same authors observed that after exposure to ultraviolet radiation wool lost its elasticity, and exhibited less power of fluorescence. They also pointed out that its solubility in water and alkali was increased, and further, that the sulphur content of the wool was affected by such irradiation.

In 1924, Guy Barr (Trans. Farad. Soc.), in discussing the action of light on wool, stated that wool appeared to be remarkably slowly affected by light, either from the sun or the mercury arc. It is recorded that Waentig was unable to demonstrate any very definite loss in strength of wool yarns after three months' exposure at a distance of 10 inches from his mercury arc.

In 1925, Heerman and Sommer in discussing the influence of ultraviolet rays on the strength properties of fibre material, pointed out that in point of view of sensitivity, wool might be considered as definitely highly resistant to their influence.

In 1928, a table was put forward by German observers recording observations on the length of time for irradiation to cause the strength of materials exposed to assume half of its initial value in each case. This table is appended herewith.

Material.	Time of exposure necessary to reduce strength to one-half of its initial value.
Silk	200 hours.
Jute	400 "
Rayon (art silk)	900 "
Cotton	940 "
Flax	990 "
Hemp	1,100 "
Raw wool	1,200 "
Chrome wool	1,920 "

The results show that wool is extremely resistive to the effects of weathering of this kind, and the effect of chroming is to enhance greatly its resistivity to the efforts of ultraviolet radiation.

In a series of articles on the "Durability of Textile Fibres", published in "The Textile Manufacturer", 1928, it was shown that wool withstands the rotting action of sea-water, apparently for several months without damage. So far as heat is concerned, wool is fairly susceptible to its influence, when subjected to unduly high temperature. The subject of the decomposition of wool has been investigated by a number of workers, including J. L. Raynes (*Journ. Text., Inst.*, 18, T46), and more recently, by W. E. Emley. In an article (*Text. World*, 71, 171, 1927) the latter author records a table regarding the effect of heat on wool, which is interesting.*

Temperature	Effect.
At 130° C. . .	Decomposition probably commences.
170° ..	Odour quite noticeable, indicating decomposition.
220° ..	Some scorching is evident
260° ..	Tendering is apparent.
290-300°	Incipient charring occurs, with 25 per cent. loss of weight ; hygroscopic properties of the sample are, however, not affected.

It is probable that a great deal of damage is done during the washing and drying of wool and wool garments, due to the temperature to which it is exposed becoming too high. Certain aspects of wool drying have already been detailed in the discussion on its hygroscopic properties.

With regard to the action of chemicals, Speakman has shown the effect of various agents on the plasticity of wool, but it can be shown that dilute acids have very little effect on wool itself, whereas concentrated acid destroys the fibre. Wool is peculiarly sensitive to alkalis, and probably more harm is done to it by high alkalinity, than in the case of other factors which affect its durability.

In the process of chlorination, or the rendering of wool unshrinkable, the whole treatment depends on partial fibre damage, which may vary from being very slight to quite extensive proportions.

The scales of the wool in the case of over-chlorination are almost completely removed. The durability of wool is one of its most valuable features; it resists abrasion to a very large extent and as a textile raw material its value is largely enhanced because of its extremely hard-wearing properties.

The durability of wool is a subject in which there is ample scope for research, but its further treatment is somewhat beyond the limits of this treatise.

DIMENSIONAL CHARACTERISTICS.

Fibre Length.

Of all attributes of the fibre its actual length would seem to be of primary importance, and its measurement falls under well-defined headings:

- (i) Measurement of length of an individual fibre.
- (ii) Measurement of average fibre length in a lock or manufacturer's sample.
- (iii) Measurement of the rate of growth of the fibre on the living animal.

To subject individual fibres to separate linear measurement is a tedious and laborious task, and when a large number of fibres have to be examined, calls for considerable expenditure of time and patience.

The effect of the slight tension applied in such measurements, in order to eliminate the effect of crimp or curl, as well as the degree of removal of the waviness itself, render direct linear measurement of the fibre length somewhat unreliable and of doubtful accuracy. The analysis of a composite sample of uncombed wool is attendant with the danger of fracture of the fibre due to the entanglement of the fibres with each other in the mass. In the case of combed tops, the Schlumberger machine provides a reasonable means of analysis into groups of equal fibre length, but there again the subsequent evaluation of these fibre lengths and the numerical proportion of each class is a matter of considerable tedium and labour. Some method, other than linear measurement, capable of great accuracy has to be found. In the analysis of tops, Wilkinson used a gravimetric method and this was developed for individual wool fibres by the author and A. T. King, afterwards adopted by Roberts and considerably enhanced by him in technique for larger samples. Firstly, therefore, we will deal with the adaptation of a gravimetric method for the estimation of length of a single fibre and later develop the method to deal with the determination of average fibre length of a composite sample, containing a large number of fibres. An elementary piece of mathematics will deduce an expression which is the basis of all future work on the gravimetric method. For the time being let us assume that we are dealing with a fibre whose cross-sectional contour may be circular, elliptical or irregular in shape, the value of whose cross-sectional area is signified by (A).

If the area of cross section (A) is multiplied by its length (L), and this again is multiplied by the density of wool (D), *i.e.* its weight per unit volume, then the value of the product of such multiplication gives a figure which expresses the actual weight (W) of the fibre. We thus arrive at the expression :—

$$W = L.A.D.$$

which forms the basis of subsequent work on the measurement, not only of fibre lengths, but also estimations of cross-sectional area. From the above equation it is obvious that since the density of wool is known (A. T. King gives its value as 1.30) and the value of (A) can be measured, experimentally or otherwise, then if the fibre is weighed under known conditions of temperature and humidity, its length can be determined.

Weighing the Fibre.—For the determination of weight of a single fibre two methods are available :—

- (i) Weighing the fibres individually on a microbalance.
- (ii) Weighing a known number of fibres of the same quality and cross-sectional area, cut to a known length, and calculating the mean or average weight from the result.

The Microbalance Method is comparatively easy, and although there are many types of such instruments on the market, a simple form of the instrument has been successfully used and is described by A. T. King and the author in their paper comparing the microbalance with actual microscopic measurement. The instrument is of simple construction and consists of a fine phosphor bronze filament which is 0.002 cms. in diameter, and about 10 inches long. The filament is secured at one end by means of a clip attached to a torsion head, and at the other end by means of a similar grip to a device for tension regulation. The balance beam, one end of which serves as indicator (passing vertically over a graduated scale), consists of a thin glass rod, at one end of which a fine sharp-angled hook is bent by fusion, the other end of which (as indicator) is drawn to a fine point. The beam is carefully balanced at right angles to the filament at its centre point, and when the accurate poise is secured it is fixed in position by a drop of molten shellac and is ready for use.

With such an instrument it is an easy matter to determine directly the exact weight of a fibre to one-millionth part of a gram. Let us now consider the procedure in greater detail for the determination of average fibre length of a sample by means of the microbalance. It is essential to assume that in the sorting of the sample the fibres selected are of approximately equal cross-sectional area. This assumption is justifiable by actual measurement if the careful selection indicated above is made. If this equality of cross-sectional area is not assumed, then the area of each fibre must be determined separately by methods to be indicated later.

Let us take a typical fibre from the sample and cut it to a known length (l). Previous to cutting, the fibres should be rendered thoroughly clean and free from adhering greasy matter, by extraction in alcohol and rinsing in distilled water. The fibre so prepared and cut can now be weighed on the microbalance and its weight (W) noted. We now have data for the weight (W) of a known length (l) of the fibre. From the original sample a number of other similar

fibres are selected, cut and weighed. From the data obtained it is a simple matter of arithmetic to calculate the average weight per unit length of the fibre $\left(\frac{W}{l}\right)$, and this quantity is now available for future use on this sample. It is now a matter of experiment to count out a number (n), say two or three hundred, of fibres from the sample and to weigh them on an ordinary chemical balance with great accuracy. Suppose the weight so obtained is (w). The average fibre weight is given by the quotient $\frac{w}{n}$ and the average fibre length of the sample by $\frac{wl}{nW} = L$.

Since in the above expression the only unknown quantity is (L) the average fibre length, we have, therefore, a ready expression and accurate means available for its determination. The process is not so lengthy and laborious as it would seem, and recent work by Roberts shows that the method is comparatively expeditious in performance, and capable of considerable precision. The importance of fibre length in the manufacturing processes cannot be overestimated. It is well known that a merino wool, of which every fibre had been cut to one-half of its original length, would not spin to its original fineness or count. The drafting of fibres in the reduction of the roving in the worsted process depends largely on the fibre length, so that its accurate determination has a direct bearing on its value for its subsequent use in manufacture. A recent example of the influence of staple length on spinning power may be of interest. A. W. Stevenson has reported that in the case of experiments on soft twist yarns, it can be shown that yarn strength depends very markedly on fibre length. A difference of greatest fibre length in rovings from $6\frac{1}{4}$ to 5 inches and an average difference of $3\frac{1}{4}$ to $2\frac{3}{4}$ inches, made a very marked difference in tensile strength of the yarn. Stevenson suggests that the ratio between fibre length and tensile strength for soft twist yarns is probably logarithmic in character.

In the case of combed tops the analysis of the material into its constituent portions of various lengths, as has already been mentioned, carried out by means of the Schlumberger machine. In this machine the apparatus successively withdraws from a selected length of top, the fibres in descending order of magnitude as regards length and these can be used for preparation of a fibre diagram for the particular top, or directly estimated by weighing each portion

separately and dividing by the weight per unit length and the number of fibres in each portion. Such a fibre diagram is illustrated here-with (figure 8.) It is really a mechanical reproduction of the manual method used by the trade for years. In the case of uncombed wool the problem is more difficult, and up to the present no satisfactory apparatus or method has been devised. The need for research on this point is obvious in consideration of the importance of having a ready means of fibre length determination to place in the hands of the wool producer, by which he could readily determine the average length of fibre in the lock.

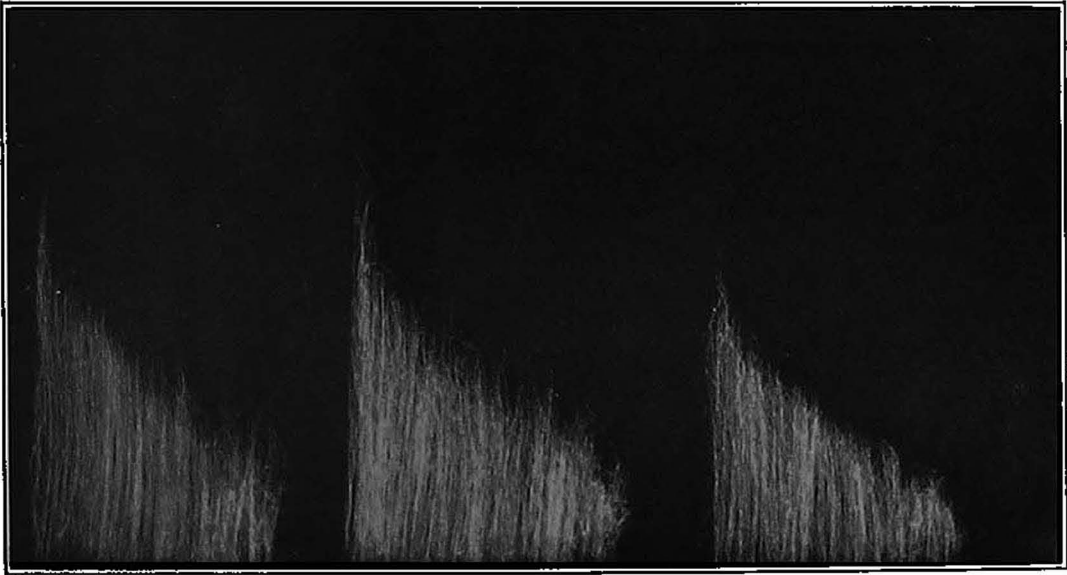


Fig. 8.—Top fibre diagram.

Yet another factor to be examined in connection with fibre length is the careful observation of the rate of growth of the fibre on the living sheep. A biological factor of considerable importance to the wool producer, it has as yet not been properly investigated, chiefly due to the lack of satisfactory method and technique for the obtaining of accurate results. It is, therefore, inadvisable for any discussion to be made as to the rate of wool fibre growth, but it is of interest to point out at this stage the need for carefully organised research to be made on this factor, almost the first point of interest in wool production.

Determination of Fibre Fineness.

The history of the measurement of fibre fineness is well set out in a recent publication by G. Krauter ("Ueber die Wollfeinheitmessung," *Text. Forschung*, 1929, 11, Heft 1). He points out that the earliest recorded measurements of wool fineness coincide with the time when combing and carding machinery replaced the old hand methods for these processes. Working without the aid of machinery necessitated the passing of all the wool through the hands of the comb or carder in small amounts. It was therefore very easy to combine the operation of sorting with that of combing or carding. With the introduction of machinery, however, it became possible to handle the wool in large quantities and sorting necessarily became a separate operation, and the need for a quick efficient method arose.

The measurement of wool fineness was first mentioned in 1777, by Daubenton and the interest which followed the publication of his work, coupled with the urgent need mentioned above, resulted in numerous investigations into the possible methods of measurement of wool fineness. Daubenton emphasised the importance of establishing different fineness grades for wool both in order to avoid uncertainty in trade and also for the determination of breeding results. In his own experiments he took the coarsest fibres, which he found occurred at the end of the lock, and used a microscope with a micrometer scale for the measurements. He found the thickness of different wool fibres to vary between the values of 16μ and 28μ .

In 1785 Ploucquet mentions the use of the micrometer for the measurement of wool fineness and in 1811 Dollond constructed his eriometer for this purpose. Four years later Voigtländer used a screw micrometer and measured the width of ten fibres lying side by side. Block in 1820, assuming the fineness of the fibres to vary with the size of the crimp, measured crimp in wool by means of a small scale notched at intervals of half a Prussian inch. Wagner in the following year projected fibres, illuminated by the sun, by means of a microscope object glass; while in the same year Winkler used a graduated cylinder on which he wound the fibre so that each winding touched the next and measured the length which so became covered by the fibre. This length divided by the number of windings gave the diameter of the fibre.

In 1823 Tauber attempted the use of an instrument which measured the number of crimps per unit length to estimate fineness and in 1824 Young utilized the property of fine bodies to deflect

light. The coloured bands produced at each side of a wool fibre examined against a bright light are wider the finer the fibre. Measurement of the distance between a pair of bands of the same colour, one on each side of the fibre, gave comparative figures from which it was possible to calculate the absolute thickness of the fibre examined.

In 1826 Pilgram's eriometer was constructed and several other methods were used, such as the determination of the weight of a determined length, Elsner's method of twisting a number of fibres

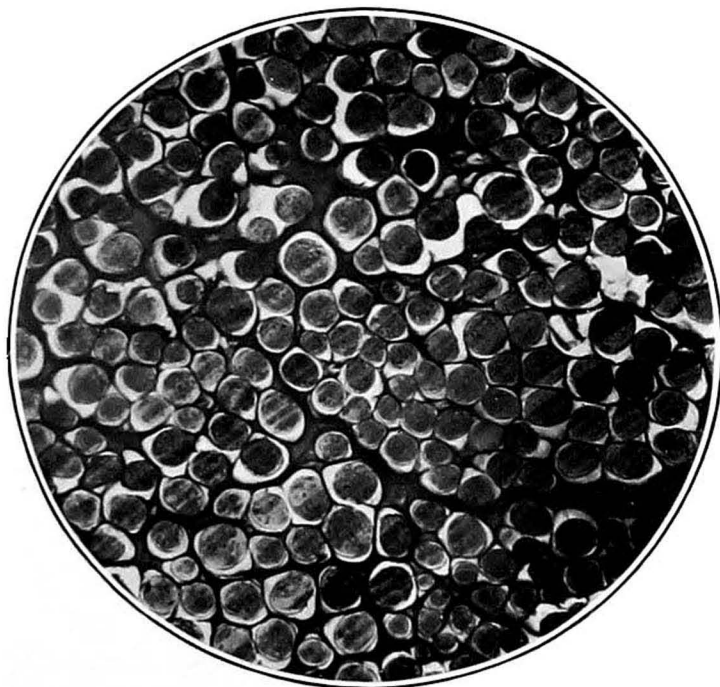


Fig. 9.—Cross sections of typical wool fibres.

together and comparing with a standard sample, and Baron v. Postacky's method of mounting two fibres on a dark background and comparing their thicknesses by determining the difference in the distance necessary between the observer and the fibre before the fibre became invisible. The thinner fibre was invisible, of course, at a shorter distance than the thicker one. In 1831 Grawert, Ledebour and Skiadan all attempted methods of direct measurement and in 1847 Thaer invented an improved weighing apparatus and also an instrument employing calipers. Meanwhile the establishment of wool classes by crimp measurements was still being attempted and Osumbor and von Pabst invented crimp measurers.

W. von Nathusius (1866-68) was the first to recognize the dissimilar nature of fibres and the fact that they are not round, as had been claimed, but oval. Attempts to overcome the difficulties these discoveries involved by measuring a large number of fibres, were not altogether successful and the further the investigations were pursued the more it was realized how difficult was the problem with which the investigator was faced, and indeed the problem is not fully solved up to the present time.

One of the conclusions in his paper is precisely that obtained by ourselves from other considerations, namely, that fineness measurements alone, without regard to other factors, cannot give correct results for classification of wool as regards spinning power.



Fig. 10.—Romney wool fibres.

In ordinary life we are accustomed to filaments and wires of circular contour, and it would seem a natural sequence of thought to assume that because wool is a fine filament it should be considered as being circular in cross section. This seems to have been the case, with the result that the effect of the shape of the wool fibres, and its influence on manufacturing treatment, has been largely ignored. Wool is not circular in cross section, but in general tends towards

ellipticity. The accompanying diagram (figure 9), a reproduction of the actual photograph of the cross sections of fibres, is typical. The fibres are far from being circular. The second illustration (figure 10) shows a similar picture for a Romney fleece, the sample being taken from the shoulder. Its irregularity is obvious. A third illustration (figure 11) illustrates a similar procedure adopted with regard to a wool of extraordinary spinning power. The preponderance of circular or nearly circular fibres in the sample is explanatory of its spinning power.

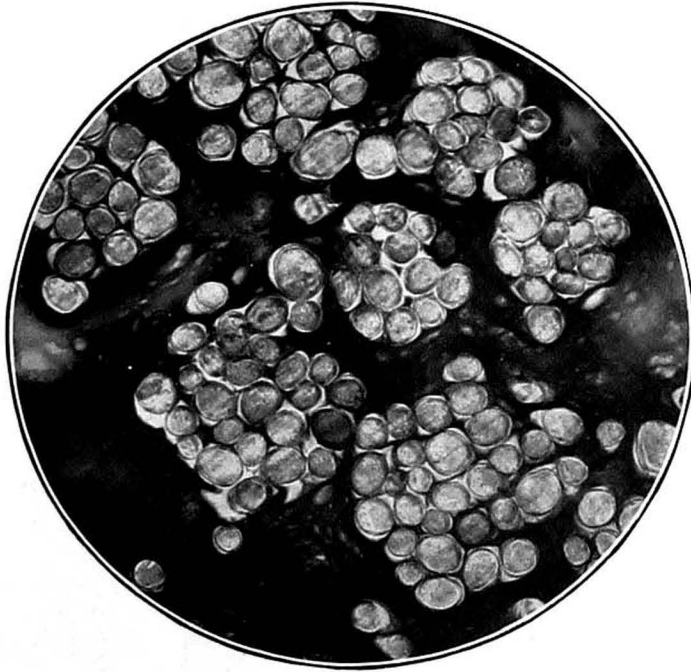


Fig. 11.—Typical good spinning wool fibres.

The whole question of fibre contour will be referred to later. At the outset, therefore, since the wool fibre is only circular in cross section in extraordinary cases, it would seem to be an erroneous method of expression to speak of fibre "diameter" when such a quantity is non-existent as a general rule. The measurement of the width of an elliptical fibre is, therefore, a matter of some uncertainty, if one considers that either the major or minor axis or some intermediate value may be obtained, according to the position of the fibre during investigation. Even on the same fibre totally different results can be obtained, according to the direction of measurement across the ellipse. It has been found in practice that as a rule the

major axis or some near intermediate value is usually obtained, the fibre naturally setting itself to lie on the slide with its major axis horizontal. A rotational method, however, yields a different result. The idea of measurement of both major and minor axes was primarily due to H. R. Hirst for, in his measurements of the swelling of fibres. He used a Polikeit apparatus, by which this could be done, in order to get an accurate estimate of the amount of the turgescence. The author, however, applied this method of measurement to the determination of fineness. In the case of South African Merino wools, Duerden has taken standards from good, reliable wools by determination of "diameter" microscopically, and found fair agreement with practice as shown in Table XIX:—

TABLE XIX.

South African Wools (Grootfontein School of Agriculture) with the buyer's quality numbers compared with the quality numbers based on their measured diameter.

Sample.	Buyer's Quality.	Proposed Diameter Standard.	Measured Diameter.	Quality based on Diameter.
E Grassveld ..	90's	16-17 μ	16.98 μ	90's
K Karroo ..	80's	17-18 μ	16.77 μ	90-80's
D Grassveld ..	80's	17-18 μ	17.44 μ	80's
C Grassveld ..	70's	18-19 μ	18.73 μ	70's
H Karroo ..	70's	18-19 μ	16.14 μ	90's
B Grassveld ..	64's	20-22 μ	19.51 μ	66's
G Karroo ..	64's	20-22 μ	20.66 μ	64's
A Grassveld ..	60's	22-24 μ	23.96 μ	60's
F Karroo ..	64's	20-22 μ	20.35 μ	64's
" ..	60's	22-24 μ	22.90 μ	60's
" ..	58's	24-26 μ	23.12 μ	60's
" ..	56's	26-28 μ	26.75 μ	56's
" ..	56's	26-28 μ	27.17 μ	56's
" ..	54's	28-32 μ	28.36 μ	54's

but it is probable that the agreement is due to his measurements being those of the major axes and also to the fact that good wools of regular contour were used.

Duerden has certain classes of anomalous wools, and it would be interesting to note how far these were accounted for by ellipticity or irregularity of contour. Arising out of his work, Duerden (*Wool Record*, 1928) compares the values for fibre "diameter" obtained by

microscopic measurement of the samples graded by an experienced woolman and, as the result, suggests a scale for standard quality numbers and their corresponding mean "diameter."

TABLE XX.
Standard quality numbers and their mean diameter.

Qualities ..	100's	90's	80's	70's	66's
Diameters ..	15-16 μ	16-17 μ	17-18 μ	18-19 μ	19-20 μ
Qualities ..	64's	60's	58's	56's	54's
Diameters ..	20-22 μ	22-24 μ	24-26 μ	26-28 μ	28-32 μ

Certainly, the limits of divergence for good wools, such as used by Duerden, are small, but none the less significant.

A. F. Barker, in his excellent report on Peruvian wools, also gives a table showing Bradford standards and their equivalent diameters, as set out below :—

TABLE XXI.

British— Bradford.	Diameter.	Counts.
70's/80's	1/1686 in. to 1/2500 in.	70's upwards
70's	1/1361 in.	64's
64's/70's	1/1299 in.	60's
64's	1/1180 in.	{ 58's
60's	1/1064 in.	{ 56's
56's	1/953 in.	48's
50's	1/795 in.	46's
46's/48's	1/696 in.	36's
44's	1/648 in.	32's
40's	1/595 in.	30's
36's	1/470 in.	16's
28's/32's	1/314 in.	16's
		12's

The gravimetric method, however, is to be preferred for accurate work, as will be shown later. For quick comparison the microscopic method is justifiable and reasonably accurate for rapid estimation. In point of fact no practical method is as yet perfect, and research on

this point is necessary. In any case, the spinning power of the fibre is not dependent on "diameter" alone, and one has seriously to consider, in the prescription of standards, what is the real basis upon which they should be built.

Barker and Burgess in their analysis of the spinning power of various wools (Wool Record, 1928) showed that as a general rule the average ratio between the major and minor axes of the ellipse constituting the cross section of wool fibres is about 1.2 to 1.25. Values of unity would, of course, signify perfectly circular fibres. Values up to 1.95 have been obtained in the investigation of ordinary samples. The idea of fibre "diameter" is largely discounted in that reference is being made to an unreality in the case of wool since the cross-sectional contour of the fibre varies from the circular to almost a ribbon-like ellipse, even disregarding the extreme cases of irregular and almost bean-shaped fibres which are found.

It has already been mentioned that the error due to the microscope is small in the case of good wool, and probably when the only object is to obtain the degree of fineness for classification it is quite accurate enough. As an illustration of the difference between the microscope and the microbalance estimation of fibre "diameter" for a sample of good wool of 70's quality the following figures can be quoted, obtained by the author and A. T. King.

Average diameter of 70's quality wool weighed on microbalance
= 2.164×10^{-3} cms.

Average diameter of 70's quality wool found by microscope
= 2.166×10^{-3} cms.

These results were in good agreement, but when more irregular varieties were tested, the concordance was only of the order to be expected from a knowledge of the contour variations of the samples tested. It can, therefore, be concluded that the microscope yields results which, though not absolutely accurate, are sufficiently reliable for purposes of classification without regard to the spinning ability of the wool. The microscope, however, is limited in its action by the fact that it only gives the average of measurements at a number of points along the length of the fibre and does not give a measure of its entire average thickness. The use of the microbalance for the purpose of fineness determination eliminates this objection in that it gives a figure representative of the whole fabric. It has already been

shown that the weight (W) of a fibre can be expressed in terms of its area of cross section, (A) its length (L) and its density (D), by means of the equation :—

$$W = L.A.D.$$

This can be rewritten in the form :—

$$A = \frac{W}{L.D.}$$

and it is this form of the equation that forms the basis for the determination of fibre thickness on the gravimetric method. If the fibre is assumed to be circular then the area $A = \frac{\pi d^2}{4}$ — where d is the diameter and the above equation can be rendered as :—

$$d^2 = \frac{4.W}{L.D.\pi}$$

We thus have directly a measure of the average diameter of the fibre. It is obvious that if we take into consideration only unit length (*i.e.*, $L = 1$), and since π and the density (D) are constants, we can state that the weight per unit length of the fibre is a direct measure of its cross-sectional area, whatever its contour, and that if it is circular the weight is directly proportional to the square of the diameter. If we determine the weight of a large number of fibres individually by the microbalance, and take the average value of the weights so obtained, then the square root of this mean value is proportional to the root mean square diameter of the sample, which is the mathematical quantity which we desire to obtain. The adoption, therefore, of a *definition of fibre fineness in terms of the weight per unit length*, has many advantages and, whilst easy to obtain, it :

- (a) Gives an immediate measure of the average value for thickness of the whole fibre.
- (b) Gives a value independent of the shape of the fibre.
- (c) In the case of circular fibres gives a value for the root mean square diameter.
- (d) Is proportional to the cross-sectional area of the fibre and, as will be shown later, is a matter of importance in determining crimp and other relationships.

In any case the correct measure of fibre fineness is its cross-sectional area, and it is this notation that it is proposed to use throughout this discussion, and which it is hoped will be adopted elsewhere. As a

matter of precaution, it should be stated that in the use of any gravimetric method, as also in the case of microscopic investigation, due regard must be paid to the humidity and temperature conditions prevailing at the time of test. Wool being of a very hygroscopic nature, the equation stated above for the determination of fibre area must be corrected so as to allow for the regain or moisture content of the fibre, unless standard conditions prevail for atmospheric conditions during test. Such conditions are only attainable in a constant temperature and humidity room, such as is in being at Torridon, otherwise a correction must be made. For this purpose the table appended under the heading of Regain may be applied.

Note on Correction for Influence of Humidity.—If R is the regain of the fibre at the particular humidity existing in the surrounding atmosphere at the time of test and W_c the weight of the conditioned fibre as taken on the microbalance or otherwise, then a correction has to be applied to the density, as the figures quoted in the table refer to dry fibres only. From the notes on regain quoted later, it is seen that the dry weight of the fibre— W_{dry} , will be given by :

$$\frac{100 W_c}{100 + R} = W_{dry}$$

Taking the formula evolved for diameter we now get that the diameter of the dry fibre would be :

$$d_{m,dry} = \sqrt{\frac{100 W_m}{K (100 + R)}}$$

This correction must be applied if the dry diameter is required. For comparative purposes at the same humidity, this correction is unnecessary, as is shown above.

Weighing on the Ordinary Balance.—Another method which can be adopted is to cut the fibres to a known length as before, and then weigh a sufficient number of them, say 1,000, on an ordinary chemical balance. This weight gives us the weight of 1,000 fibres of known length. An equal number of uncut fibres is then selected and similarly weighed on the chemical balance. The weighing in both cases is most conveniently done by enclosing the fibres in a small glass weighing bottle, the weight of which is carefully noted. It is merely an exercise in mathematics to develop from formulæ the average diameter of the fibres.

Contour.—It has already been shown that the methods described above are sufficient to give a measure of the cross-sectional area, but of course they do not give in any way any indication as to the precise contour of the cross sections. It has further been stated that in the case of wool, an elliptical contour much affects the spinning power of the fibre. This can well be illustrated by citing the results published by the author and Burgess in the *Wool Record*, obtained during the examination of the contour of wools of known spinning power. Table XXII is illustrative of the general type of the results obtained, A and B representing the major and minor axes of the cross-sectional ellipse respectively.

TABLE XXII.

Test No.	Origin of Sample, etc.	Diameter in $\frac{1}{1,000}$ \sqrt{AB}	Contour A B	Deviation from Circular A-B.	Mean Staple Length in inches.	Limit of Spinning Count.	Remarks.
		Mean of 500 Fibres.			Mean of 200 Fibres.		
1	50's hog top..	1.31	1.090	0.115	8.84	44	Produced a very good spin.
2	Top	1.27	1.152	0.147	4.49	—	Exceptionally good spin.
3	South African (64's) I.	0.884	1.058	0.063	3.37	—	64's quality imported Australian ram's wool, 12 crimps/inch.
4	South African (80's) II.	0.725	1.081	0.048	3.99	—	Fine, soft wool, 80's quality, 13 crimps/inch.
5	Australian top	0.852	1.073	0.056	4.18	80	Good spinner.
6	Continental yarn.	0.790	1.057	0.044	2.37	2/90's	Mule spun—good yarn.
7	Australian fine wool.	0.788	1.055	0.041	1.78	120	Exceptional 90's quality, spun to 120's.

In all cases in the above Table the wools were designated by the Trade as being good spinners. One point was noticeable throughout the whole work and that was the variation in diameter of the various samples higher than 80's quality. It would seem as though the rule linking diameter with quality broke down at the higher values and that quality in fine wools, whilst depending primarily on fineness of the fibre, depended as well on some other factor for the ultimate limit to which it could be spun. This factor may to some extent be explained by contour, as one contributory agent. In the above Table one case is of special interest.

No. 7 was a sample of yarn which was considered unique in spinning qualities. Actually defined as a good 90's, it spun to nearly 120's. Certainly its diameter indicated its quality as about 90's, as compared with others, but its abnormal spinning power could not be explained thus. The frequency curve for the sample affords explanation. The low values of A/B and (A-B) for this sample, and also its short staple length may first be noted. An examination of the curves throws some light upon this abnormal behaviour (Fig. 12).

To turn to the contour curves (A/B) it is remarkable that over the range up to 1.1, that is within 0.1 of being circular, 393 fibres out of 500 occur, or 78.6 per cent. of the total number examined. A noteworthy feature is that actually 241 out of the 500 fibres were measured as being perfectly circular. It is, therefore, obvious from this sample which is of such abnormal spinning power, that the presence of circular or nearly circular fibres greatly influences the count to which it can be spun, even beyond the influence of the diameter of the fibres themselves. It is also to be noted that we have here extraordinarily short staple length. Of all the samples examined this sample offers the best case showing the largest proportion of circular fibres and also the most exceptionally good spinning properties.

It was particularly noticeable that when an exceptionally good spinning property was characteristic of the wool, the contour figures were remarkably low.

A further example may be quoted. Taking seven samples of wool of known spinning power, and mounting them in the manner described in the paper, a very interesting result was derived by projecting them and examining them visually for roundness, circularity of cross section or otherwise. The Table appended herewith shows the results

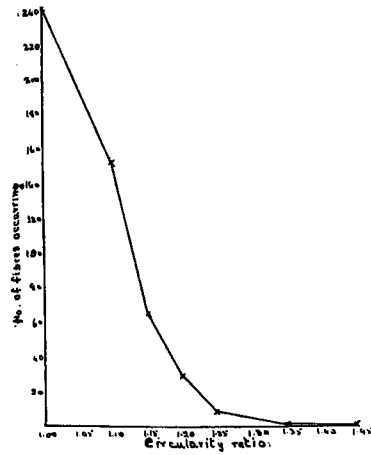
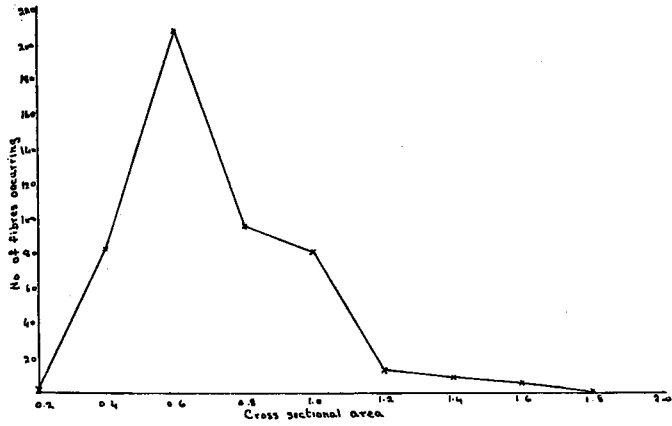


Fig. 12.—Frequency curves for Australian fine wool 120's.

and is the outcome of a quick visual method of determination with regard to the seven samples examined. They were taken by mounting and projecting the actual yarn as it had been spun.

TABLE XXIII.

Wool Samples.	Spinning Quality.	No. of Regular Fibres.	Total Fibres.	Per cent. of Regular Fibres.
I	Good, 90's spun to 100's	17	24	70·8
II	Bad, 66's spun to 60's	2	29	6·9
III	Ordinary spin	37	60	61·7
IV	Bad spin	9	58	15·5
V	Fine yarn ; good spin	28	41	68·3
VI	90's spun to 120's ; very good ..	12	16	75·0
VII	Good spin	70	104	67·3

If the fibre is circular then when it is twisted the torsional effect is in the nature of a simple twist, without any longitudinal displacement along the length of the fibre. In the case of the elliptical fibre, however, not only is a state of strain set up, due to the twist itself, but there is also a longitudinal displacement of the fibre material.

It can be shown experimentally and mathematically that :—

(1) Evenness of configuration of cross section or contour gives even rate of twist for the same twisting forces.

(2) Varying degrees of ellipticity give consequent varying degrees of sensitivity to twist due to torsional forces.

(3) An ordinary wool sample of any particular quality contains fibres of varying degrees of ellipticity and circularity. It can therefore be suggested that the more nearly circular the fibres, the nearer their rate of twist will approximate to the natural average for the sample.

(4) The greater the diversity of configuration of cross-sections of fibres in a sample the greater the variation in twist in the individual fibres and consequently the worse the spinning power of the sample. Evenness of configuration means evenness of rate of twist.

(5) The higher the proportion of circular fibres in the sample the more even the twist of the fibres and the closer the approximation to the mean value of rate of twist for the sample.

(6) Circular rods give no longitudinal displacement of material particles of the fibres and remain circular in cross section when twisted.

(7) Strains are produced in twisting elliptical rods or fibres due to longitudinal displacement and these strains assume a maximum value at the extremities of the minor axes of the ellipse.

These mathematical findings are borne out by practical experiments, and it may also be shown that the contour of the fibre affects its elasticity.

It is, therefore, a matter of some importance that a ready method for measuring contour should be available. Unfortunately it is not such a simple matter as one might imagine.

The first point to be considered is a ready method for mounting the fibres ready for a microscopic examination, and this has been very effectively worked out by Burgess, and published in the *Wool Record*.

It may be mentioned here that in addition to wool fibres, alpaca, mohair and camel hair have been successfully cut by means of Burgess' method. This method is very handy, because the microscopic slides can thus be viewed through a microscope, or, if a photographic method is employed a lantern slide can be made and the fibres projected at very high magnification. It is a simple mathematical process to deduce the degree of ellipticity of the fibres if a measurement of the major and minor axes of the ellipse is taken, and it is well known that in the case of a circle the ratio of these two axes will be unity. The closer the value of the ratio of the lengths of the axes to unity, the more nearly circular the fibre.

Methods for Rapid Fibre Comparison.—The importance of fibre thickness in assessing the value of the fibre for manufacturing purposes has led to the design of various types of instrument for execution of its measurement. Most of these are based on a

“ diameter ” theory and hence do not serve except for comparison of representative samples. Two things are essential in such instruments :—

- (1) Facility of handling and speed of recording results.
- (2) Reasonable magnification and accuracy of measurement.

In 1921 Zipser (“ Textile Raw Materials and their Conversion into Yarns ”) outlined an instrument of great precision known as the “ Eriometer.” This instrument consists of a compound microscope, fitted with a dispersion (concave) lens, which is placed in front of the object glass, and is cut diametrically into two equal pieces which can be mutually adjusted in the direction of the cut by means of a micrometer screw. The screw vernier is graduated to $\frac{1}{2500}$ of an inch. The wool fibre to be measured is stretched at right angles to the line of intersection, and is thus visible to the observer as magnified 50 times. On adjusting the two halves of the dispersion lens, two views of the object appear. The extent of the adjustment is equal to the breadth of the object, and is read off in a 50-fold state of magnification on the vernier. Each degree of the latter represents, therefore, $\frac{1}{50 \times 2500}$ part of an inch. The instrument is therefore capable of great accuracy of measurement, and has been designed for wool investigations by Dollond.

In the *Journal of Textile Science* for 1928, Ewles has put forward a method of wool fibre measurement. A description of this instrument may be quoted as follows :—

“ When light diverging from a luminous point or slit passes by the edges of an opaque obstacle, a series of coloured bands, formed by diffraction, are seen parallel to the edges of the obstacle. If, instead of a single obstacle, we have a large number of irregularly distributed obstacles it may be shown that the diffraction pattern is the same as that produced by a single one multiplied in intensity by the number of obstacles. If the particles are spherical, the pattern takes the form of coloured rings, as, for example, in the well-known coloured rings or coronæ seen round the sun or moon in a hazy atmosphere, or round a street lamp seen through a wet or dusty window. Thus, if a brightly illuminated slit is viewed through a bundle of fibres arranged roughly parallel to the slit, a system of bright bands with coloured edges, separated by dark bands, is seen. It may be shown that the angular width of the bands is inversely as the diameter of the fibres.

"An instrument designed to utilize this principle has been made up in an easily portable form. It consists of a pair of brass tubes, each about 8 inches long, "telescoping" into each other. At the end of the outer tube is a slit about $\frac{1}{16}$ inch wide and $\frac{1}{2}$ inch long; on one side of this slit are two pairs of very fine holes, the line of the inner pair being 3 mm. from the centre of the slit, and of the outer 5 mm. The end of the inner tube is closed except for a small hole about $\frac{1}{4}$ inch diameter. A small wisp of the fibres is taken and the fibres arranged roughly in line and placed over the hole, being kept in place by a cap provided with an eyehole. Looking through the eyehole and holding the apparatus up to the light (either daylight or fullolite lamp a few yards away), the system of coloured bands separated by dark bands referred to above will be seen. The inner tube is turned till the bands are parallel to the slit (*i.e.*, the fibres lie parallel to the slit), and the inner tube drawn in or out till one pair of fine holes (whichever is possible) fits into the middle of the first dark band. The reading of the bevelled edge of the outer tube on the calibrated inner tube then gives directly in mm. the mean diameter of the fibres. For greater accuracy, a number of settings should be taken quickly and a mean value struck. In addition, particularly if wool fibres are being measured, it will be advisable, owing to the variability of the staple of this material, to take a number of samples. In this way, since each reading gives the mean diameter of something like, say a hundred fibres, the mean of many hundreds can be obtained in a minute or two."

In 1926 Henster, (*International Review of the Science and Practice of Agriculture*, 1926, 4. (New Series) No. 3., p. 513), put forward the idea of a projection type of instrument for the direct measurement of the thickness of wool fibres. The apparatus was designed by Dr. Doehner, of Chemnitz, and has been used at the Institute for Animal Breeding and Biology of the Technischen Hochschule of Munich. The early design of this instrument was cumbersome and heavy and the magnification was small, but, from a short note at the end of the paper, it appears that many simplifications have been effected and the apparatus is now more portable. The magnification has been increased to 500 by a special lens system. Measurements of "diameters" of fibres are carried out by a revolving screen ruled in millimetre squares. The apparatus is made by Reichart, of Vienna, and is marketed in Germany.

For the *comparison* of samples of wool fibres it was felt that this apparatus was too complicated and expensive, while it lacked the very desirable feature of allowing two samples to be viewed in adjacent fields simultaneously. It is not advisable to compare two samples by viewing them alternately, as the eye rapidly loses its fine sense of size, and accurate comparison becomes impossible. If the samples are seen alternately measurements have to be made as in the Doehner instrument, and this involves considerable time as many measurements are necessary owing to the large variations in fibre diameter. When two samples are seen simultaneously, accurate judgment can be made as to which has the larger diameter. Thus, if some standard wools are available for the making of slides it is very easy to get an accurate judgment of the quality of any other wool.

This simple projection type of microscope has, therefore, been designed by the British Research Association for the Woollen and Worsted Industries, with two separate optical systems, giving adjacent images of two sets of fibres on the same screen, one being the sample and the other the standard.

Optically the instrument is of the simplest possible construction. The wool fibres are illuminated by a small electric lamp. The light is concentrated by a condenser on to the slide containing fibres. The microscope objective causes a magnified image of the fibres to be formed on the ground glass screen which is placed at some distance away in order to get a large magnification.

In the actual instrument now on the market a plane mirror was introduced in the path of the rays from the objective so that the image of the fibres is formed on a screen situated above the objective. The advantages gained by this alteration to the design are:—

- (1) The instrument is very much more compact, being nearly halved in length.
- (2) The slides containing the fibres are under control while under observation on the screen.
- (3) The provision of a "funnel" round the screen enables the comparator to be used in any room without other screening. The position while working is also more comfortable.

In this design all parts are either easily and cheaply made or can be purchased from stock. Both of these factors render the instrument easy and relatively cheap to build. The magnification at

present used is about 80 and is found very convenient. The appearance of the completed apparatus can be seen from the photograph (figure 13.) Higher magnification can be attained if desired by exchange of the standard parts of the optical system of the instrument.

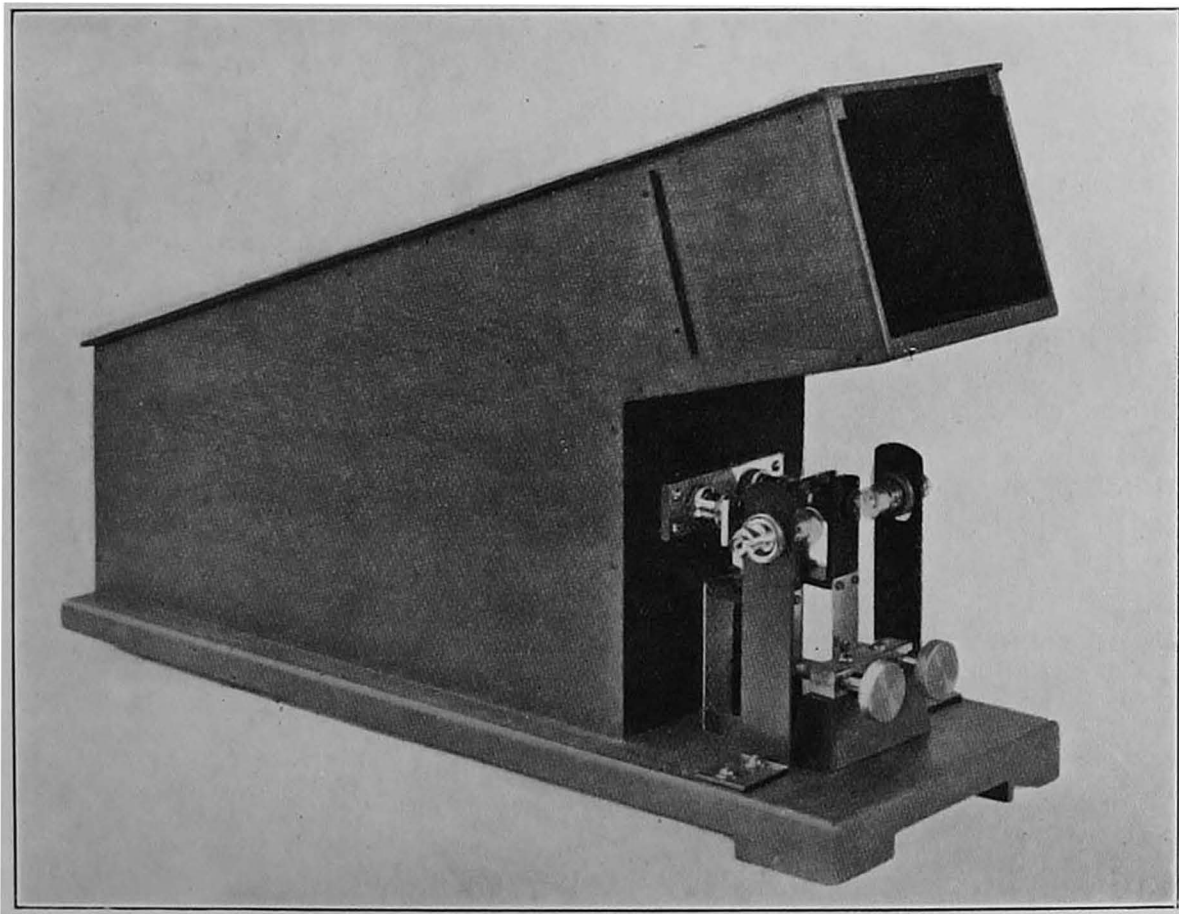


Fig. 13.—Wool fibre comparator.

A detailed description of the parts was published in the *Wool Record* dated June 1st, 1928. Since then, however, the instrument has been made much more compact by allowing for a collapsible top, so that it has now been rendered portable, the whole fitting into a small-sized box. The fibre, or slide holders are of unique design. They have been specially designed with two objects in view :—

(1) To obviate the need for making up microscope slides in the usual laborious manner. This is accompanied by the provision of suitable springs on the slide holders, so that the fibres under

test may be placed between a microscope slide and glass cover slip and held under the springs, without any further preparation or manipulation.

(2) To allow a large area of the slides to be available and to provide means so that they may be moved about these first positions without risk of leaving contact with the springs.

Illumination of the fibres is effected as follows:—Each optical system is illuminated by a separate electrical lamp, but both are controlled by one switch. The lamps are 6-volt, 3-watt lamps of the type used in motor-car side-lamps, and are, therefore, easily obtainable. A shield is provided to keep direct light from the lamps out of the eyes of the observer.

For measurement of the actual diameter of fibres a very convenient method is provided. Owing to the fact that the objective and screen are fixed the magnification is constant. A circular piece of celluloid, 3 cms. in diameter, is provided with marks of various sizes on its periphery. Each mark or hole corresponds to the diameter of a fibre, multiplied by the magnification. The celluloid scale is laid on the ground glass screen over the image and is moved about until a mark is found which just fits the thickness of the fibre. The number corresponding to the mark is the diameter of the fibre in thousandths of one millimetre.

Contour Estimation by Fibre Rotator.—The variation of contour and thickness along the length of the wool fibre is also a point of considerable importance. The production of wool with a sound staple and the measurement of the degree of variation has hitherto been a matter for visual investigation, and hence a matter of opinion. In order to afford a direct means of measuring the contour and the thickness at any point along the staple without in any way injuring the fibre an instrument has been devised by the author. The instrument comprises an improved form of Polikeit apparatus, capable of taking fibres up to 10 inches in length and of smaller lengths down to less than one centimetre. The fibre is held at each end by a special type of "chuck," and is capable of rotation simultaneously at both ends by means of a special rotatory device. Both ends can be rotated to exactly the same degree and a graduated scale is provided which records the degree of such rotation. The bed of the instrument is so arranged that the fibre

can be moved laterally without in any way disturbing its position in the "chucks." The whole is mounted so that the fibre replaces the filament in the optical system of an Einthoven galvanometer, and thereby a magnified image can be secured up to 500 or more diameters. A small right-angled prism on the eyepiece end of the instrument projects the image horizontally. With this instrument it is possible to examine a fibre successively at any stage along its length, and further, at each selected stage to rotate the fibre through 360 degrees and thus measure its width in every possible direction across its cross section. The exact contour can thus be measured at any part of the fibre, and a succession of such measurements gives an accurate estimation, not only of the amount of its variability, but also an exact measurement of its width at each point. By means of this instrument it has been possible to show that even in apparently straight fibres there is a small degree of rotation or waviness during growth. Further, the instrument is useful in affording a complete measure of the fibre, previous to further testing for elasticity, etc., since it leaves the fibre unimpaired in any way, contrasting thus with other microscopic methods by which the fibre is damaged or destroyed in mounting on a slide.

Obviously, only the very fringe of the subject has been touched as yet, but it is possible with the improved methods and technique now available that the results of measurement will provide a suitable basis for correct methods of standardization.

Another point of interest with regard to contour is afforded by some recent work done by C. G. Winson. The measurement of the contour of greasy and light-greasy wools has been undertaken. The wools were similar in character and from a practical test were known to have a different spinning power. The greasy wools were undoubtedly good spinners, and the less greasy samples showed a deficiency in this regard. The curves shown herewith (figure 14) for typical New Zealand wools of 50's quality are interesting. From the curves it is seen that in general the greasy wool, although classed by the wool man in the same category as the less-greasy, contains a maximum number of fibres which are very much finer in cross-sectional area. With regard to the circularity, there again it is shown that in the classes of lowest ellipticity the greasy fibre exceeds the less greasy.

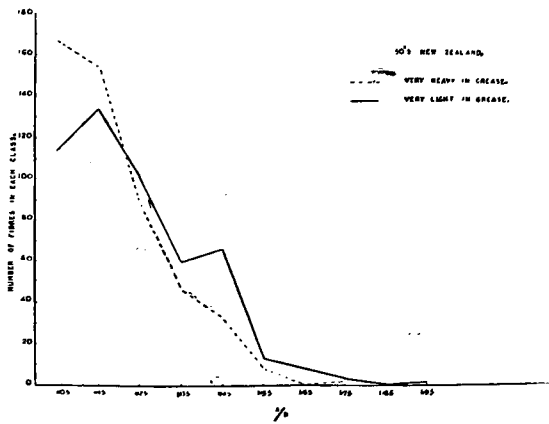
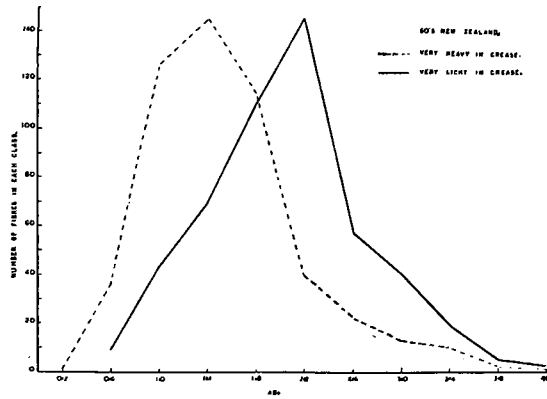


Fig. 14.—Analyses of wools heavy and light in grease.

A summary of the results from Winson's paper is of interest, and will illustrate these points for a number of wools. These results are shown in Table XXIV :—

TABLE XXIV.

Quality.	Range of AB, <i>i.e.</i> area of cross section.	Per cent. in given Range.	Circularity ratio $\frac{a}{b}$ per cent. Fibres within range 1.00-1.25.	Grease Content.
Australian fleece wools—		Per cent.	Per cent.	Per cent.
56's, greasy	0.60-1.40	75.8	81.2	13.28
56's, non-greasy	0.60-1.40	65.8	69.6	8.48
58's, greasy	0.60-1.40	76.0	72.4	10.24
58's, non-greasy	0.60-1.40	76.0	72.8	8.36
60's, greasy	0.60-1.40	95.0	80.6	12.69
60's, non-greasy	0.60-1.40	79.4	75.0	10.40
64's, greasy	0.60-1.40	89.2	86.8	13.43
64's, non-greasy	0.60-1.40	80.4	76.0	11.99
64's, West Australian (heavy in grease).	0.20-1.00	87.6	82.6	22.40
64's West Australian (light in grease).	0.20-1.00	84.6	71.8	10.56
50's, New Zealand (very heavy in grease).	1.00-1.80	75.0	82.0	10.14
50's, New Zealand (very light in grease).	1.00-1.80	44.4	69.8	4.05

It appears from the above examination of twelve samples of fleece wools that the greasy samples differ from the samples of the same quality, but with a less grease content in the following ways :—

- (1) They are on the average distinctly finer.
- (2) In general they are more uniform in their fineness, *i.e.*, less variation of size of cross section occurs in the greasy samples.
- (3) In all cases the greasy fleece wools are more circular in cross section.
- (4) In all cases the variation of shape of cross section in the greasy wool is less.

It is well known that the first two facts undoubtedly make for higher spinning capacity. Experiments have shown, too, that a high degree of circularity in fibres results in a better spin. Taken together, therefore, the results indicate that from these standpoints the greasy fleece wools should be superior in spinning power to the wools of corresponding quality, but containing a less percentage of grease in the natural state.

These tests are not isolated, but similar to many others which have been taken and published in Winson's paper. The obvious inference that a greasy wool possesses a more regular and less elliptical contour indicates to some degree the reason for the superiority of its spinning power. It is possible that in exuding the grease the skin of the animal is kept more supple and that the orifice of the follicle is less likely to be deformed in shape or partially obstructed by solid matter. This, of course, is mere surmise, and once again a problem of considerable interest and importance is presented for research work on the living animal and its production of wool grease, etc.

Apart from anything else, careful note should be taken of the coefficient of variation of both cross-sectional area and ellipticity in the case of greasy and less-greasy wools. Invariably the greasy wool is more regular than the less-greasy. It would seem, therefore, from this work that a tremendous field for research is opened out in that we might say that, other things being equal, greasy wool would spin better than less-greasy. The full causes of such a phenomenon are yet to be elucidated, but the findings are in agreement with practical experience. In any case, however, it would seem that in the determination of spinning power it was extremely unsafe to base one's standard in any way on a diameter measurement, and even in this case on a cross-sectional area alone. One would, therefore, wish to adopt some standard method of determination of cross-sectional area which would be truly representative in every way. The previously proposed method of weight per unit length seems at the moment to be the most suitable.

It is interesting to note that if one considered a circular fibre of 90's quality, the diameter would be, roughly, $1/2,000$ th of an inch, and 100 miles of such wool fibre would be necessary to weigh one ounce.

Crimp or Waviness.

The elucidation of the cause and effects of crimp has not received the attention that it deserves, chiefly because the knowledge of the actual growth of the hair from the follicle is so scanty. The literature of the subject is confined to very few papers and can be quickly surveyed. Nathusius-Konigsborn in "Das Wollhaar des Schafs", published in 1866, draws attention to the phenomenon, whilst in 1908 Bowman in his work on the structure of the wool fibre discusses it at some length. Bowman remarks that it is difficult to explain the cause of crimp or waviness since no mechanical means of production are evident in the follicle or the skin of the animal. He suggests an unequal contraction of the cells on the two sides of the fibre, first in one direction and then in the other, but at the same time observes that it is impossible to detect any feature in the arrangement of the constituent cells to account for this peculiarity. A paper by N. Burgess (Queckett Microscopical Club, 1867) also refers to the same phenomenon and postulates the idea that as soon as the point of the fibre has protruded through the skin of the animal, a small part of the epidermis is converted into wool, and then a rest takes place. The growth is thus intermittent, hence one side grows quicker than the other and in consequence curl takes place. After the interval another growth takes place and thus another ring of fibre is added. Bowman points out that the epidermis is not converted into wool, but the unequal extrusion of the hair as the cells become consolidated after leaving the skin might account for the phenomenon. He further proceeds to discuss a possible explanation in that "the cells which are to constitute the fibre are large and plastic within the lower part of the follicle, and become more consolidated as the fibre is pushed upwards. The cells which constitute the cortical part become elongated by the pressure to which they are subjected by the shrinking in of the outer cells. These outer cells shrink until they completely collapse, and thus form the epidermal plates, although they probably retain the laminated structure, and are capable of expanding again when subjected to variations of pressure, humidity and temperature; and, as they shrink inwards, their gelatinous nature enables them to adhere together till they form a solid epidermal layer, which tightly binds the constituent cells of the cortical part. Unequal shrinking of this ring would give a tendency to curl."

This statement is put forward as a possible explanation; but, as will be shown later, does not meet the requirements of a generalization to account for the different types of crimp found in wool.

course of his paper, Bowman gives a table showing the general relation between the number of curls and waves and the diameter of the fibre, remarking that the coarser wools exhibit the curl least, and the finer the most.

Bohn, in his "Schafzucht," had previously noted this correlation between the fineness of the fibre and the number of curls per inch, incorporating his results in tabular form.

A far more exhaustive series of tests to determine the relationship between the number of curls per inch and the fibre length and diameter of a wide range of wools had also been given in a report by Professor M'Murtie (Illinois Industrial University, Report of the Commissioner of Agriculture, Washington, 1886), and although a large number of recapitulations and deductions are made, his results only served to show the wide range of variations which can occur in fibres, both in the same sheep and in different classes of sheep, according to the influence of conditions of health, climate, breed, nutrition, etc., to which the animal has been subjected.

Matthews ("Textile Fibres," 1916) accounts for crimp by postulating an unevenness of the growth and arrangements of the cortical cells, with the result that the fibre is contracted first on one side and then on the other, giving rise to curl or waviness. His remarks are similar to those of Bowman. Zipser ("Textile Raw Materials," 1921) remarks that curliness is most developed in merino wool, to a less extent in unimproved stock, and is almost absent in wool from moorland breeds. He, however, notes a distinction in the various forms of crimp, which he describes as normal crimp, deep crimp and flat wavy wool. He illustrates the wavy character of wool by measurements of the Australian Merino, including as his chief types :—

Fine ..	..	..	24 crimps per inch.
Medium	..	..	18 to 22 crimps per inch.
Strong	..	..	14 to 18 crimps per inch.

He comments on the decreased value of irregularly crimped fibres, but does not attempt any explanation of the causes to which these are due. In more recent years, greater attention has been given to the subject, and in 1926, Davenport and Ritzman ("Some wool characters and their inheritance", New Hampshire Agricultural

Experimental Station, Technical Bulletin No. 31), give a survey of a comprehensive nature in reviewing their work on the subject. They classify crimp or waviness into different types :—

- (1) A tendency to form ringlets (Angora and Dartmoor sheep).
- (2) The extreme case of the above—the formation of a flat spiral (Karakul lambs).
- (3) Uniplanar waves (Merinos).

The diameter of the spiral is given as approximately one millimeter, or more. They remark that “ the degree of crimp seems to be correlated with fineness of wool ”, but conclude that “ on the whole our data yield support to the view that (within limits) there is no necessary relation between crimp and fibre diameter ”. This conclusion is borne out by subsequent work as will be shown later. Davenport and Ritzman attempted to find a correlation coefficient between diameter and crimp for a number of wools taken from Rambouillet sheep and from crosses between this breed and the Southdown and Hampshire. The table given below, incorporating their results, is of interest.

TABLE XXV.

Correlation found between diameter of Fibre and per cent. of crimp.

1.	Rambouillet only	..	..	..	..	..	..	- 0.216 ± 0.094
2.	F ₁ Southdown × Rambouillet	F ₁ ♀	..	..	..	..	..	+ 0.052 ± 0.109
3.	F ₁ .. × ..	F ₁ ♂	..	..	..	..	..	+ 0.040 ± 0.116
4.	F ₂ .. × ..	F ₂ ♀	..	..	..	..	..	+ 0.020 ± 0.093
5.	F ₂ .. × ..	F ₂ ♂	..	..	..	..	..	+ 0.205 ± 0.104
6.	Hampshire × Rambouillet all	..	..	..	..	..	..	+ 0.040 ± 0.067

On account of these results they find that the amount of correlation between crimp and diameter of wool varies in the different groups examined by them, and that nowhere was it significant. A point of note in their work was their observation of the variation of crimp along the length of the fibre, and an observation that in the short waves of the fine wool a much larger proportion of the total length of the fibre is represented in the crimp than is the case with the longer waves of coarse wool; hence the percentage of the total extended length of fibre that is taken up by crimp may also serve as a basis for comparison in the raw wool. This statement is open to criticism and it will be shown later that actual measurement on particular fibres is not in accordance with their views. A further

study of crimp, published 1927 by Hultz, ("Wool studies with Rambouillet sheep," Univ. of Wyoming Agricultural Experiment Station, Bulletin No. 154) examines the range and average number of crimps in wool for different fleece ranks and body location on the animal itself. The range of crimp appears from the results to lack definite order, but it is noted that the greater number of crimps are in the higher rankings. He attempts to find a correlation coefficient between diameter and crimp in the same way as Davenport and Ritzman, and evaluates it as -0.321 ± 0.081 as compared with the latter's value of -0.216 ± 0.094 . One of the most assiduous workers on this subject has been Duerden, who has examined the phenomenon from many points of view. His publication in 1926 ("Waves in wool, how crimps are produced," *Farmer's Weekly*, November 17th), outlines a theory of crimp formation by a consideration of wool growth from the birth coat of the lamb onwards.

He states that in the coat of the newly born lamb the wool is found in spiral tufts which he considers are the foundation of the later locks and staples. After birth the tufts continue their growth, and if the wool is not dense, they are able to retain their spiral form, each lock growing as a separate long ringlet or curl. Duerden then puts forward a theory of uniplanar crimp in that as the fleece becomes denser the fibres and locks will press upon one another, and will be restricted in space so that the spiral form cannot develop completely. He hypothesises that whilst emerging from the follicle, and still plastic they become flattened by the lateral pressure mutually exerted upon each other in the lock. Such a natural spiral tendency, with insufficient space to express itself, will be degraded into plane waves. Duerden draws a parallel of a corkscrew flattened out by lateral pressure. It is doubtful, however, if this theory is tenable, since the lateral pressure of hair on hair or even in the lock would be insufficient to create the effect which actually exists in crimped wool. Another theory to be discussed later, however, can be made to express adequately every form of crimp. A recent paper by Bosman, ("Standardization of wools: crimps and quality counts," *South African Journal of Science*, December, 1927) describes experiments directed towards the standardization of South African Merino Wools. His findings can be summarized as:—

- (1) The crimps in natural wool are deemed to be of great assistance as an indication of the thickness of the fibres, and thereby the quality counts. In general, it is found that a high

number of crimps per inch, indicates a fine wool, *i.e.* one which will spin to high counts, whilst a low number of crimps indicates a thicker wool, or one of lower spinning power. He then proceeds to determine to what extent the crimps correspond with fineness and quality counts.

(2) Twenty-three samples of wool and tops were measured microscopically for diameter, and directly for crimp. Thirteen of the samples indicated a definite relationship between the estimated quality counts as regards fibre thickness, in the case of raw wool, and in the case of tops the results were in agreement in six instances.

(3) A less general relationship between crimps and quality counts is indicated; namely, that the higher the number of crimps per inch, the higher the quality counts. There were many exceptions, showing that too great reliance could not be placed upon them. He found the number of crimps per inch for 64's quality varied from 11 to 15, that for 60's from 9 to 11, whilst 15 crimps per inch serve for both 70's and 64's. Only a general correspondence was therefore indicated between thickness and crimp, and he concludes that crimps are of less value than direct measurements of thickness for standardization of quality counts. Duerden, (*Journal Textile Institute*, May, 1928) however, attempted to correlate the two factors for South African Wools and found a fair measure of agreement, for good wool.

He states that for sound, well-grown wools, with the exception of those from folds and plates, the crimps form a fairly reliable guide to the quality number and the mean thickness. He asserts that in using crimps as a guide, woolmen make consistent estimates of the quality number, and fibre thickness. The estimates are unlikely to be valid for impoverished wools or those associated with folds and pleats. Duerden indicates that it is hoped to be able to show that crimp may be taken as an index of the pliability, an important factor bearing on spinning. Two other points of interest in Duerden's work may be mentioned; namely, that his method of measurement of crimp to a first approximation is new, and consists of matching the crest of each wave against a standard indicator, and secondly his table showing the standard thickness limits and number of crimps per inch for South African Merino wools. This table is appended herewith.

TABLE XXVI.

Standard Thickness Limits and Number of Crimps per inch.

Quality Number.	Thickness Limits.	Crimps per inch.
150's	14.0-14.7 μ	28-30 ; 27-30
120's	14.7-15.4 μ	25-27 ; 24-27
100's	15.4-16.2 μ	22-24 ; 21-24
90's	16.2-17.0 μ	20-21 ; 19-21
80's	17.0-17.9 μ	18-19 ; 17-19
70's	17.9-18.9 μ	16-17 ; 15-17
66's	18.9-20.0 μ	14-15 ; 13-15
64's	20.0-21.3 μ	12-13 ; 11-13
60's	21.3-23.0 μ	10-11 ; 9-11
58's	23.0-25.5 μ	8-9 ; 7-9
56's	25.5-29.0 μ	6-7 ; 5-7

It would appear, therefore, that up to this point no work on crimp has resulted in a theory applicable to all cases in a general sense. The work of Barker and Norris, however, has resulted in a theory of crimp which satisfies all cases, and though purely physical, opens a new field for biological investigation. The anomalous wools of Duerden have been shown to be included as special cases of a general law. Examination of a wide range of wools shows that many definite types of crimp and curl occur. Thus, a single fibre may be in the form of :—

- (1) A simple spiral which may be circular or elliptical.
- (2) A spiral which at certain periods of its growth has reversed its direction of rotation.
- (3) Uniplanar waves.
- (4) Uniplanar waves in which the plane of vibration is gradually changing along the length of the fibre.
- (5) Combinations of each and every one of the above in the same fibre.

Examples of these types are shown in the photographs of figure 15.

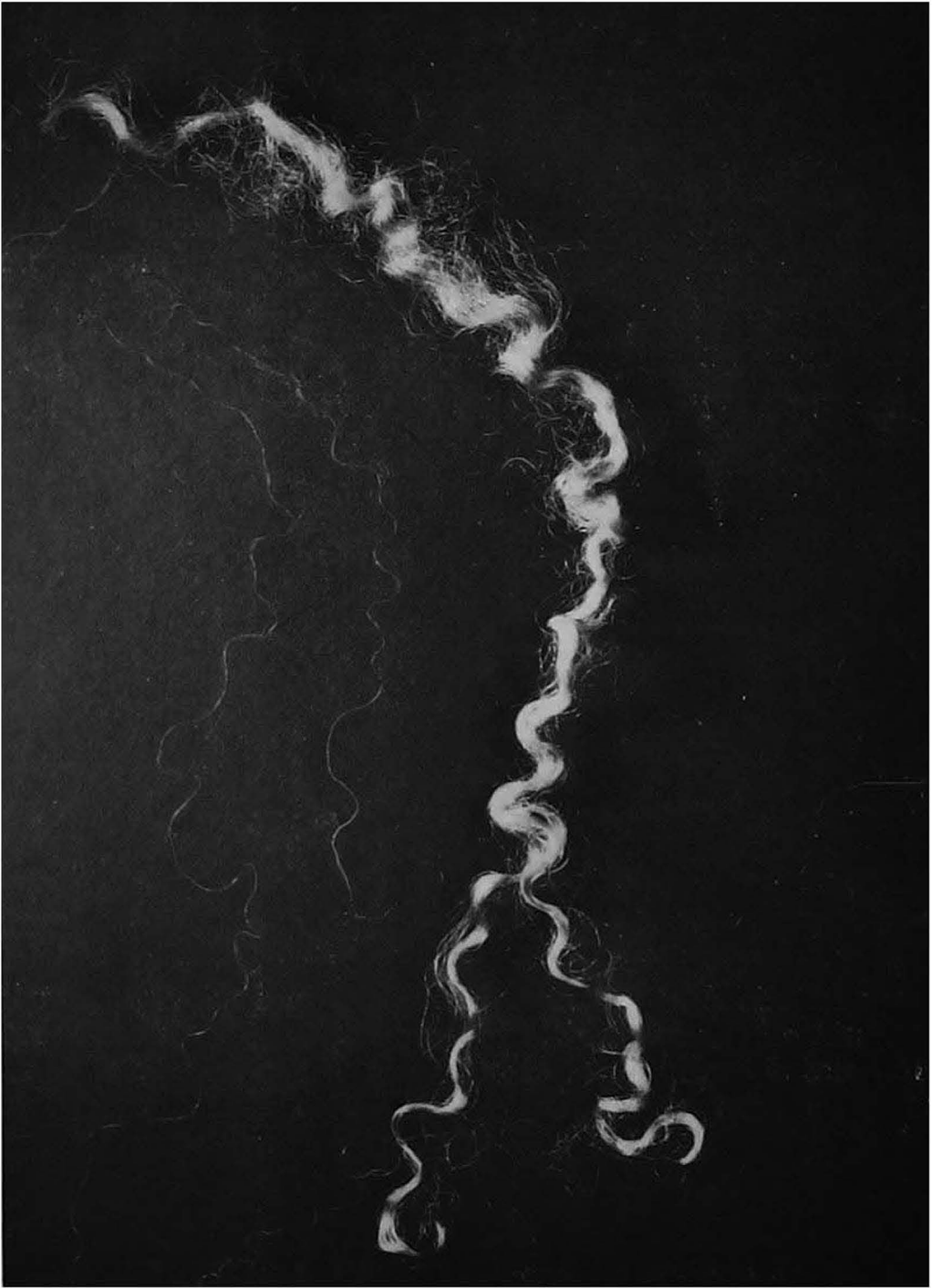


Fig. 15a.—Wensleydale wool showing corkscrew curl.



Fig. 15b.—Lock of wool showing reversal of direction of spiral.

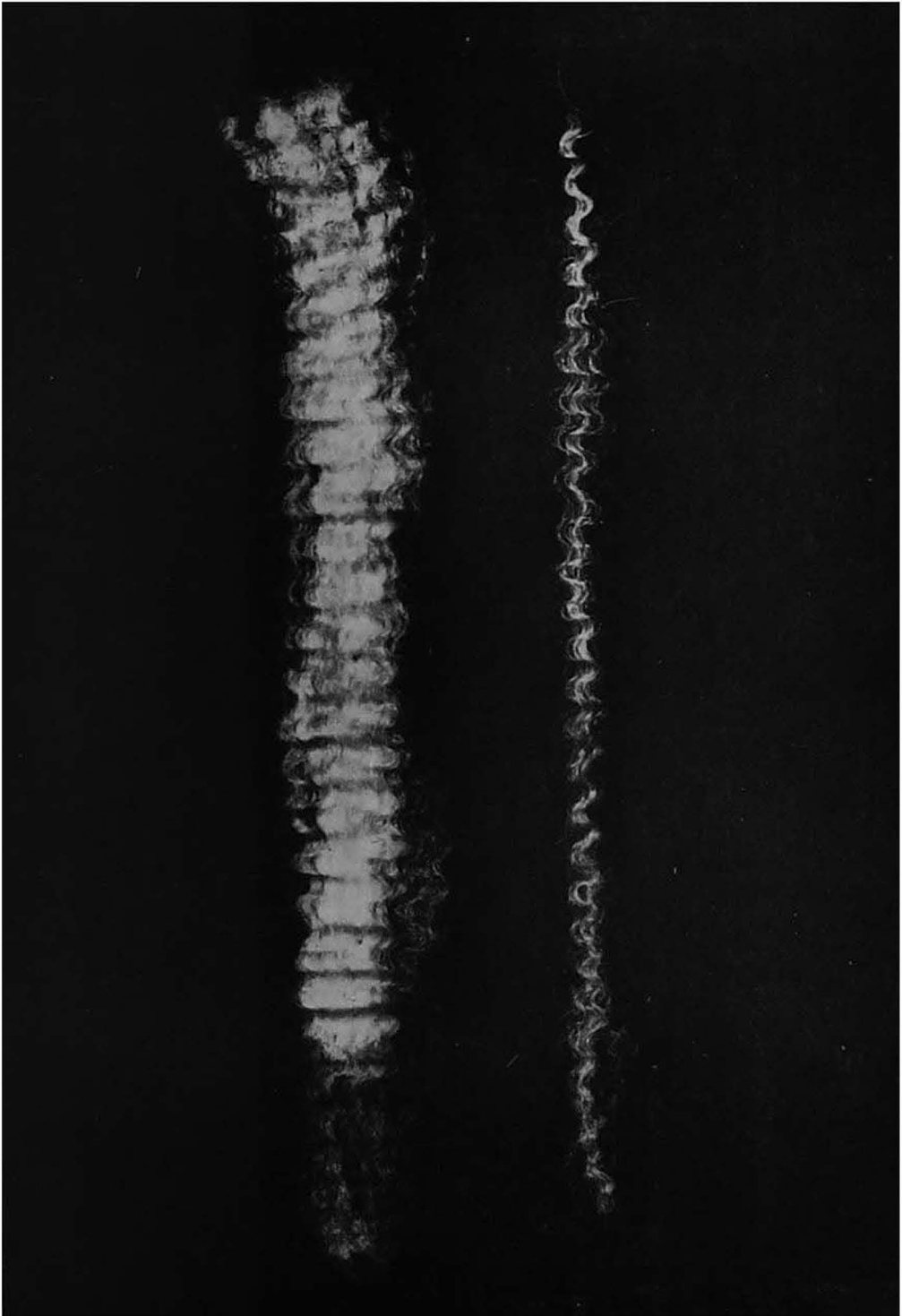


Fig. 15c.—Lock of wool showing uniplanar waves.



Fig. 15d.—Another type of uniplanar waves.

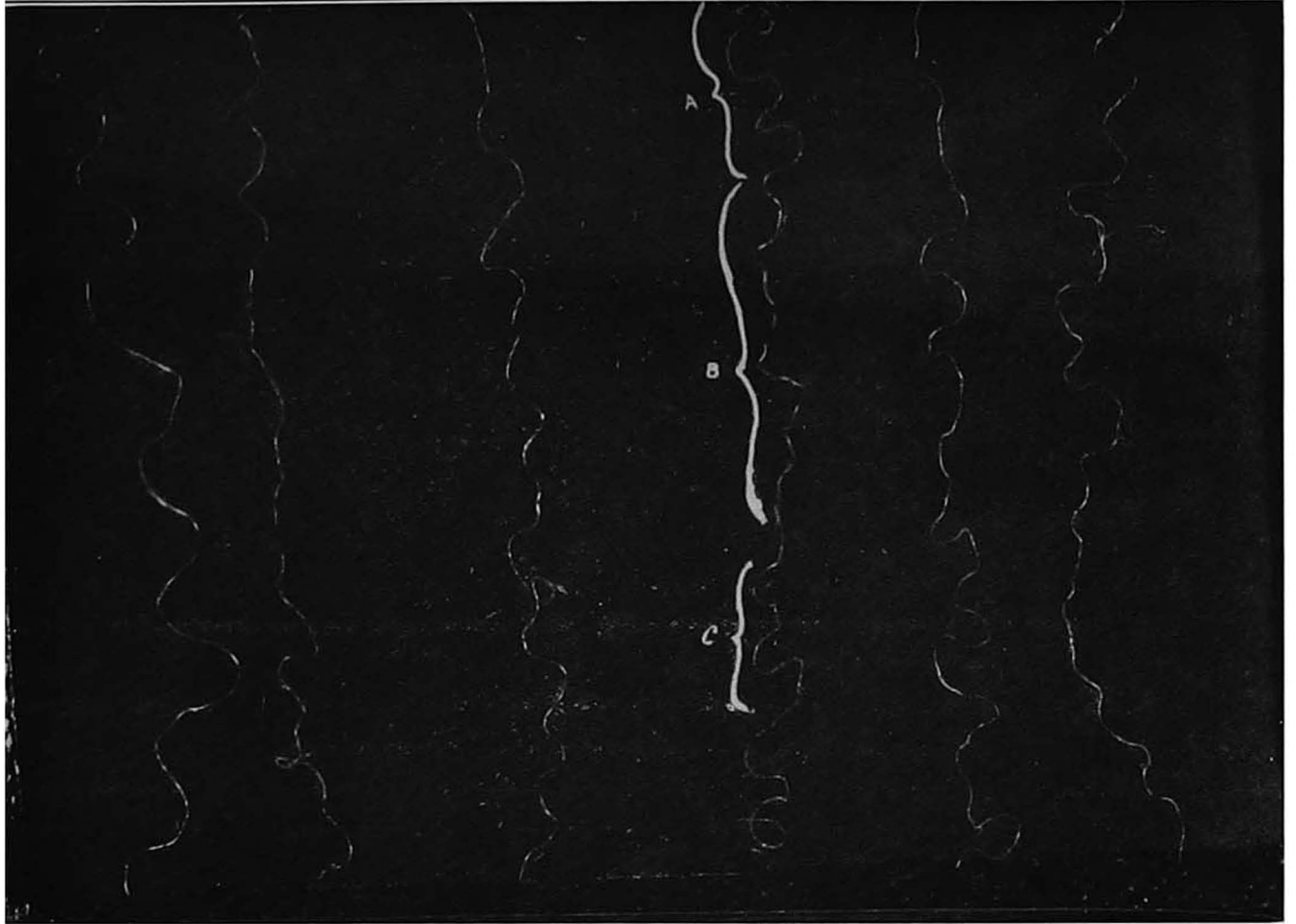


Fig. 15e.—Examples of fibres showing rotation of the plane of crimp.

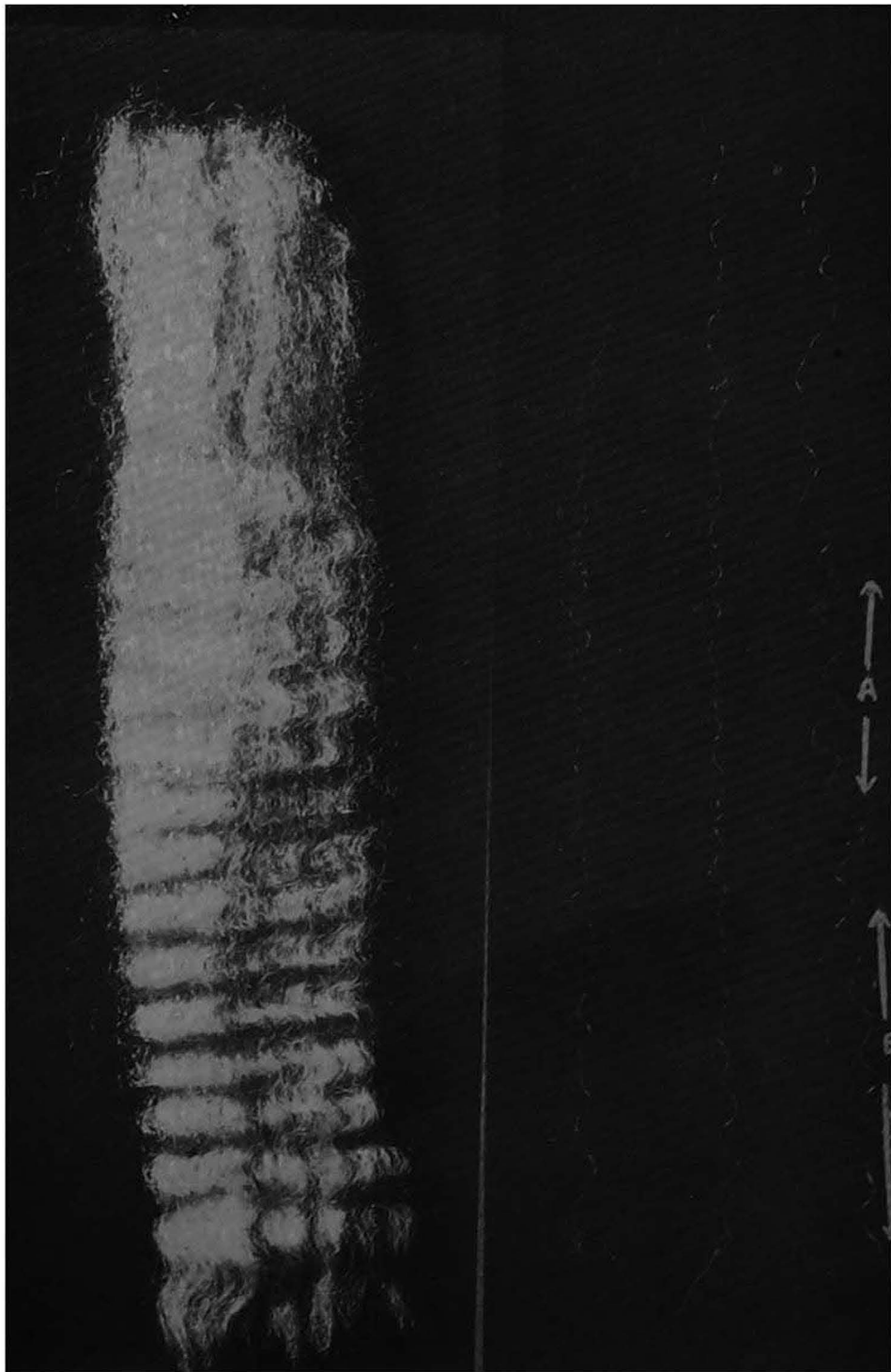


Fig. 15f.—Lock showing uniplanar waves with tendency to corkscrew formation towards tip.

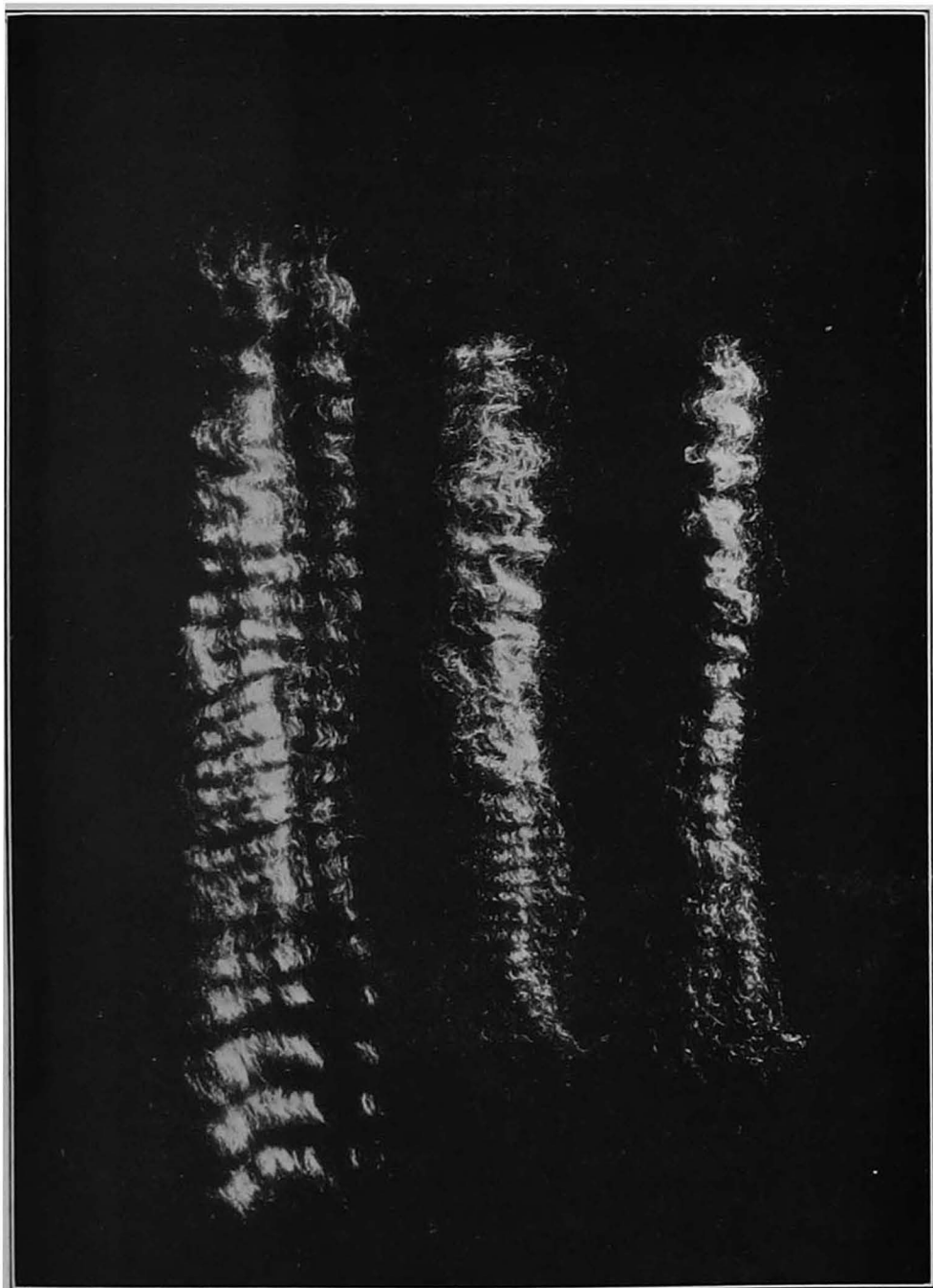


Fig. 15g.—Locks showing change in size of crimp in different regions of the same lock.

Beside each lock of wool are seen two or three fibres that have been extracted from that lock.

- (a) and (b) illustrate the corkscrew curl. They are from a Wensleydale sheep. The arrow in (b) indicates the position of the change of direction of rotation in this lock.
- (c) is a lock of wool from a merino sheep, and is a good illustration of uniplanar waves. The small piece of the lock that has been detached from the rest clearly shows that all the crimp waves are in the plane of the paper on which it is lying.
- (d) presents a different appearance from the lock (c), although it is seen from examination of the single fibres that all the crimp waves of a single fibre lie in one plane. The undulating appearance of the lock is due to the arrangement of the fibres relative to each other.
- (e) shows fibres illustrating uniplanar crimp in which the plane of crimping rotates along the length of the fibre. On the fibre marked, the plane of the crimp has turned through 180° between the regions (a) and (c). The crimp at the region marked (b) was just as distinct as at (a) and (c), but it is not seen in the photo because the plane of crimp is at an angle to the plane of the paper.
- (f) shows a lock containing fibres which exhibit uniplanar crimp at the region (a) and a tendency to corkscrew formation at the region (b).
- (g) is a lock of wool in which the size of the crimp waves shows a distinct variation in different parts of the same lock.

We thus have to find some general expression which will account for these various forms of crimp or waviness, and which will be comprehensive to take in each and every one.

From a purely physical basis the solution of this problem is not so difficult as it may seem, and Barker and Norris, in analysing crimp, consider that if two simple harmonic motions at right angles be considered as existing at the follicle, in addition to the force of extrusion, the problem can be solved. It has already been detailed that all types of curl and crimp are found in the wool sample, varying from the simple spiral to uniplanar crimp waves. In every form all portions of the fibre in its unstrained state lie within a short distance of the axis of that form.

(1) When the fibre assumes a helical formation we get an approximation to the form obtaining in a spiral spring where the axis of the spring is inclined at a finite angle to the horizontal. A not infrequent occurrence in this type of curl is a reversal in the direction of rotation of the spiral, a right-handed spiral may become left-handed and vice versa.

(2) When the waviness lies in a single plane the plane may remain constant throughout the length of the fibre or may be found to twist so that when a fibre is placed on a flat surface the plane of part of the crimp will be in the same plane as that surface, and part will be in a plane or planes inclined at an angle to the plane of that surface.

In order to reproduce any of these forms of crimp mathematically or actually with a mechanical model it is necessary to assume two simple harmonic motions working at right angles. Whether any such state of affairs exists at the hair follicle has not been demonstrated, but there is certainly evidence, in the field of biological observation, that periodicity or rhythm is not an unusual feature in the growth of hair. Thus the hair of insectivores and rodents, and also of some other forms, is characterized by a discontinuous medulla. Hollow spaces alternate regularly with bridges of solid material. There is a type of pigment distribution in these hairs that is no less strikingly periodic. Granules may be seen at the proximal portion of each air space. In an albino rabbit the granules are colourless, but if the hair is grey these granules are black. Alternating bands of different colours are often seen in hairs, and it is noteworthy that the transition from one colour to another is sharp and definite. Another type of periodicity was observed in *Coenolestes* in which hairs showed a regular alternation of portions with and without a medulla.

In the growth of feathers in birds far more striking rhythms are to be found. Apart from such alternations in colour, as is shown in the barring of breeds of fowls such as the Plymouth Rock, there is the case of the ostrich feather, in which it has been demonstrated that alternating bands reflect the difference between day and night temperatures.

Hair follicles are able to produce fibres that show an immense range of difference in structure along their length. For example, the protective outer hairs of the rabbit have a swollen distal portion that

is many times the diameter of the finer proximal portion. A somewhat similar, though less striking condition is seen in the heterotype fibre in the sheep. There is also considerable evidence that the same hair follicle may at different times produce hairs that are of totally distinct types.

As stated before, three motives may be considered as acting on the hair emerging from the follicle :—

- (a) The action of extrusion.
- (b) Two simple harmonic motions acting at right angles to each other in a plane perpendicular to the direction of growth of the fibre.

The two latter forces may be signified as :

$$x = a \sin \omega t,$$

$$\text{and } y = b \sin (\omega t + \alpha)$$

where a and b are the respective amplitudes and α the phase difference between the two. An elementary piece of mathematics would show that when the phase difference (α) is equal to 90° the equation can be compounded to give :

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1,$$

which is the equation representing an ellipse.

If the amplitudes are considered as equal (*i.e.*, $a = b$), this equation becomes :

$$x^2 + y^2 = a^2,$$

which represents a circle.

Thus we have the two cases where the orifice of the follicle would create a circular motion during extrusion and the fibre would assume a helical or spiral form. A small change in the value of α (the phase difference) would cause a change in the form of the spiral. Thus we can account for spiral crimp or waviness.

Suppose, however, there is a gradual loss of phase, *i.e.* α continuously alters until the value of the phase difference becomes 90° in the opposite direction, *i.e.* α becomes -90° . It is obvious that the resultant motion will be a spiral in a direction opposite to that previously created. We thus explain the case of reversal of direction of the spiral observed in certain wools.

Lastly, consider the case where there is no phase difference at all, namely, when $\alpha = 0$. The two equations become :

$$\begin{aligned}x &= a \sin \omega t \\y &= b \sin \omega t\end{aligned}$$

from which we see (by division) that—

$$y = \frac{b}{a} .x.$$

This is the equation to a straight line and thus we have the case of a simple uniplanar wave. The term $\frac{b}{a}$ is the trigonometrical tangent of the angle which the direction of the line makes with the x axis. Any variation in the ratio $\frac{b}{a}$ would naturally result in a corresponding alteration of the direction of the plane in which the waves were being created. Thus we account for uniplanar waves, as also for the case of uniplanar waves in which the plane of rotation is gradually changing in direction. It is also obvious that there can be a change of the value of the ratio $\frac{b}{a}$ without affecting the resultant uniplanar amplitude in that since

$$A = \sqrt{a^2 + b^2} \text{ where } A \text{ is the amplitude,}$$

A can remain constant, even with variation of a and b , according to the above equation. This theory, which has been worked out in detail by Barker and Norris, completely accounts for all forms of crimp, but it is purely physical in character, and it remains for the biologists to link up their work with a possible mechanism in the follicle to produce the effects described. The agreement with actual examples of crimp is complete. The matter is one for *biological and histological research*. As already shown, such periodicity in growth is *not unknown in other cases*.

Neither is it necessary for us to confine ourselves to the field of biological science in searching for examples of periodicity exhibited during an otherwise continuous process. A wealth of examples can be found described in the literature of physical chemical processes.

Hedges and Myers, in their little book "Physico-Chemical Periodicity" (Arnold, 1926), have given an excellent survey of the subject and they append a full bibliography. In the closing paragraph of the book they say :—

"Periodicity as a feature of the processes and functions of living organisms is so apparent that enumeration of examples seems unnecessary, but consideration of the heart-beat indicates that it is a feature of fundamental importance. It is not impossible that the same property is at work in these cases, for living organisms are made for the most part of colloidal matter. It may be that a periodic stimulus is caused by a progressive increase in concentration of some substance at an active surface in the organism. This is a matter for the future ; for the present it is sufficient to show that periodicity is a feature of purely physical as well as biological systems."

It would appear, therefore, that the phenomena of crimp need not necessarily depend on some fundamentally biological property, but that an explanation on purely physical grounds would be quite feasible. However, the explanation, whatever it is, still remains to be found, but the above remarks may serve as an incentive to the research worker in this field.

It has already been described how various workers have sought to link up fibre diameter with the number of crimps per inch, and how a search for a generalization has proved largely abortive.

Barker and Norris have again considered this subject from a purely physical basis. A consideration of a fibre of length (L) bent into (n) waves by a compressional force (F) acting along its length gives the relationship :—

$$L \cdot \sqrt{\frac{F}{E \cdot I}} = n \pi$$

where I is the moment of inertia of the filament and E the modulus of the elasticity of the fibre material.

Three considerations may now ensue

- (a) When the moment of inertia (I) is variable and (E) the modulus of elasticity is constant.
- (b) When (I) is constant and (E) variable.
- (c) When both (I) and (E) are variable.

Let us consider the first case. The general expression given above now assumes the form :

$$\frac{L}{n} = \pi \sqrt{\frac{E}{F}} \sqrt{I}$$

If we deal with the number of waves per unit length, it is obvious that L becomes unity. The quantity $\sqrt{\frac{E}{F}}$ is also constant (K), hence the equation now becomes—

$$\frac{1}{n} = K \sqrt{I}$$

Substituting the value of I for elliptical fibres, the equation becomes :

$$\frac{1}{n} = K \sqrt{\frac{\pi a b^3}{4}}$$

or in terms of the cross-sectional area (A) and the ellipticity ratio $\left(\frac{b}{a}\right)$ The equation finally becomes :

$$\frac{1}{n} = K A \sqrt{\frac{b}{a}}$$

It is obvious that for circular fibres $\left(\frac{b}{a}\right)$ is unity and A is $\frac{\pi d^2}{4}$ hence in this case we have a definite relationship between n and d of the form.

$$n d^2 = \underline{\text{constant}} \quad \dots \dots \dots \text{(I)}$$

for circular fibres, and

$$n \cdot A \cdot \sqrt{\left(\frac{b}{a}\right)} = \underline{\text{constant}} \quad \dots \dots \text{(II)}$$

for elliptical fibres.

Taking the experimental results of Duerden and treating them according to equation (I) (since Duerden measured " diameter ") we get a curve in which $K = 8 \times 10^{-6}$.

Two points must be emphasized, namely :—

(1) These values relate to good Merino wools only—anomalous results due to impoverished wools, etc., were rejected.

(2) No notice was taken of the fact that the fibres are not circular and that (d^2) is not truly representative of the area of cross section.

To correct for the second factor above, an ellipticity value $\left(\frac{b}{a}\right)$ of 1.25 was taken, this being a normal average value arrived at from

thousands of results for ordinary wool fibres. We thus have a range of values from $1.25d^2$ to $d^2/1.25$. Drawing these limiting values as separate curves, it is found that Duerden's values fall within this range almost without exception. As a result of work with wool of all types, Barker and Norris find that the value of K is approximately 9×10^8 , and that almost all wools, if allowance is made for their ellipticity, come within this general law.

The above results, however, have ignored one important factor, and it is probable that besides ellipticity, the diversion from the general law is due, in part, to variation of structure of the fibre and consequently its elasticity. In the above, it has been assumed that the modulus of elasticity is constant for all fibres, but this cannot be strictly justified, although the variation may be only small. The measurement of the modulus of elasticity for various types of wool has yet to be fully made. Auerbach, in his paper on "The elastic constants of textile materials" (*Kolloid Zeit.* 1923, 32 pp. 369) has measured the modulus of elasticity for a few samples of wool. His values are given as follows —

Kind of Wool.	E		T	
	Kgs. per sq. mm.		Kgs. per sq. mm.	
Australian wool—scoured	109		0.074	
	131		0.051	
German wool—unscoured	86		0.158	
	92		0.047	

The variability in the value of Young's modulus is obvious and further support for our theory is found in the discussions of relevant subjects and data by others.

Speakman, (*Journal Textile Institute*, 1927) points out that plasticity is more highly developed in Merino than in Cotswold wools. Barritt and King (*Journal Textile Institute*, 1929) in their work on the sulphur content of various wools note that sulphur is inherent in wool substance and that keratinising, or hardening, of the primary plasmic material into wool cells is brought about by incorporation of sulphur in the form of a cystine nucleus. This takes place to different extents in different types of wool, with results analogous to the vulcanization of rubber.

As already mentioned, high sulphur content of wool, is usually associated with lower moisture absorption properties and thus it is not impossible to predict that, as with rubber, other physical properties would be affected by the chemical constitution of the wool. Further, Duerden, (*Journal Textile Institute*, 1929) suggests that crimps may possibly be taken as an index of the pliability of the wool fibre.

Bearing these points in mind, it would seem necessary, therefore, to consider the effects of the theory now proposed if the elasticity were variable, which undoubtedly is the case. Let us revert to the general expression previously quoted :

$$\frac{L}{n} = \pi \sqrt{\frac{E \cdot I}{F}}$$

Let us assume that we are dealing with fibres of like contour and cross section area, hence the factor (I) will be constant.

We thus get for unit length (L = 1)

$$\frac{1}{n} = K, \sqrt{E}$$

or :

$$n \sqrt{E} = \text{constant} \dots \dots \dots \text{(III)}$$

Thus it is seen that the elasticity of the fibres is in inverse relationship to the number of crimps. This relationship is important as regard the spinning power of the fibres, since the elasticity of the fibre is of paramount importance in this process. The fact that the possible variation in elasticity was disregarded previously, would account, in part, for the digression from the curve of the various points, when all kinds of wool were considered. In actual practice, therefore, the variations of elasticity and the value of the cross-sectional area have to be considered simultaneously. Hence, in any work on the relationship of wool quality to spinning power, as also on crimp, it is obvious that at least two characteristics of the wool have to be regarded, namely :

- (1) *Dimensional characteristics*—which would influence size of the fibre, cross-sectional area, contour, fibre length, etc.
- (2) *Constitutional characteristics*—which would influence elasticity, etc., e.g. chemical composition, internal or physical structure, etc.

The present theory of crimp is an attempt to relate these factors, and the fair agreement obtained with experimental values is encouraging as to its validity. Crimp can thus be related :

- (a) To the cross-sectional area of the fibre
- (b) To the modulus of elasticity of the fibre

under the general law shown above. Assuming, however, that for a definite type of wool, as *e.g.* was the case with South African Merino, the value of modulus of elasticity is almost invariable, then the rule that the product of the number of crimps per inch, and the area of cross section of the fibre gives a constant, is valid.

No discussion of crimp would be complete without a brief reference to the means of measurement commonly adopted. It is a well-known fact that crimp can be measured by ordinary visual means, by counting the number of crests or troughs of the waves alongside a steel rule and estimating their number per inch. It is obvious that this method is of very limited accuracy and for precisional purposes is not to be encouraged. For ordinary work, however, it gives a tolerable result and, as already stated, has been improved upon by Duerden with a crimp scale which he has described in his paper in the *Journal of the Textile Institute* (1929).

A second method of crimp measurement consists in measuring the fibre in the wavy condition and again when stretched to its full length so as to remove all trace of crimp. The increase in length per inch is taken as a measure of the crimp. There are many objections to this method, in that it is difficult to estimate the length of the fibre, either stretched or unstretched, with any degree of precision, and secondly the amount of tension used to remove the crimp is variable. Measurements made in this manner in a particular case of a fibre showing six crimps per inch at the root and twelve crimps per inch at the centre, showed the amount of stretch in each case to be almost the same, *viz.* 24 per cent. The method is, therefore, considered unreliable, although it has been used by a number of workers with comparative success.

The method now adopted by Barker and Norris is to mount the fibres either in the lock or separately between two pieces of rubber so that they are in no way distended, and to adjust these two rubber pieces in a special frame close to the ruled side of a process plate. The process plate was ruled to 150 squares per inch, and after affixing

the fibres in proper position the whole was placed in an enlarging lantern and thrown on to a screen some distance away. An enlargement up to about 15 diameters was secured with perfect definition, and thus each square on the screen was enlarged fifteen-fold, so that each tenth of an inch of the projected image corresponded to 1/150 inch on the actual fibre. By this means very great accuracy of measurement can be secured. Since the apparatus is simple and easy to manipulate it is to be recommended for scientific work, and if possible it is to be developed on a commercial scale.

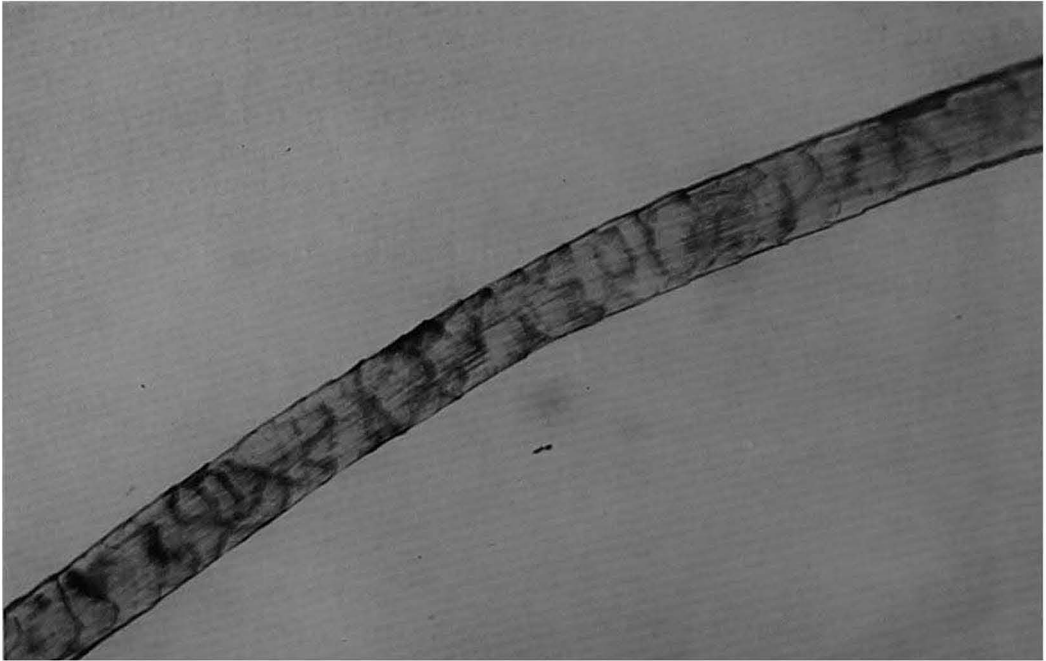
From the foregoing, it is obvious that crimp, which is such a prominent feature of wool, offers a very large field for investigation, and until we have fully analysed the causes of the waves, and further, known more of their relationship to the internal structure of the fibre, as also its consequent effects in manufacturing processes, the question of standardization of wool quality will remain largely unanswered.

An attempt has thus been made to formulate theories accounting for crimp on a physical basis, and also to show which factors in the wool fibre are directly concerned with the phenomenon. The biological consequences of this theory have yet to be investigated.

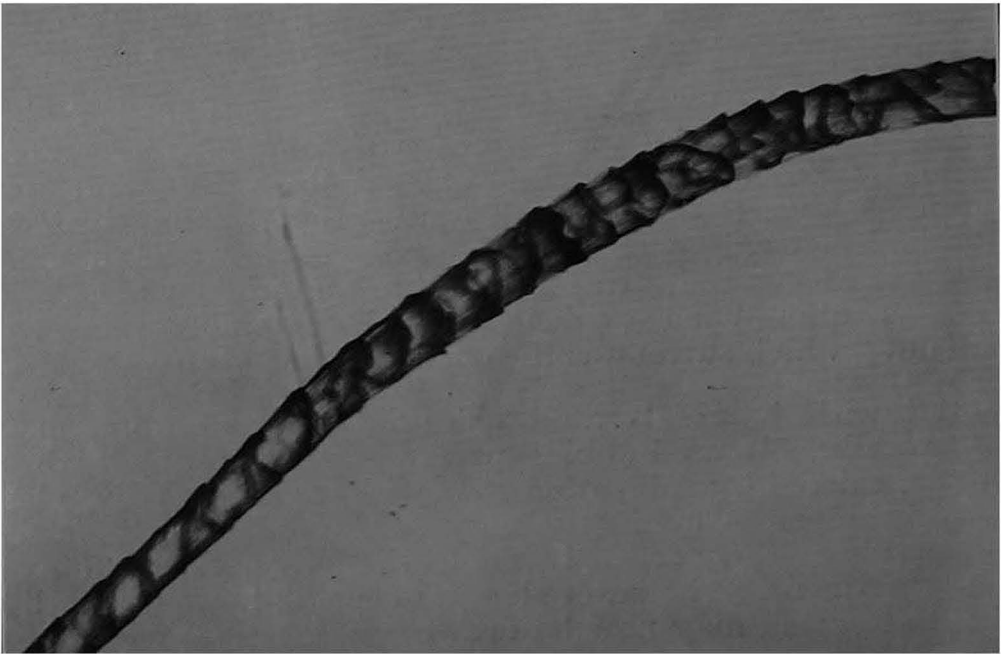
Scales on wool.

In a paper to the British Association (Oxford 1926) Hirst, Barker and King, described the wool fibre as a complex mass of spindle shaped cortical cells, with or without medulla, surrounded by a thin membranous layer: the whole held together by imbricated outer scales, which not only constitute the outer covering of the fibre, but serve as a protective sheath for the fibre materials. The Allworden reaction is quoted as evidence of the membranous layer or "elasticum" which surrounds the cortical cells.

Treated with half saturated chlorine water, a fibre, examined microscopically, shows bubbles protruding from under the outer scales; considered by Allworden to be the swelling of the elasticum layer. The layer is evidently very sensitive to alkali, since the reaction does not occur with wool which has received excessive alkaline treatment. The outer sheath of scales, however, is the point to which attention may now be drawn.



(a)



(b)

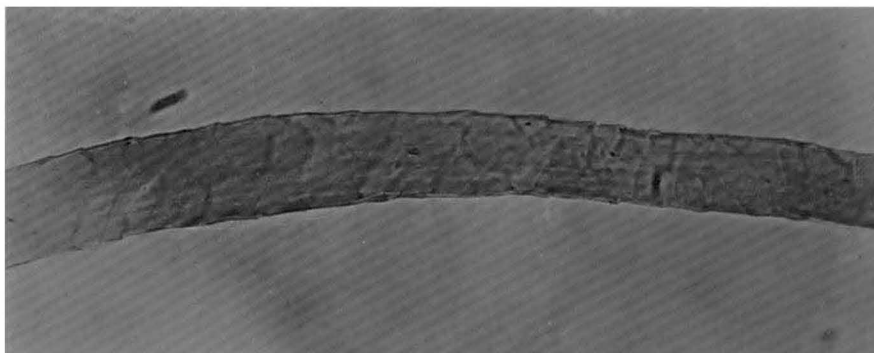
Fig. 16.—(a) normally scoured (b) over scoured, wool fibres.

Bowman ("Structure of the Wool Fibre," 1908) describes these scales, and notes that as compared with hair they are stronger and less numerous in proportion to the thickness of the fibre. They also bend outwards from the shaft of the fibre at a greater angle than for hair, and hence present a serrated edge with points of the scales in the direction of the growth of the fibre, *i.e.* from root to tip. He calls attention to the fact that the number of scales per inch, the crimp, and the fibre thickness, all seem to be related in some way to each other, but the precise nature of this relationship is unknown. The shape of the scales is described as "rhombic" for long-wooled sheep, such as the Lincoln, and "imbricated ring shape" for finer fibres. It is probable that the scaliness of the fibre exterior has a profound influence on its lustre, but this point has yet to be carefully investigated.

The scientific work done on the scales of wool is comparatively small, little being recorded in the literature regarding their growth or their precise function in manufacturing processes, either mechanical or chemical. As already mentioned, probably the greatest attention has been paid to the effects of scaliness in the chlorination process to render the fabric unshrinkable. Excessive alkalinity in scouring (figure 16) also has a disintegrating effect on scale structure; so have the effects of weathering. In the case of the latter, Trotman and Langsdale (*J. Soc. Chem. Ind.*, 1923, p. 12T.) showed that ozonized air attacked the epithelial scales of the wool and produced soluble sulphur, and further that the effects of weathering could be ascribed as similar to those produced by bacterial attack. Later Trotman and Sutton confirmed these results and undoubtedly the damage to, or removal of, the scales promotes a condition of susceptibility to bacterial attack. The use of Pauly's reagent (diazobenzene sulphonic acid in alkaline solution) as a staining agent affords an efficient means of detection of damage to the scale structure of the fibre.

Barritt (figure 17), in his work on the nitrogen content of wool, notes in the chlorination process, the loss in weight of wool due to removal of the scales. The number of scales per inch on ordinary fibres would seem to follow the rule that the less the thickness the greater the number of scales per inch. It is recorded that over 6,000 per inch have been discovered on one class of wool, whilst American authorities claim to have discovered as many as 24,000 per inch. In a pure Lincoln, the ordinary value is about 650 per inch, but the same American authority claims 7,000 per inch, according

to his method of estimation. It is obvious, therefore, that the subject is one for precise and exact scientific research. Certain it is that the scales play some part in the friction of fibre on fibre, which is so valuable an asset in drawing, spinning and other mechanical processes in manufacture. Barker and Marsh have shown that



(a)



(b)

Fig. 17.—(a) normally chlorinated (b) over chlorinated, wool fibres.

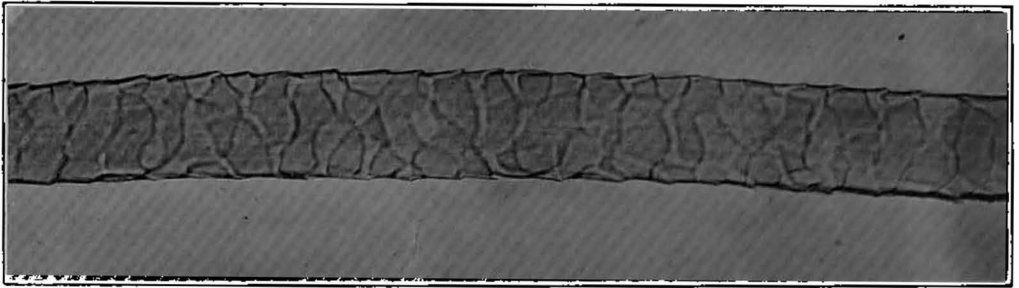
there is a great difference in the friction of a dry fibre on a card tooth or metal wire, according as it is drawn along the direction of the scales or against them. Their figures showed that the friction in the antiscalar direction was 20 per cent. higher than in the direction of the scales.

Felting or Milling.

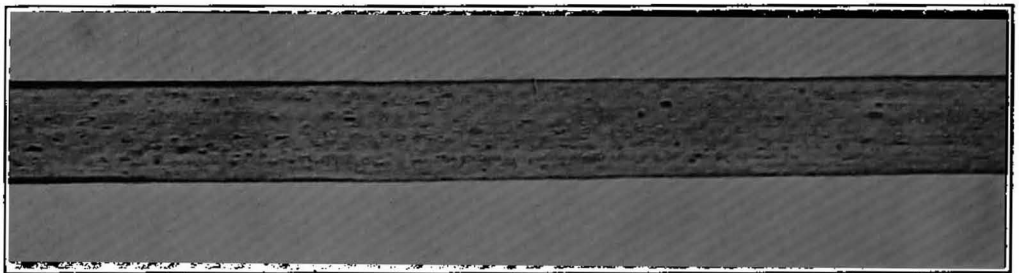
The interlocking of the scales was for a long time considered as the explanation of felting or milling of wool fibres, the hypothesis being that the fibres were interlocked with absolute fixity by the scales of one fibre being interjected into the scales of another placed in opposite direction alongside it. Shorter, however, (*Journal Society of Dyers & Colourists*, 1923, p. 274) ascribes to the scale structure a position of primary importance in milling and felting. He postulates a uni-directional freedom of motion of the fibre, as opposed to absolute fixity, such a form of motion being a characteristic effect due to the scales, and secondly, that this freedom involves the scales on the entangled fibre, not those on the entangling fibres. Lobner, ("Studien und Forschungen über Wolle und andere Gespinnstfasern," p. 230) describes a theory of felting in which he notes that the felting begins at the root end of the fibre, and that this end clings to the neighbouring fibres. "Whilst the tendency of the hair to move in the direction of the root continues, the root end which has already felted sufficiently with other hairs is hindered in its movements. Owing to the continued tendency to move away from the tip, it must finally wriggle into a spiral or loop, curl up and pull itself together." Shorter remarks that this explanation, whilst dynamically unsound is nearly correct, and proceeds to explain felting as already mentioned above. There is little doubt that actual felting is due to the imbricated nature of the outer scales of the fibre, intermittent pressure with consequent disturbance and friction of the wool causing creeping in the direction of the root ends. On meeting with resistance from adjacent fibres, bends and loops are formed, with the result that a more tangled and closer packed mass of fibres results. Felting is also essentially dependent on the plastic nature of the wetted and swollen fibres, and it has already been noted earlier that this depends on the moisture content, the alkalinity or acidity of the milling liquors, etc. Shorter sums up the situation by stating "there are, therefore, two fundamental factors in milling. (1) Uni-directional freedom of motion due to serrations on the fibre, and (2) lack of flexural rigidity of the fibre. The action of moisture and of milling agents is to produce conditions of fibre contact favouring the operation of the first factor."

It is therefore, evident that the degree and size, together with the very nature of the scales, is of great importance in manufacturing processes, and it again affords a wide field for research. Certainly

in classifying fibres according to their suitability for subsequent use in manufacture, the scaliness is a factor which must be seriously regarded. Finally, a step forward in research on scales has been furnished by A. T. King, (*Biochemical J.* 1927, p. 344.) who has devised a method of mechanical removal of the scales (Fig. 18)



(a)



(b)

Fig. 18.—(a) original and (b) descaled wool fibre.

from fibres by drawing them over the edge of a glass plate of suitable character, so as to leave the cortex or inner core free for physical and chemical investigations. The scaly material can thus be separated from the rest of the fibre, and the process, though slow and laborious, opens out a new aspect of fibre research. It is certain, however, that subsequent work on this point will be of great material value to all concerned, and that investigation into the true value, function, and nature of the scales on wool must form part of any comprehensive scheme of fibre examination which has as its object the elucidation of the relationship between fibre characteristics, and their precise function in manufacturing processes.

THE MICROBIOLOGY OF WOOL.

The study of the relation between micro-organisms and wool is a subject which has recently come into prominence. Wool, like all other organic bodies, is liable to attack by these agents of decay, and it frequently happens that the trade suffers considerable financial loss through their activities. The trouble is not confined to any particular type of goods, but is almost universal ranging from the raw wool to the finished article. Indeed, certain cases have come to hand where the wool fibres have been attacked while still on the living sheep. It is during the process of manufacture, however, and particularly in warm weather, that the conditions are most favourable for the development of the so-called "mildew."



Fig. 19.—Example of wool fibres damaged by micro-organisms.

The growth of the organisms is usually accompanied by a weakening, or, in extreme cases, a complete disintegration of the fibres. The first stage in this process of tendering is a loosening of the protective

epithelial scales. This is followed by a separation and dissolution of the spindle-shaped cortical cells. At the same time the wool fibres usually become brown in colour and, if they are under tension, rupture takes place resulting in the brush-like ends so typical of wool damaged in this way.

As already mentioned, the aid of a sensitive test such as staining with Pauly's diazobenzene-sulphonic acid, enables the entire process of tendering to be easily followed. Thus, microscopical examinations of slightly damaged wool materials treated with this reagent have shown that attack is first focussed upon those fibres which have previously been damaged, as for example, by weathering while still on the fleece, by mechanical abrasion or by chemical action, such as often occurs during scouring.

The two kinds of micro-organisms, bacteria and mould fungi, which cause mildew may act either individually or conjointly, depending largely upon the moisture content of the wool. Thus, bacteria are chiefly responsible for the damage which occurs to wool goods which are left for some time in a wet and slightly alkaline state, while, on the other hand, the mould fungi flourish best under less moist conditions, such as those which obtain when wool is kept in an atmosphere saturated with water vapour. Consequently, the latter organisms are more often associated with the mildew which develops during storage on such goods as tops, roving and yarn. Of the two the action of the bacteria is somewhat more vigorous, but when the actual amount of trouble caused is considered, the moulds are by far the most important. Several strains of another group of micro-organisms, the *Actinomycetes* are also able to give rise to mildew, but only one specific case of commercial goods being attacked has yet been observed.

Owing to the urgent demands of the trade for some means of combating the growth of mildew, the attention of investigators has so far been concentrated chiefly in a search for antiseptic substances which would produce the desired effect. Consequently, very little research work has been done on the more fundamental studies of the classification and physiology of the organisms concerned.

With regard to the bacteria, the ability to break down the wool fibre is confined to certain members of the *Bacillus subtilis* group as, for example, *B. subtilis* and *B. mesentericus*, both of which are commonly found in soil water. These organisms are very sensitive

even to weak concentrations of acid, so that in this respect activities are restricted. On the other hand, slightly alkaline conditions favour them, and since wool goods are almost invariably alkaline the opportunities for bacterial action are many. Thus, Hirst and King have described the rapid tendering which takes place when cloth, fresh from the scouring bath and hydroextractor, is left to dry off slowly ; while Smolens demonstrated the bacterial origin of faults produced during the process of bleaching with alkaline peroxide. A valuable contribution to the subject was made by Trotman and Sutton, who showed that a relation existed between the extent of bacterial action, the amount of ammonia evolved, and the solubility of the damaged wool in sodium carbonate solution.

The majority of the mould fungi which attack wool belong to the two genera *Penicillium* and *Aspergillus*, but there are many other types which are equally effective. Some thirty different species, which, in pure culture, are capable of causing the disintegration of commercial wool, have so far been isolated in the laboratories of the Wool Research Association and the list is continually being added to. These organisms, unlike the bacteria, are not adversely affected by acidity ; neither are they inhibited from growing when the wool contains the maximum amount of alkali likely to be present on commercial goods. As the result of an extensive investigation on the growth of moulds on wool, Burgess arrived at the following conclusions :

- (1) Mould fungi are almost entirely responsible for the mildew which develops on commercial goods which at the time of storing had a moisture content in keeping with the standard regain of about 17 to 19 per cent.

- (2) The development of mildew is enhanced by the presence of the soaps, condition fluids, wool creams and vegetable oils commonly used in the trade. This is due to the additional available food supplied by these substances whether directly or indirectly in the form of alkali which, by combining chemically with the wool, renders it more readily attacked. The greenish yellow stains commonly found on mildewed wool arise as the result of mould action on the soap present.

- (3) By washing either scoured or unscoured wool in several changes of water, the tendency to mildew is considerably reduced.

One of the most important aspects of the phenomenon of mildew on wool goods is its effect upon subsequent dyeing processes. This subject has received attention by Hirst and King, who showed that micro-organisms and, in particular the bacteria, were responsible for many faults, the cause of which was previously unsuspected. The areas attacked either fail to take the requisite amount of dyestuff or, conversely, become too deeply dyed. Such faults are specially undesirable as they are usually invisible before the wool is dyed and only become apparent when it is too late to remedy them. Trotman and Sutton have also carried out experiments on this subject.

The preceding instance is but one of many in which the ultimate effects of mildew are out of all proportion to the actual amount of fibre damage. Others might be quoted such as the breaking of yarn during weaving or knitting, and the tearing of pieces of cloth during finishing, both of which cause considerable delay in manufacturing operations and reduce the output.

With these illustrations in mind the very urgent need for some means of preventing mildew will be readily appreciated. The greatest difficulty in the solution of the problem is the fact that wool is hygroscopic. Recent research has shown that mildew will not take place unless the atmosphere in which the wool is stored is saturated with water vapour to the extent of about 97 per cent. of its water-holding capacity. Under these conditions 100 gm. of dry wool absorbs some 27 gms. of moisture. As a rule this holds good for all types of scoured and processed wool though when size or very large quantities of soap are present, mildew occurs at a somewhat lower humidity. In any case, the minimum moisture requirement of the mould fungi is far in excess of that present in goods conditioned to standard regain. Hence it follows that the most effective way of preventing mildew during storage is to ensure efficient ventilation and to avoid the formation of localized areas of stagnant air. This procedure is specially necessary in view of the fact that goods are generally stored in buildings provided with ordinary concrete floors which, through their ability to transmit water from the earth below, tend to increase the humidity of the atmosphere.

Further precautions against mildew can also be ensured by avoiding the use of many soaps, and certain agents designed to assist conditioning, by rendering the goods as free as is practically possible from any foreign matter which promotes the growth of micro-organisms and by reducing to a minimum the period of time during

which wet or damp materials have to stand between different processes. Strongly alkaline conditions should be particularly avoided on both chemical and biological grounds. Except in the case of sized goods, the above methods should be adequate to ensure protection for wool under the control of the manufacturer. When, however, the wool passes out of the latter's hands, such as during transshipment abroad, the liability to mildew is increased, and it is expedient that antiseptics be employed. In this connection it must be admitted that no substance has yet been discovered which meets all the requirements consistent with an ideal antiseptic for wool. At present sodium silico fluoride, in a concentration of 0.5 per cent. reckoned on the weight of the wool, is being recommended to the trade with satisfactory results, but it can only be regarded as a stop-gap pending the introduction of a more suitable agent.

In the case of high-class goods woven with a sized warp and wet weft, protection is obtained during the somewhat prolonged process of weaving by adding 2.5 per cent. of salicylic acid to the flour or starch.

Apart from the latter instance the application of antiseptics is an undesirable procedure, and it would be better if such treatment could be dispensed with entirely. The customary practice of dispatching goods in air-tight containers is also to be deprecated, for the stagnant conditions so produced favour the growth of fungi by setting up localized areas of moisture condensation. By arranging the materials so as to allow a free circulation of air about them and by introducing compulsory measures to secure adequate ventilation in ships' holds, the annual loss sustained on the ground of mildew would be considerably reduced.

CONCLUSION.

Early in this treatise we asked the question, What is Wool? and once again at the conclusion we must recognize the incompleteness of the answer. What a field for scientific enquiry has been opened out! The practical man may say he wants concrete results, and possibly mainly theories have been his reward up to date. But, as in life the potentialities of the infant child are vast and unknown, so in scientific research in wool, yet hardly emerged from its embryo, is there a great opportunity for development and lasting good to the industries who claim its parentage. The infant child, scientific research, must be nurtured and fostered in the family circle of its

own wool industries, drawing upon the ripe practical experience of its parents for guidance and advice in its development and growth. Thus will it become an integral part of the industries themselves, serving them to the best of its ability, bringing in new ideas and new methods born of a new generation. To pursue the simile further, from perhaps a somewhat mundane aspect, the development of the child is not without expense to the parents. Each year until maturity arrives its demands on the family exchequer become greater. More food, more clothes, higher education, etc., are required and demanded as development ensues, until finally the erstwhile infant attains manhood, and takes its place as an equal partner in the family circle, bearing its share of the burden of industry and economics. Thus, scientific research must be fostered if the family circle of the wool industries is to be perpetuated.

For real effective development increasing demands will undoubtedly be made on financial resources, and the results will be, in both quality and quantity, largely in proportion to the amount and speed of payment. Science in industry has become a popular cry, but has it ever had a chance in the wool industries? Primarily, is our scientific knowledge of wool yet so far developed that the scientific worker is able to take his place alongside the technical man, conscious of an equal efficiency and status in his own particular domain? Until this can be accomplished, the true application of science to the wool industries cannot be effected. Scientific research, therefore, is the necessary preliminary to the ideal, and if, in the highly scientific age now developing, the wool industries are to prevail, knowledge of the fundamentals of the fibre itself is the real foundation for the future superstructure of their efficiency and security from both the manufacturing and the agricultural aspects. Finally, therefore, one may look forward to the day when in the nursery the rhyme of "Baa, Baa Black Sheep" may be obsolete, the proverbial "Mary's little lamb" may have scientific ancestry and upbringing, and thus even in infancy the child of a future generation will realize from an early age the efficacy of scientific method.

The booklet now ends; the real work is just begun, and our object will be fulfilled if this survey creates interest and discussion. The sins of omission and commission are deeply realized, but we have endeavoured to place in the hands of our fellow-workers in wool a treatise containing a compilation of the findings and results of the thought and work of others.

ACKNOWLEDGMENTS.

The author wishes to acknowledge with grateful thanks the assistance of all those who have made the task of compilation of this book as light as possible. The bibliography, appended herewith, endeavours to identify the various sources of information. In particular, the author would recognize the help of his colleagues, Mr. Arnold Frobisher, Deputy Director of Research; Mr. J. A. F. Roberts, Chief Biologist, for help with the biology section; Mr. A. T. King, Chief Chemist, and Dr. Rimington for assistance in the chemical section; Messrs. Hirst and Burgess for many practical hints, and lastly to the Misses M. H. Norris and C. M. Jones for the painstaking work during the writing and correction of the work. These members of the staff of the Wool Research Association have each ungrudgingly given their help and advice. The author also wishes to acknowledge with special thanks Mr. J. B. Speakman, of the Textile Department of the University of Leeds, for so generously placing at his disposal the X-ray report and photographs, as well as much other unpublished information. Finally, thanks are tendered to the British Research Association for the Woollen and Worsted Industries for granting permission to write this booklet. The Empire Marketing Board, under whose auspices this book is published, also place the author under a deep obligation, and in his endeavour it is hoped he may have been successful to a small degree in justifying their confidence and fulfilling their wishes by the stimulation of additional interest in scientific research upon wool.

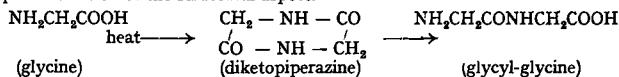
APPENDIX.

A. T. King, in his paper on "Chemical Aspects of Wool Research" (*J. Text. Inst.*, 1927, **18**, T 361), says:

"In view of the marked changes in textile properties, particularly dyeing affinity, brought about by exposure, and by chemical processing, which produce little or no effect on the physical appearance of the fibre, it is certain that some form of incipient hydrolysis occurs which, if not actually detaching these simpler proteins, at least liberates their active groups, by opening lactone or other ring formations in the complex.

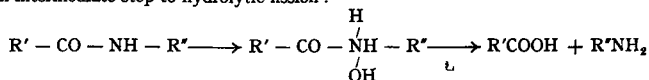
"There is no information, however, as to which part of the keratin complex is attacked, or whether different portions are attacked and different groupings liberated according to the particular conditions of hydrolytic action which cause specific textile effects."

The synthetic method first employed by Fischer for synthesising polypeptides, involving the successive closing and rupture of diketopiperazine rings, affords a simple illustration of the structural aspect.

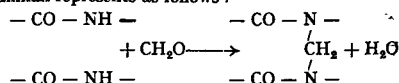


The diketopiperazine nucleus may possibly be considered to represent one of the ring formations present in keratin (although the existence of diketopiperazine in native proteins is as yet by no means a certainty) and its behaviour on hydrolysis as representative of that occurring with keratin. It is obvious that with the various amino acids derivable from keratin, numerous substituted diketopiperazine ring formations are possible, but the prospect that the actual arrangement of such nuclei in the keratin complex will ever be determined is, as Leathes has pointed out (*British Association Report*, 1926, p. 210), extremely remote.

In a recent paper Speakman ("Plasticity of Wool," *Proc. Roy. Soc., B.*, 1928, **103**, 378) regards the absorption of water as due, at least in part, to chemical hydration, as an intermediate step to hydrolytic fission:—



Conversion of the imino group into forms incapable of the molecular hydration represented above, should, it is pointed out, diminish hygroscopic capacity, and it is shown that this actually occurs on treatment with inorganic acids, and especially with formaldehyde, which brings down the regain to as low a figure as 59 per cent. of that of untreated wool (Trotman, *J. Soc. Dyers and Col.*, 1928, **44**, 49). This reaction Speakman represents as follows:—



The reduced affinity for water, and the strengthening of molecular structure and consequent resistance to degradation thus postulated form an interesting interpretation of the action of formaldehyde when used in practice for hardening wool, *e.g.*, for roller lappings. Investigations along these lines can scarcely fail to result in a better understanding and control of existing processes, and also in new practical developments.

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M.B. 22.



THE DEMAND FOR CHEESE IN LONDON

REPORT OF AN INVESTIGATION INTO THE RETAIL
MARKETING OF CHEESE IN LONDON BY THE
ECONOMIC SECTION OF THE EMPIRE
MARKETING BOARD.



NOVEMBER, 1929

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F9

CONTENTS.

	Page
FOREWORD	5
I. INTRODUCTION	7
Imports	7
Period and Scope of Survey	8
Classification of Shops Visited.. .. .	9
II. CHEDDAR CHEESE	11
Types of Cheddar Stocked	13
Relative Sales of Types of Cheddar	14
Retail Prices	14
Buying and Storage	16
Colour	16
Flavour	17
III. CHESHIRE CHEESE	17
IV. STILTON CHEESE	18
V. WENSLEYDALE CHEESE	19
VI. CONTINENTAL CHEESE	19
(i) <i>Dutch Cheese</i>	19
Gouda	20
Edam	20
(ii) <i>Fancy Cheese</i>	20
Gorgonzola	21
Camembert	22
Gruyere	22
Roquefort	22
Parmesan	22
(iii) <i>Other Kinds</i>	23
VII. PROCESSED CHEESE.. .. .	23
In Blocks	23
In Cartons	24
Effect on Sales of Bulk Cheese	25
VIII. SEASONAL DEMAND	26
IX. SUMMARY	26

FOREWORD.

THE need for a more thorough study of the retail demand for Empire products has been emphasised both in the reports of the Imperial Economic Committee and by the Agricultural Economics Committee of the Empire Marketing Board. It is of considerable importance to oversea producers to understand the working of the agencies through which their produce passes, and to ascertain as closely as possible the preferences of consumers in the matter of quality, grading and presentation.

The Empire Marketing Board has accordingly set on foot a systematic study of the retail demand for certain Empire products, starting with those on which the Imperial Economic Committee have already published the results of their more general survey.

The retail trade constitutes a particularly difficult problem for study since so little exact knowledge is available. The number of retailers selling foodstuffs is very large, and they do not specialise in the sale of a few commodities as in the wholesale trade. Further, retail shops differ greatly in size, type of management, class of trade, and in many other respects. It is impossible, therefore, by reference to a few firms only, to obtain a clear picture of the variation in conditions and in policy; it is necessary to study the practice of a large number of shops before reliable knowledge of the retail marketing of even one commodity can be obtained.

The present Report on the Retail Marketing of Cheese in London is the first of a series and is based on a preliminary survey which was to a large extent experimental. The investigation was limited to a number of specific questions and the information was obtained by interviews with the proprietors or managers of retail shops in London during the six months June to November, 1928. The value of the results will be enhanced by a comparison with later reports dealing with similar investigations in other towns.

The Board has been gratified with the sympathetic response with which the enquiry has been received by the Trade. Acknowledgments and thanks are here given to members of the wholesale and retail distributive trades in London for the assistance they have so willingly afforded.

ECONOMIC SECTION,
EMPIRE MARKETING BOARD.

NOVEMBER, 1929.

REPORT OF AN INVESTIGATION INTO THE RETAIL MARKETING OF CHEESE IN LONDON.

I.—INTRODUCTION.

Imports of Cheese.

The United Kingdom is the largest importer of cheese in the world, the total imports in 1928 amounting to about 3 million cwts. An estimate made by the Ministry of Agriculture and Fisheries, based on the last Census of Production, showed that imports constituted about 77 per cent. of the total consumption.

In 1928, 84 per cent. of the imported cheese came from the overseas Empire. New Zealand was the main source of supply with 1,555 thousand cwts., Canada sent 920 thousand and Australia 74 thousand cwts. From foreign sources, 228 thousand cwts. of Dutch and 142 thousand cwts. of Italian cheese were imported. The remaining 87 thousand cwts. came from Switzerland, France, the United States and other countries. The percentages are as follows :—

From New Zealand	..	..	52 per cent.
„ Canada	..	..	30 „ „
„ Australia	..	..	2 „ „
„ Other Countries	..	..	16 „ „
			100

A comparison of imports from within the Empire during the periods 1909-13 and 1928 shows that the most notable development has been the great increase in the amount of cheese arriving from New Zealand. While Canada's contribution has decreased over the period under review from 1,458 thousand to 920 thousand cwts., that of New Zealand has grown from 462 thousand to 1,555 thousand cwts. Supplies from Australia have increased from five thousand to 74 thousand cwts.

In regard to seasonal distribution of imports, over 70 per cent. of the supplies of New Zealand cheese reach this country during the six months January to June, while 74 per cent. of the cheese from Canada arrives between midsummer and Christmas.

each borough being roughly proportionate to population ; for purposes of reference this has been termed the " General Survey." Later, the Metropolitan borough of Lambeth and the City of Westminster were surveyed more exhaustively, records for practically all shops stocking cheese being obtained.

The total number of records for the whole Survey was 500.

General Survey.—The first part of the Survey was undertaken during the months of June, July and August, 1928. During this period, shops were visited in each of the 28 Metropolitan boroughs, and 245 interviews were obtained with retail grocers and provision dealers.

Lambeth. During the four weeks September 10th to October 6th, 166 retail shops in Lambeth were visited, exclusive of the visits made in this area during the General Survey.

Lambeth is a typical cross-section of London, south of the Thames. It is a long, narrow strip extending a distance of seven miles north to south from Waterloo Bridge to the Crystal Palace, and at no point is it as much as two miles wide. The district nearest to the river, from Waterloo to Vauxhall and the Oval, is predominantly working-class and poor ; the Brixton area in the centre of the borough may be described in the main as lower middle-class ; while in the area round Brockwell Park, West Norwood and West Dulwich, at the south end of the borough, there are a number of residential districts.

Westminster. In the City of Westminster, the enquiries were made from October 14th to November 10th, when 89 retailers were interviewed, exclusive of the visits made in this area during the General Survey.

Westminster is a compact area in the centre of London, extending north and south from Oxford Street to the Thames, and east and west from Temple Bar to Knightsbridge. It includes the two high-class residential districts of Belgravia and Mayfair, many streets of middle-class flats and boarding houses, the tenement districts in Pimlico, a working-class section near to Covent Garden, the foreign population of Soho, the whole of " theatre-land," the Government offices in and near Whitehall, and a large number of restaurants.

One marked difference between Westminster and Lambeth is the larger proportion of small independent shops and dairies found in Lambeth; in contrast, much of the Westminster provision trade appears to be concentrated in a comparatively small number of large establishments. In the wealthier districts of Westminster, the residents apparently obtain their supplies almost entirely from department stores and other large shops in the main streets. Another factor influencing the provision trade in Westminster is the very large supplies required for catering. In shop after shop in this area, the largest and most regular customers for cheese and other provisions were found to be restaurant and hotel keepers, and in many instances the character of the stocks was considerably influenced by the requirements of this class of customer.

Classification of Shops Visited.

The shops visited during the Survey were of very different types, and for the purpose of analysis have been roughly classified in three ways:—First, according to organisation of business—whether independent, multiple, department or co-operative, with dairies as a special group; secondly, according to neighbourhood and class of trade; and thirdly, according to size as measured roughly by the number of assistants. No account has been taken in this enquiry of volume of sales.

Tables 1, 2 and 3 show the relative distribution in each class.

TABLE 1.—*Shops Classified according to Organisation.*

Organisation.	General Survey.	Lambeth.	Westminster.	Total.
Independent	154	73	51	278
Non-Local Multiple	29	26	9	64
Local Multiple	42	21	5	68
Department	9	—	4	13
Co-operative	5	5	—	10
Dairies	6	41	20	67
Total	245	166	89	500

In Table 1 the term *Non-Local Multiple* refers to a firm with branches not only in London, but in the provinces; *Local Multiple* refers to a firm whose branches are confined to the Metropolitan area. *Independent*, or *private* refers to a firm with a single shop. *Department* refers to the large general store selling all classes of goods.

During the General Survey, after an interview had been recorded with a multiple firm or co-operative society, the usual practice was to pass over the branches as there was an evident tendency for stocks to be standardised; in the intensive surveys of Lambeth and Westminster, all branches in the areas were visited.

Dairies do only a very small proportion of the total cheese trade, but as cheese is stocked in some form by most dairies, they were included in the intensive parts of the Survey, though six only had been visited during the earlier investigation. Of the 67 dairies noted in Table 1, 50 appeared to be independent, and 17 were branches of a multiple organisation.

TABLE 2.—*Shops Classified according to Neighbourhood and Class of Trade.*

	General Survey.	Lambeth.	Westminster.	Total.
Districts mainly wage-earning, or where the trade is of a poor class	158	95	48	301
Districts mainly residential, or where the trade is of a high class	75	71	32	178
Districts where population is predominantly Jewish or foreign	12	—	9	21
Total	245	166	89	500

Many of the shops, perhaps the majority, were catering for a mixed trade, and this method of classification should be regarded merely as a rough indication of what seemed to be the dominant character of the trade and immediate neighbourhood. In Lambeth, for instance, of the 71 shops listed in Table 2 as doing a high-class residential trade, 21 were in main thoroughfares and combined a "family and order" trade among the richer residents with a large "counter" trade with poorer customers.

TABLE 3.—*Shops Classified according to Size.*

	General Survey.	Lambeth.	Westminster.	Total
Large	93	19	25	137
Medium	78	41	23	142
Small	74	106	41	221
Total ..	245	166	89	500

Here again the basis of classification was of a somewhat arbitrary nature. Shops where more than four assistants were employed were classed as "large," shops with three or four assistants as "medium," and shops employing not more than two assistants as "small."

During the General Survey, in which only a small number of shops were visited in each locality, a fair proportion was maintained as between shops of different size, though the tendency was to select the larger and more important. In Lambeth and Westminster, where practically every shop selling cheese was visited, the figures illustrate clearly the different character of the districts. Reduced to percentages the shop classifications are :—

	Lambeth.	Westminster.
	<i>Per cent.</i>	<i>Per cent.</i>
Large	11	28
Medium	25	26
Small	64	46

II.—CHEDDAR CHEESE.

Of the 500 retailers visited, 440 (88 per cent.) were stocking bulk Cheddar, the three main types being New Zealand, Canadian and English. In two shops only was Scotch or Australian Cheddar stocked.

II

TABLE 4.—Percentage of Shops Stocking New Zealand, Canadian or English Cheddar.

	General Survey. (June-Aug.)	Lambeth. (Sept.-Oct.)	Westminster. (Oct.-Nov.)
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
New Zealand	88	48	30
Canadian	29	28	53
English	45	19	37
No. Shops visited	245	166	89

As already stated, over 70 per cent. of the New Zealand cheese imports is received in the first half of the year ; in the case of Canada, 74 per cent. is received between the months of June and December. Since the Survey was undertaken between June and November, some evidence of the seasonal interchange of New Zealand and Canadian Cheddar was to be expected. It will be noted from Table 4, that as the Survey proceeded, the number of shops stocking Canadian Cheddar rose from 29 per cent. to 53 per cent., while in the case of New Zealand Cheddar the corresponding period shows a fall from 88 per cent. to 30 per cent. It should be added, however, in this connection, that the Survey was completed in Westminster—a relatively high-class district.

In addition to the stocks held at the time of interview, an attempt was made to ascertain the types of Cheddar habitually stocked throughout the year. This information has been summarised in Table 5, which should be read in conjunction with Table 4.

TABLE 5.—Percentage of Shops Habitually Stocking the Three Main Types of Cheddar at some Period of the Year.

	General Survey.	Lambeth.	Westminster.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
New Zealand	94	74	76
Canadian	77	67	76
English	51	24	40
No. Shops visited	245	166	89

Types of Cheddar Stocked.

An analysis of the returns shows that of the 440 shops stocking Cheddar, 164 (37 per cent.) were stocking three types at the date of interview ; 214 (49 per cent.) were stocking two types ; and 62 (14 per cent.) were stocking one type only.

Table 6 shows the number of shops by organisation stocking one, two or three types of Cheddar.

TABLE 6.—*Number of Shops Stocking One, Two or Three Types of Cheddar.*

	One Type.	Two Types.	Three Types.	Total.
Independent	41	132	80	253
Non-Local Multiple	8	23	33	64
Local Multiple	4	29	32	65
Department	—	2	10	12
Co-operative	1	3	6	10
Dairy	8	25	3	36
Total	62	214	164	440

It should be added that the majority of the shops stocking three types of Cheddar were large shops in residential districts.

Table 7 shows the types of Cheddar stocked in "one-type" and "two-type" shops.

TABLE 7.—*Types of Cheddar Stocked in One-Type and Two-Type Shops.*

	One Type.			Two Types.		
	New Zealand.	Canadian.	English.	New Zealand and Canadian.	New Zealand and English.	Canadian and English.
Independent ..	34	2	5	122	8	2
Non-Local Multiple..	8	—	—	22	1	—
Local Multiple ..	4	—	—	29	—	—
Department ..	—	—	—	1	1	—
Co-operative ..	1	—	—	3	—	—
Dairy ..	4	2	2	25	—	—
Total ..	51	4	7	202	10	2

In practically all the shops where two types of Cheddar were stocked, these were New Zealand and Canadian. Thus, out of 214 retailers, only 12 claimed to stock a different combination.

It should be added that, in many cases, retailers did not themselves distinguish between New Zealand and Canadian Cheddar. Sometimes they used the term "Colonial," sometimes "Empire," often merely "Cheese" or "Cheddar," with a description such as "choice" or "finest" added.

Relative Sales of Types of Cheddar.

In the earlier part of the Survey, enquiry was made as to the various types of Cheddar stocked, but no attempt was made to ascertain the relative volume of sales. In the later part of the Survey, this was attempted. It was found that 173 shops stocked imported Cheddar only, 154 shops were selling more imported than English, and only 19 were selling more English than imported. Of the 19 shops in which English Cheddar predominated, 15 were in residential districts. No shop supplying the ordinary needs of neighbourhoods predominantly working-class was selling more English than imported Cheddar.

A comparison of the sales of New Zealand and Canadian Cheddar showed that of 253 retailers supplying information, 167 were selling more New Zealand than Canadian, 39 more Canadian than New Zealand, while 47 were selling equal quantities at the time of visit. Many retailers emphasised the fact that the relative quantities of New Zealand and Canadian which they stocked in the course of a year were governed by no fixed policy or preference, but depended on the fluctuations of the wholesale market and on the seasonal interchange, described in connection with Table 4.

Retail Prices.

The retail prices collected during the course of the Survey are shown in Table 8.

Although it was not practicable to obtain prices at all interviews, certain points nevertheless emerged as a result of the enquiry. In every shop in which all three types of Cheddar were simultaneously on sale, English was priced highest and featured as the best, Canadian ranked second, and New Zealand third. The price differential was usually 2d. In the early weeks of the Survey, the series was English 1s. 4d. or 1s. 6d., Canadian 1s. 2d., New Zealand 1s. 0d.; later it was more often English 1s. 6d. or 1s. 8d., Canadian 1s. 4d., New Zealand 1s. 2d.

TABLE 8.—*Number of Shops Selling New Zealand, Canadian and English Cheddar at the following Prices per lb.*

	Price per lb.	June.	July.	Aug.	Sept.	Oct.	Nov.
<i>New Zealand</i> ..	<i>s. d.</i> 1 0	18	2	—	—	—	—
	1 1	6	28	—	1	—	—
	1 2	14	59	41	50	19	3
	1 3	—	1	—	5	3	3
	1 4	—	2	1	9	7	4
<i>Canadian</i>	1 0	1	—	—	—	1	—
	1 1	3	—	—	—	—	—
	1 2	10	4	—	21	25	11
	1 3	3	2	1	2	4	1
	1 4	8	14	3	6	13	4
	1 6	—	1	—	—	1	2
<i>English</i>	1 2	1	2	—	1	—	—
	1 3	—	—	—	1	2	—
	1 4	4	11	4	5	5	1
	1 6	8	20	2	11	6	7
	1 8	6	5	1	1	7	6
	1 9	—	—	—	1	—	—
	1 10	—	—	—	1	1	—
	2 0	—	—	—	—	—	1

New Zealand Cheddar.—In the early weeks of the Survey, practically all the shops where price was noted were selling New Zealand at 1s. 0d., but this price was encountered only twice after the third week in June. For a short time the price varied between 1s. 1d. and 1s. 2d., but after the second week in July, it became practically standardised at 1s. 2d.

Canadian Cheddar.—During June, July and August, most of the Canadian Cheddar in the shops was old season's cheese. The most frequent price at this period was 1s. 4d. especially in residential districts and in shops where the price of New Zealand had already risen to above 1s. 0d. In shops with a mixed trade in main thoroughfares, matured Canadian was being sold at 1s. 2d. In September, October and November, the situation had altered. A few of the better class shops were still selling matured Canadian at 1s. 4d., but a large number had by this time made their annual change-over from

New Zealand Cheddar to the newly arrived Canadian as their staple cheese. In all these shops, Canadian Cheddar was being sold at 1s. 2d., the same price as the New Zealand Cheddar which it had superseded.

English Cheddar.—In all but a few exceptional shops, the price of English Cheddar was 1s. 4d., 1s. 6d., or 1s. 8d., the most frequent price being 1s. 6d. In seven shops, the price fell below 1s. 4d.; in four shops, it was higher than 1s. 8d. Of the four shops where prices were above the normal, two were somewhat isolated in suburban residential areas, and the other two were restaurants in central London, which carried on a provision trade as a side-line.

Buying and Storage.

Of 294 retailers replying to the question on buying and storage, 59 per cent. habitually bought their cheese weekly or fortnightly. Many of those who bought sometimes at longer intervals did so only in order to take advantage of a rising market, not for the sake of maturing the cheese.

Throughout the course of the Survey, it became abundantly evident that the old custom of storing and maturing cheese on the retailer's premises had largely been abandoned. Even when cheese was bought from three to twelve months ahead of requirements, the general custom was to leave it with the wholesaler, factor, or importer, and to draw supplies as required. Here and there an independent grocer claimed to buy in advance and store the cheese for the sake of maturing it under his own supervision.

Colour.

Of 355 shops stocking bulk cheese of the Cheddar type, 65 per cent. stocked white only, while 35 per cent. stocked white and coloured in varying proportions. In no shop was coloured Cheddar found exclusively.

In over 80 per cent. of the shops stocking both kinds, it was stated that sales of white were at least twice those of coloured.

The districts where coloured cheese appeared to be sold in the largest quantities were Deptford and Woolwich, both in South-east London, and Poplar in the neighbourhood of the Docks. The only other area where the demand for coloured was noticeably above

the average was the extra-Metropolitan district of Willesden, in which the preference was attributed to the presence among the railway workers of many Irish and north country families. The percentage of shops stocking coloured cheese was higher in Lambeth than in Westminster, but throughout London the preference was preponderatingly in favour of white.

Flavour.

About 60 per cent. of the retailers interviewed said that their customers preferred a mild-flavoured cheese, the remaining 40 per cent. claiming that most of their customers preferred it more matured and stronger. It was stated that there was a good demand for a full-flavoured cheese in working-class districts, but the difficulty was to supply such a cheese at a price within the reach of the customer. This preference for a strong cheese was noted in widely separated parts of London, and was said to be on the increase in most areas, whatever the class of business done.

III.—CHESHIRE CHEESE.

Of the 500 shops visited during the Survey, 66 (13 per cent.) stocked Cheshire cheese either continuously or during some months of the year. The enquiry showed that Cheshire tended to be stocked mainly in shops situated in the residential areas, or doing a good class trade.

About 25 per cent. of the retailers selling Cheshire stated that it was stocked during part of the year only, usually in the months immediately before and after Christmas. On the other hand, the manager of a department store, and one independent firm doing a large trade in a good class neighbourhood claimed to sell their largest quantity in summer, on the ground that it went exceptionally well with salad. In nearly every instance, the statement was made that Cheshire appealed only to a select group of customers who asked for it regularly, and that it did not compete in popular demand with the Cheddar type. A large proportion of the trade in Cheshire was evidently concentrated in central London; shops supplying the better class catering trade sold a fair amount to hotels and restaurants.

Generally speaking, the demand for Cheshire was described as select and small, but slightly on the increase; the buyer of a large department store volunteered the opinion that if there were to be any real revival of interest in Cheshire in the London area, a demand for it must first be created by an advertising campaign.

The prices per lb. of Cheshire Cheese, as noted in 25 shops, are given in Table 9.

TABLE 9.—*Prices per lb. of Cheshire Cheese, as noted in 25 Shops.*

	1/10.	1/8.	1/7.	1/6.	1/4.	1/3.	1/2.	1/1.	1/-.	Total.
No. shops in which price was noted	1	5	2	3	5	3	2	2	2	25

IV.—STILTON CHEESE.

One hundred and seventy-eight retailers (36 per cent. of the total number interviewed) claimed to stock Stilton cheese during some period of the year. As in the case of Cheshire, the enquiry showed that the majority of shops stocking Stilton were situated in residential areas or were doing a good class trade.

In almost all cases, it was stated that sales were confined to Christmas time and were small in volume. In five of the big central shops in Westminster, it was claimed that Stilton was stocked throughout the year, but that its real season was during the three or four winter months. In one of these shops, it was specially recommended only during November, December and the early part of January. In one large department store, it was stocked for eleven months of the year. Apart from these, the almost invariable statement was "a little about Christmas." Everywhere, except in a few central shops, the trade in Stilton was said to be diminishing. The manager of a branch store in Kensington stated that he sold three Stilton cheeses during the last Christmas season, whereas not many years ago he could have counted on selling 20.

As the investigation took place between June and early November, it was only during the last few calls that any Stilton was observed actually on sale, the few prices noted ranging from 2s. to 2s. 4d. One firm in a busy suburban district, which was doing a large trade in provisions and cooked meats, stocked ordinary Stilton at Christmas only, but sold all the year round a "White Stilton," the retail price on the day of visit being 1s. 4d.

V.—WENSLEYDALE CHEESE.

One firm only of the 245 visited during the General Survey claimed to sell any large quantity of Wensleydale. This firm, which had a high-class trade in central London, disposed of about 500 cheese in the season. Of the remainder, eight firms said that they stocked some Wensleydale at Christmas time; three others that they obtained it now and then to order. This cheese appeared to be little known in London generally, and enquiries regarding it were not pursued during the second part of the investigation. Several shops were selling small proprietary cheese of this type.

VI.—CONTINENTAL CHEESE.

(i) *Dutch Cheese.*

Of the 500 shops visited, 84 (17 per cent.) stocked Gouda, and 242 (48 per cent.) stocked Edam; while 52 (10 per cent.) stocked Gouda and Edam simultaneously. The enquiry showed that the consumption of Gouda was largest in neighbourhoods with a predominantly Jewish population; Edam was stocked in most of the large and medium-sized shops of all classes.

There was wide agreement that Dutch cheese, of both the Gouda and the Edam type, had greatly fallen off in popularity; several retailers said that the introduction of processed cheese had been mainly responsible for this. Some had given up stocking Dutch cheese, while others said that the demand for it was so small that it was hardly worth while stocking it.

Gouda.

The largest consumers of high-grade Goudas in London are the Jews; repeatedly in Jewish shops, Goudas were said to constitute the bulk of the cheese trade, and one Jewish dealer in the Whitechapel area, who carried on both a retail and a wholesale business, said that he sold over 100 full cream Goudas a week. The price most frequently noted for the better qualities was 1s. 4d. The cheap Gouda was observed only in a few shops in poor neighbourhoods, where it was sold at 8d. or 9d. a lb.

Edam.

Edam cheese was much more widely distributed than Gouda. It was found in very nearly 50 per cent. of the shops visited, in all the department stores, and in 81 per cent. of the shops classified as "large."

In a few shops, including the branches of one large multiple firm, two qualities of Edam were on sale together, with a difference of 2d. or 3d. in the price per lb.; but, as a rule, only one quality was stocked. The price ranged from 7d. to 9d. for the cheapest kind; and from 10d. to 1s. 4d. for the higher grades. In Lambeth, the price most frequently noted was 1s., in Westminster 1s. 2d. In 50 shops it was stated that the cheap variety only was stocked.

(ii) *Fancy Cheese.*

Table 10 shows the percentage of shops stocking each of the five types of "fancy" cheese concerning which enquiry was made during the Survey—namely, Gorgonzola, Camembert, Gruyere (in bulk), Roquefort and Parmesan.

TABLE 10.—*Percentage of Shops Stocking each of Five Types of Fancy Cheese.*

	General Survey.	Lambeth.	Westminster.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Gorgonzola	66	52	78
Camembert	29	17	54
Gruyere (in bulk)	17	5	47
Roquefort	14	9	40
Parmesan (in bulk)	12	4	39
All five together	8	3	29
No. shops visited	245	166	89

In 51 shops, or 10 per cent. of the total number visited, all five types were habitually stocked : in several others, four of the group were found, the one usually missing being Roquefort. Throughout London generally, fancy cheese was said to amount only to a very small proportion of the cheese trade as a whole.

Table 10 shows how markedly the demand for various kinds of fancy cheese was focussed in the central area ; in each case, excepting Gorgonzola, the distribution in Westminster was far in excess of that in other parts of London. The high-class trade of the Westminster shops, the demands of the caterers, and the special requirements of the large foreign population, combined to render the trade in Camembert, Gruyere, Roquefort, and Parmesan of much greater importance in that district than elsewhere. During the General Survey, only 17 per cent. of the shops visited were stocking Gruyere, against 47 per cent. in Westminster : in the case of Parmesan, the comparison was 12 per cent. and 39 per cent. Again in London generally, 8 per cent. only were found to be stocking all five types of fancy cheese simultaneously, as compared with 29 per cent. in Westminster.

Gorgonzola.

Of the five types, Gorgonzola enjoyed very much the widest distribution. It was found in all the department and co-operative stores, in nearly all the multiple shops, and in most of the large shops and the shops in residential areas. Even in working-class districts, more than half the shops were stocking it, though the amount sold represented a smaller proportion of the total cheese sales than was the case in residential areas. In central London, two large firms stated that Gorgonzola represented a third of their total cheese trade, and one put it at very nearly half : two others said a fifth, and one a tenth. Part of the exceptionally high demand for Gorgonzola in this area was undoubtedly due to the restaurant trade. One dealer who supplied several restaurants said that many people ate Gorgonzola when they were lunching or dining out, but never bought it for home use. Some of the shops in working-class districts, especially in Lambeth, stocked Gorgonzola during the cold weather only, and dropped it altogether in the summer months.

The two most frequent prices were 1s. 4d. and 1s. 2d. In about 20 shops in working-class districts, the price was 1s. 1d. or 1s. In two restaurants in central London, which did a " counter trade " in addition to providing meals, 3s. and 2s. a lb. respectively were being charged.

Camembert.

In point of distribution, Camembert ranked next to Gorgonzola, being stocked either regularly or at intervals in 146 (29 per cent.) of the shops visited. In volume of sales it probably does not stand high, as more than 20 retailers said they kept it only occasionally, or during the winter months, and many of those who stocked it all the year said that the demand was relatively very small. In one of the largest department stores doing a good trade in all the fancy cheese, Camembert was placed at the bottom of the list, the order of sales being given as Gorgonzola, Gruyere, Roquefort, Camembert.

The highest price noted for Camembert was 1s. 6d. per box of about $\frac{1}{2}$ lb.; more often it was 1s. 4d., 1s. 3d., or 1s. 2d. One multiple firm was selling it in two qualities at 1s. 2d. and 11d.; another had boxes of different sizes on sale at 10 $\frac{1}{2}$ d. and 6 $\frac{1}{2}$ d.; while on the provision counter of a large restaurant boxes were obtainable in three sizes, at 1s. 2d., 7d. and 4d.

Gruyere.

Gruyere in bulk was found in 92 shops, or 18 per cent. of the total. Of these, most were large shops in residential neighbourhoods or in the central area of Westminster. All the foreign provision shops in Soho were stocking Gruyere, and in some of them it was stated to be the staple trade. In some of the Jewish shops Gruyere appeared to rank next to Dutch Gouda in popularity. The chief trade in bulk Gruyere was, however, with the restaurants, hotels and clubs, and this accounted for its concentration in the central area. Once only during the Survey were the large 2 $\frac{1}{2}$ cwt. Gruyeres seen, and in that shop these were being sold at the rate of two a week.

The prices noted for Gruyere ranged from 1s. 4d. to 2s. 6d., the most frequent being 1s. 8d., 1s. 10d., and 2s.

Roquefort.

Roquefort was stocked in 85 shops (17 per cent.), most of which were large shops in residential districts. The higher-priced Roquefort was usually French, the cheaper Danish. In no case was it claimed that sales were large; and in working-class districts this cheese was treated as an occasional change from Gorgonzola.

Parmesan.

Parmesan in bulk was stocked in 71 shops (14 per cent.), half of which were in Westminster. The prices noted ranged from 1s. 10d. to 3s. 6d., the most frequent being 2s., 2s. 6d., 2s. 8d. and 3s. In a

few shops different qualities were on sale together. Parmesan in bulk was said to be used chiefly in hotels, restaurants and clubs for the purpose of flavouring dishes, and in the larger private houses where a chef was kept.

(iii) *Other Kinds.*

Among varieties of cheese not mentioned in the questionnaire, those most frequently observed were the Italian Bel Paese and the French Port de Salut and Brie. Some other kinds of Italian cheese noted were Bella Milano, Stracchino and Pecorino; while of home produce, Gloucester, Leicester, and Caerphilly were occasionally found. Caerphilly was sold in at least three of the Jewish shops, together with Old Dutch and Spiced Dutch. Several Jewish retailers sold for quick consumption a curd cheese which they made on their own premises. A cheese that was encountered only once was Schapzigar, said to be used for flavouring soup.

With regard to fancy cheese generally, one retailer said that there were occasional runs on one sort or another, so that each in turn became a temporary fashion; such variations from the normal, however, never lasted long, customers returning after the experiment to their accustomed staple.

VII.—PROCESSED CHEESE.

Processed cheese, as distinct from cheese in bulk, was found in 456 shops, or 91 per cent. of those visited. Block processed, in 5 lb. boxes, was stocked in 321 of these: and cartons, containing small packeted portions, in 449.

In Blocks.

Processed cheese in 5 lb. blocks has been on the market for some years, and at the time of the Survey its sale appeared to be fairly steady. Retailers said that it had to a considerable extent taken the place of the two types of Dutch bulk cheese, Gouda and Edam, but that it had not appreciably affected the sale of bulk Cheddar. Some thought that in its turn it was losing ground in favour of the cartons. About 40 small retailers in poor districts had tried block processed for a short time and dropped it because of the small demand.

The prices of block processed varied from 10*d.* to 1*s.* 6*d.* a lb. In one Westminster shop doing a large, working-class trade, it was said that a Dutch brand at 1*s.* a lb. was selling very well and that it always did so while the price of Cheddar was high; as soon as Cheddar dropped to 1*s.* a lb. or less, however, the demand for the Dutch processed fell away entirely.

In Cartons.

The trade in processed cheese, put up in cartons of four, six, eight or twelve small packeted portions, has developed very largely during the past year, and a number of fresh brands were put on the market during the period of the Survey. From the point of view of most retailers, this method of selling cheese has a great deal to recommend it, and the majority of those expressing an opinion were emphatically in favour of encouraging the trade as much as possible. Among the reasons given were that it involved no waste or deterioration, no risk of over-cutting, and no expenditure of time and labour on unpacking and stripping, while the product carried a fair and fixed margin of profit. The small margin obtainable on bulk cheese was frequently eaten up by waste and over-cutting.

Again, in the sale of a proprietary packeted article, the independent shopkeeper found himself able to meet the multiple firms on fairly equal terms. It was freely admitted that the multiple firms could buy bulk cheese more advantageously.* The multiple firms themselves, however, were no less interested than the independent retailers in the rapidly growing carton trade, and three at least of the larger multiple firms were selling processed cheese under their own labels during the earlier part of the Survey, while a fourth had followed suit before the Survey was completed. It was noted also that brands were being put on the market not only by manufacturers, but by wholesalers.

The only objection to selling cheese as a proprietary packeted article came from the older independent retailers who had sufficient capital at their command to enable them to take advantage of a favourable market. Many of these professed to regard the development of the packeted trade generally as a symptom of declining tradesmanship.

* An interesting feature in this connection is the development of local associations of independent retailers for buying purposes.

Effect on Sales of Bulk Cheese.

It seems clear that a large body of consumers have come to believe that packeted cheese possesses certain advantages compared with bulk. The most frequently alleged advantages were its keeping quality, its cleanliness and portability, its attractive appearance and, in spite of the high price per lb., its economy. In small households, where the consumption of cheese is low and spasmodic, portions bought from bulk frequently become too dry to eat and are wasted, whereas wrapped portions of processed cheese will keep for six weeks or longer without noticeable deterioration. Evidence was repeatedly given that cartons were being bought increasingly for small families in lieu of $\frac{1}{2}$ lbs. of bulk. In homes where the consumption of cheese was larger and more regular, the substitution was not nearly so noticeable, and where the custom was to buy 1 lb. or 2 lbs. of cheese at a time, bulk was still preferred. In districts where there were numbers of hotels and boarding houses, packeted cheese sold well.

In certain instances, the sale of packeted cheese is increasing at the expense of bulk. But it was widely asserted by retailers that the main trade in packeted cheese represented extra business. Many retailers further claimed that their sales of bulk cheese were steadily increasing, in spite of the added sale of packeted: some advanced the opinion that packeted cheese had actually stimulated the sale of bulk by introducing cheese to people who had not previously been cheese-eaters, and who had begun with packeted and gone on to bulk. Several retailers said that they found the demand increasing most rapidly for the Gruyere varieties of packeted cheese; at the head office of a large multiple firm, this was also emphasised, and it was pointed out that for ordinary households Gruyere was not suitable in any other form. Bulk Gruyere dried up too quickly for small consumers, and was sold mostly to restaurants.

It was impossible to obtain any reliable estimate of the relative sales of bulk and processed cheese, but it would appear that although the demand for the latter is rapidly increasing, it still represents a very small percentage of the total cheese trade.

The great majority (413, or 82 per cent.) of provision shops of all grades stocked both bulk and processed cheese, and most of these stocked processed in both blocks and cartons. Most of the shops that stocked only processed were dairies, the remainder being small independent shops in side streets.

A feature of the processed trade, noted increasingly during the latter part of the Survey, was that several manufacturers have begun to put up cheese in $\frac{1}{2}$ lb. packets, and that these appeared to be finding favour.

VIII.—SEASONAL DEMAND.

About 40 per cent. of the retailers interviewed gave it as their opinion that more cheese was sold in the summer months, and about 30 per cent. that more was sold in winter ; the remaining 30 per cent. held that their sales were fairly uniform throughout the year. As a rule these opinions were given without reference to books. In some cases, however, verification was sought, and one manager of a large multiple branch shop with a mixed trade, found from his weekly sales records that the summer average was 10 per cent. above the winter.

Among the retailers who thought that their sales of cheese were fairly uniform, there seemed to be general agreement that household food budgets varied very little throughout the year. Another comment was that the seasons balanced one another, more people buying cheese in summer, but those who bought in winter buying larger quantities.

IX.—SUMMARY.

(i) *Nature and Scope of Survey.*

The Survey was undertaken from June to November, 1928. First, the 28 Metropolitan boroughs were sampled, the number of shops visited in each borough being roughly proportionate to population. Later, the borough of Lambeth and the City of Westminster were surveyed exhaustively, records for practically all shops stocking cheese being obtained.

The total number of records for the whole Survey was 500.

(ii) *Summary of Results Obtained.*

Table 11 shows the number of shops stocking the main varieties of cheese.

TABLE 11.

Cheese.	No. Shops.	Percentage of Total Number of Shops Visited (500).
		<i>Per cent.</i>
Cheddar	440	88
Cheshire	66	13
Stilton	178	36
<i>Continental Cheese.</i>		
Gouda	84	17
Edam	242	48
Gorgonzola	316	63
Camembert	146	29
Gruyere	92	18
Roquefort	85	17
Parmesan.. .. .	71	14
<i>Processed Cheese.</i>		
Block	321	64
Cartons	449	90

(iii) *Cheddar Cheese.*

The staple cheese of the great mass of the London population is Cheddar of the New Zealand, Canadian and English types. Of the 440 shops stocking bulk Cheddar at the time of the interview, 37 per cent. were stocking all three types; 49 per cent. were stocking two types; and 14 per cent. were stocking one type.

White is much more in demand than coloured.

The popular taste is for a mild cheese; but the demand for the matured product of stronger flavour is said to be on the increase.

(iv) *Cheshire Cheese.*

Cheshire cheese in bulk was stocked mainly in shops in residential areas or in those doing a good class trade. The demand for it is small and select, though slightly on the increase.

(v) *Stilton Cheese.*

The majority of shops stocking Stilton were in residential areas, or carrying on a good class trade. Sales tend to be concentrated in the Christmas period.

(vi) *Dutch Cheese.*

There was general agreement that the popularity of Dutch cheese, both of the Gouda and Edam type, had fallen off somewhat.

The trade in Gouda is largely with the Jewish population.

(vii) *Fancy Cheese.*

The demand for fancy cheese is focussed mainly in the central area of London, except perhaps in the case of Gorgonzola, which appears to be generally popular.

(viii) *Processed Cheese.*

There are clear signs of an increase in the popularity of packeted cheese of all kinds; it does not appear, however, that this increase has taken place entirely at the expense of bulk. It has been widely asserted that the main trade in packeted cheese represents extra business, and some retailers are of opinion that packeted cheese has actually stimulated the sale of bulk.

(ix) *Seasonal Demand.*

Opinions were divided on this point. About 40 per cent. of the retailers interviewed gave it as their opinion that more cheese was sold in the summer; about 30 per cent. said that more was sold in winter; while 30 per cent. thought sales were fairly uniform throughout the year. A common view was that the seasons balance each other; fewer people buy cheese in winter, but they buy larger quantities.

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THE GROWING DEPENDENCE OF BRITISH INDUSTRY UPON EMPIRE MARKETS

By

F. L. McDOUGALL, C.M.G.,
Representative of Australia on the Empire Marketing Board.



DECEMBER, 1929

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PREFACE

THE facts and possibilities of Empire trade have lately attracted a growing share of public attention both in the United Kingdom and in the Empire countries overseas. No one dissents from the proposition that Empire trade should be promoted; but opinions differ about the measures which should be taken for its promotion, and even about the significance of Empire trade as it exists to-day. The question is one which demands patient investigation and ample discussion. It has, as yet, scarcely secured that measure of attention by trained economists which its importance and complexity require.

Part only of the field comes within the immediate sphere of the Empire Marketing Board whose work is confined to the furtherance of the marketing of Empire products in the United Kingdom. Yet the Board's experience increasingly suggests that the successful prosecution of its own purpose depends upon an understanding of many factors which might, at first sight, seem remote from Empire Marketing. The Board have, therefore, felt themselves legitimately concerned to encourage the study and discussion of the subject.

The paper here printed has been prepared upon his own responsibility by Mr. McDougall. It treats of difficult and controversial questions, and its treatment of them, as the author would be the first to recognise, is itself open to argument. The paper touches upon many questions of first-rate importance, and it has seemed to the Board desirable that further discussion and further study of the facts should be provoked. They have, therefore, felt it not inappropriate that the Board should publish what is to be regarded as a valuable individual contribution to a discussion and not as an approved statement of any official view. Least of all must I be taken to agree with all the statements or any of the possible implications of what is Mr. McDougall's personal contribution.

The paper is published in that spirit. The Board hope that it may encourage the wider discussion and more comprehensive treatment of a question which derives special interest from more than one contemporary development and not least from the approach of an Imperial Conference.

PASSFIELD.

October, 1929.

3

THE GROWING DEPENDENCE OF BRITISH INDUSTRY UPON EMPIRE MARKETS.

By F. L. McDOUGALL, C.M.G.

GREAT BRITAIN'S POSITION IN WORLD TRADE.

There is unanimous agreement that the prosperity of British industry depends upon an expanding export trade. This assumption underlies British economic policy.

The importance of stimulating profitable exports is greater to-day than in pre-war years. The value of imports has increased in terms of 1913 prices, from £768 million in 1913 to £895 million in 1928 and the balance of trade has become less favourable to Great Britain. The annual average for the years 1910-1913 showed a total visible adverse trade balance of £144 million and in 1928 this had risen to £359·5 million, a figure which, reduced to 1913 price levels, gives a total of £263 millions.

In 1913 the Board of Trade estimated that when the values for "invisible" exports were thrown into the scale, the balance of trade and payments left a sum of £181 millions available for overseas investment. In 1928 the Board of Trade figures, calculated upon a revised and more favourable basis, gave an estimate of £149 millions available for overseas investment. This sum at 1913 price levels would represent about £106 million.

Great Britain needs to export an increased amount of goods and services in order to counterbalance these adverse factors. It is significant that, in terms of 1913 prices, Great Britain's export trade in 1928 was still considerably below the 1913 mark.

From the date of the post-war depression until about 1926, it was generally assumed that the depression in British export trade was mainly due to the impoverishment of her overseas customers. Since 1927, however, it has been evident that world trade is definitely

recovering from the effects of the war. Statistical confirmation of this assumption is to be found in the latest figures published by the Economic Section of the League of Nations.*

The value of world trade in terms of 1913 price levels was, in 1926, about 8 per cent. and, in 1927, 20 per cent. greater than in 1913. Although allowance has to be made for the fact that the number of exporting nations is greater than in 1913, the evidence is sufficient to prove that the pre-war volume of trade has been exceeded to a considerable extent. It is not possible, at the present time, to give definite figures to illustrate the further increase in world trade for the year 1928 but an examination of the trade statistics of the more important nations indicates that on the whole, the recovery which became an accepted fact in 1927, has not been lost and that some further progress has been made, although the rate of advance was slower than in 1927. It has been estimated by the president of the International Chamber of Commerce that world trade increased by 5 per cent. in 1928 as compared with 1927 if the fall in prices in certain important commodities is taken into account.

The importance which European markets held for British export trade before the war, explains, perhaps, why the theory that world impoverishment was the cause of British industrial depression, was held for so long a period. In 1913 Europe absorbed 34·02 per cent. of British exports, but in 1928 this figure had fallen to 27·9 per cent.

The world recovery from the immediate post-war slump began in the United States of America and did not affect Europe for some years, and up to the end of the year 1926, European countries lagged behind the rest of the world in their rate of trade recovery.* The League of Nations report points out that "during 1927, however, there was a reaction to the tendency of recent years. European and Atlantic trade has developed more rapidly than that of the rest of the world." This memorandum further states that "the greatest progress in the last three years has been achieved in Central and Eastern Europe."

In a world in which the volume of trade is increasing, Great Britain's share of world exports fell from 13·9 per cent. in 1913 to 12·1 per cent. in 1925 and 11·4 per cent. in 1927.* In a recent

* League of Nations: Memorandum on International Trade and Balance of Payments 1913-1927, Vol. I.

issue of the Board of Trade Journal it was stated that the British share of world exports in 1928 amounted to approximately 11 per cent. Some slight reduction in the percentage share held by Great Britain in the imports into most countries was to be expected owing to changes in the composition of international trade, arising from the increased use of new or comparatively new raw materials and from the increase in the total trade in agricultural products. Nevertheless the fall in the quantum of British export trade to only 83 per cent. of the 1913 level cannot readily be reconciled with the considerable increase in the total volume of world trade. It is maintained by certain leading economists, who occupy a position which gives them particularly favourable opportunities of obtaining an impartial view of general trade tendencies that Great Britain is not achieving her share in the recovery of world trade.

In this memorandum it is intended to show that it is by the development and encouragement of Empire markets, that Great Britain can, with most certainty, hope for a revival in her export trade both to secure expansion in the near future and to provide a lasting basis of prosperity. This conclusion has been reached after an examination of the changes in the nature and extent of the competition in overseas markets which Great Britain has encountered in post-war years, of the probable permanency of such changes, and of the potentialities for Great Britain of foreign markets in comparison with Empire markets. Owing to some curious legacy of bygone fiscal controversies, there remain those who assume that a policy of Empire trading necessarily involves a decline of interest in foreign trade. There can be no sound basis for such opinion, indeed the successful development of specially favourable markets within the Empire should assist the British manufacturer in his severe struggle in foreign markets.

The general trend of British trade since the war can be summed up in the following figures showing the increasing percentage of British exports sent to Empire markets. Great Britain's exports are mainly manufactured goods so that the importance to Great Britain of overseas markets is largely relative to their capacity to purchase manufactured goods. It is of interest to note the increase in the percentage of manufactured exports from Great Britain absorbed by Empire countries since the war.

TABLE I.—*Proportion of British Exports absorbed by Empire countries.*

	Average	Average	
	1911–1913.	1927–1928. excl. Irish Free State.	1927–1928. incl. Irish Free State.
All goods	36·1 per cent.	42·2 per cent.	45·7 per cent.
Class III Manufactured goods . .	40·4 per cent.	Not available.	49·0 per cent.

A broad survey of Great Britain's position in world trade provides sufficient evidence that Empire markets are more favourable to British trade than are foreign markets. Great Britain's share of the import trade of Empire countries averages about 36 per cent.* whereas in foreign countries the average percentage is 9·6 per cent.* When it is remembered that the British Empire covers about one-quarter of the area of the world and contains also about one-quarter of the world's population, these proportions gain in significance.

In order to obtain a clearer view of the position of Great Britain in world trade and to assess the comparative value of markets, the position will be further analysed to show—

- (1) the progress of foreign manufacturing industry and export trade ;
- (2) Great Britain's trade with foreign markets ;
- (3) Great Britain's trade with Empire markets.

1. Progress of Foreign Manufacturing Industry and Export Trade.

From the industrial revolution until about 1870 Great Britain held a preponderating position in the supply of manufactured goods to the markets of the world. From Table II, it is clear that in the two

* These proportions have been ascertained by means of weighted averages calculated from data provided by the League of Nations Memoranda which made it possible to include 42 Foreign Countries and 11 British Countries in the calculation.

decades preceding the war, Germany and the United States of America had commenced to challenge this supremacy, nevertheless Great Britain remained by far the largest exporter of manufactures.

TABLE II.—*Total Exports.*

Year.	United Kingdom.	Germany.	U.S.A.
	£ million.	£ million.	£ million.
1890	263	166	176
1900	291	230	302
1910	430	367	356
1912	487	440	452

In order to analyse the growth and extent of industrial competition, both actual and potential, among foreign countries, it is convenient to divide the more important producing countries into groups. These groups will be studied separately in order to gauge their relative importance as competitors for the world markets in manufactured goods.

The first group comprises the four great industrial countries of the world: United States of America, Great Britain, Germany and France. The second group of industrial countries will include Japan, Italy, Netherlands, Belgo-Luxembourg and Czecho-Slovakia—nations which, in post-war years, have steadily increased their export trade and particularly exports of manufactured goods.

In addition to the two groups of countries already mentioned, a number of foreign countries either already are, or are likely to become, industrially important. Most nations are striving to develop the industrial side of their economic life and the number of states which remain purely agricultural is rapidly diminishing. The objective of many countries is to supply, as far as possible, the home demand for manufactured goods. Achievement of this aim varies from small beginnings in a few classes of goods to a flourishing manufacturing industry which has already commenced to seek new markets for the surplus production.

Table III shows the change in the total exports and in the percentage of manufactured goods exported from the first group of leading industrial countries :—

TABLE III.

Country.	Annual average 1911-13.		Annual average 1927-28.	
	Total exports.	Per cent. of manufactures.	Total exports.	Per cent. of manufactures.
	£ million	Per cent.	£ million	Per cent.
Great Britain	448	79.0	716	79.8
U.S.A.	447	47.4	1,027	57.0
Germany	444	66.1	560	72.0
France	262	50.6	428	56.8

An important cause of intensification of competition in world markets is to be found in the rapid industrial progress in the United States of America. In U.S.A. statistics the classification of goods into two classes of manufactures is not comparable with the British classification. In order to arrive at a basis for comparing the present position of exports of manufactured goods from Great Britain and the United States, a total of those goods exported from America which, in British statistics would ordinarily be included under " Class III, articles wholly or mainly manufactured " has been obtained. On this basis it was found that in 1928 U.S.A. exported a value of manufactured goods which was not far below the British amount, i.e. £534 million as against £578 million. This value represented 51.5 per cent. of U.S.A. total exports in 1928. It must be remembered, however, that in this total U.S.A. exports of finished petroleum products amounted to £86 million with which Great Britain is scarcely in a position to compete, except perhaps in lubricants.

In 1925, the last year for which a census of production is available, the United States of America exported about 8 per cent. of her manufactured products. There is definite evidence to show that America is determined to increase her export trade and it is important to realise that an additional export of 1 per cent. of the United States production of manufactures would represent a total value of approximately £70 million—a larger sum than the whole value of

British exports to South America. This small percentage increase would represent a very large share of the increase in the ability of the rest of the world to absorb manufactured goods.

The growth of competition from Europe may not be so spectacular as that from the United States of America but there is every reason to anticipate a steady increase. Germany has completely reorganised many of her industries and the necessity to pay reparations will force her to place a large proportion of her production on the world's markets. A most significant feature of the German economic situation in 1928 was that whereas her industrial production index fell steadily from March to December, German industrial exports were 13 per cent. higher than in 1927. German total exports increased from £510 million in 1926 to £588 million in 1928. Her progress was greatest in exports of electro-technical products, showing a rise of 35 per cent.; in machinery which increased by 40 per cent.; and in silk and artificial silk manufactures, also an increase of 40 per cent.

Among the four leading industrial nations France has recorded a rate of progress in exports second only to the United States of America.

In his report* on the economic conditions in France in 1928, Mr. Cahill states that "the French industrial fabric underwent almost complete renovation or reconstruction and general enlargement in the period from 1915 to 1925." The result has been that "in nearly all branches of manufacturing industry are recorded increased export and diminished imports. Exports of manufactured goods in 1927 were, in weight, 2½ times greater than the average exports of such goods in the five years 1909-13." In 1928 her exports showed a slight decrease but there is every reason to suppose that France's industrial progress will continue to make her a formidable competitor in the markets for manufactured goods.

The great difference between the level of the share of the world's export trade taken by each of the four chief industrial nations and that of the second group has considerably diminished since pre-war years. Japan, Italy and the Netherlands have considerably increased in significance in the world's export trade. The Italian economic

* Department of Overseas Trade.

policy of restricted emigration associated with a stimulation of the birth rate may be expected to result in a marked effort to secure increased exports of manufactures in order to obtain supplies of raw materials and foodstuffs. Belgium has now recovered from her pre-war losses. The Balfour Report states that ". . . from the point of view of the number of factories, plant and equipment, Belgium's industrial capacity to-day (1925) is greater than it was in 1913." The volume of her foreign trade is well above the pre-war level. In the last three years Belgian exports have shown a remarkable increase, rising from £128 million in 1926 to £172 million in 1928. This progress was mainly in exports of manufactured articles which increased in the three year period by 44 per cent. Czecho-Slovakia has a smaller export trade than the other members of this group, but she belongs to the group because the characteristics of her national economy are similar to those of great industrial nations. Her inheritance of the major portion of the iron and steel and textile equipment of former Austria-Hungary has helped to put her industries on a prosperous footing and the basis of Czecho-Slovakian trade is now the importation of raw materials and exportation of manufactured goods to her neighbours.

In Table IV the total exports and the percentage of manufactured goods exported from this second group of industrial foreign countries are shown :—

TABLE IV.

	Annual average—1926-1928.	
	Total exports.	Per cent. of manufactured goods exported.
	£ million.	Per cent.
Japan	194	83·4
Netherlands	155	37·6
Belgo-Luxembourg	151	56·9
Italy	148	—
Czecho-Slovakia	119	65·4

It must be remembered that in the statistics of these groups of countries the basis of the division of goods into manufactured and other classes differs fairly widely and, therefore, the percentage figures given are not strictly comparable.

Comparisons with pre-war years are largely vitiated by the difference in price levels but the following figures obtained from League of Nations sources* give the change in the quantum of exports since 1913. It must be recognised, however, that since the quantum figures are based on price indices, they may need some qualification for, as the League Statistician points out, "it is possible that the import indices of certain countries are somewhat too low or that the export indices are too high." Further, in the case of Great Britain, at least, it is probable that the wide divergence between import and export indices can be partly accounted for by the post-war tendency towards the export of higher and more expensive qualities of goods, and therefore that "the total quantum of trade in both 1926 and 1927 would be slightly greater than is suggested by the table." Unfortunately Belgian and French figures are not available.

TABLE V.—*Percentage change in the quantum of export trade since 1913.*

Country.	1924.	1925.	1926.	1927.
	Per cent.	Per cent.	Per cent.	Per cent.
Great Britain	81	80	72	83
U.S.A.	129	137	145	157
Germany	51	65	73	76
Japan	140	176	Not available.	
Italy	121	134	135	134
Czecho-Slovakia (1921 = 100) ..	106	117	118	128

* League of Nations Memorandum on International Trade, Vol. I.

In the tables already given, there is ample evidence of the growth of competition in manufactured goods from the chief exporting countries. There is also a further cause of intensification of competition in the world markets. It has been clearly shown by the Balfour Committee on Industry and Trade* that "taking the world as a whole, the widespread development of home manufactures to meet needs formerly supplied by imported goods is by general consent one of the outstanding features of the post-war economic situation, and this is perhaps the most important permanent factor tending either to limit the volume or to modify the character of British export trade."

The idea of aiming at self-sufficiency is now firmly held in certain European countries which, in pre-war years, were only slightly industrialised, and British goods which formerly found a ready sale in those markets are now wholly or partially excluded by the competition of the locally produced article under the protection of an import tariff. A similar tendency occurs among Empire countries; this is dealt with on page 20. In a short memorandum it is not necessary to discuss in any detail the effects of this tendency.

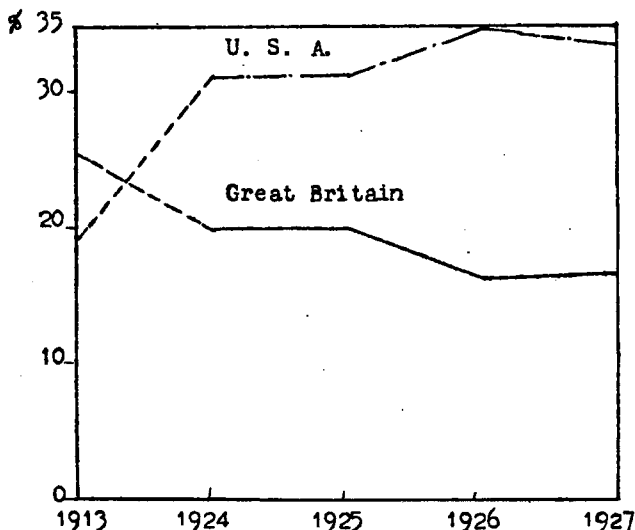
2. Great Britain's Trade with Foreign Markets.

A study of the percentage share of important markets taken by Great Britain and her chief competitors provides striking confirmation of the rapid progress of foreign industry and the extent to which Great Britain lags behind, but a percentage share cannot present the whole picture. In order to arrive at a reasonable estimate of the changed position since 1913 of British export trade in the markets under consideration, it is essential also to know the changes in the value of the total trade.

The United States of America has invaded all the markets of the world. Graph I shows an almost complete reversal in the position of the United States of America and Great Britain in South American imports in post-war years as compared with 1913. In 1927 the United States share was higher than that held by Great Britain in 1913, while Great Britain's share was in 1927 slightly below the level maintained by the United States of America before the war.

* Balfour Committee on Industry and Trade, Survey of Overseas Markets.

GRAPH I.



Graph I.—Share of Great Britain and U.S.A. in import trade of South America.
Countries :—Argentine, Bolivia, Brazil, Chile, Colombia, Paraguay, Peru, Uruguay, Venezuela.

Table VI shows the trade of the United States of America and Great Britain with South America. An approximate revaluation of South American imports in post-war years on the basis of 1913 prices shows that the purchasing power of these countries has increased from £224 million in 1913 to £240 million in 1927. British exports, on the other hand, have shown a marked decline in comparison with 1913. On the same basis they reached only £40 million in 1928 against £56 million in 1913. These figures are in striking contrast to South American purchases of U.S.A. goods which have trebled in volume in the same period.*

* Revaluations of trade figures at 1913 price levels and statements about changes in quantum trade are based on the import and export price indices published in League of Nations Memorandum on International Trade, Vol. I.

TABLE VI.—*Exports to South America.*

Year.					British exports.	U.S.A. exports.
					£ million.	£ million.
1913	..	..	..	..	56·4	28·7
1924	..	..	..	..	57·2	69·4
1926	..	..	..	..	52·8	89·8
1927	..	..	..	..	57·6	88·5
1928	..	..	..	..	63·8	97·1

Although in Europe, American exports have made considerable headway, yet no such drastic changes in the direction of trade have occurred as those recorded in South America.

The markets in Europe of special importance to Great Britain have been divided into two groups. The North-West group includes Denmark, Norway, Sweden, Netherlands and the Western European group is composed of Belgium, France, Spain and Italy.

From the point of view of British industry, the countries of Central and Eastern Europe, with the exception of Germany, are not of sufficient importance to warrant their inclusion in a memorandum of this size. These European countries (excluding Germany) purchase in one year from Great Britain less than France alone, and less than half the amount purchased by Australia.

The most striking progress made by the United States of America in European markets is in her share of German imports. In 1927 and 1928, however, there was a tendency for British trade with Germany to improve.

The demand for imported goods in North-West Europe has increased in the post-war period, nevertheless, at 1913 price levels, exports from Great Britain in 1928 were still some £5 million below the 1913 values. In Table VII the post-war development in the export trade of U.S.A., Germany and Great Britain is shown.

TABLE VII.—*Exports to North-West Europe.*

Year.	Germany.	Great Britain.	U.S.A.
	£ million.	£ million.	£ million.
1913	68·4	35·6	33·8
1924	73·4	61·4	54·4
1926	102·4	41·6	52·0
1927	103·2	48·1	56·5
1928	110·4	49·2	55·3

Countries included :—Denmark, Norway, Sweden, Netherlands.

In the markets of Western Europe the position is slightly different as the import trade of these countries has not yet attained the pre-war level. In 1913 the share of world import trade taken by Belgium Italy, France and Spain together amounted to 17·6 per cent. and in 1927 the percentage was only 13·1. If allowance be made for the price changes in British exports since 1913, it appears that British exports to these countries have fallen by nearly 40 per cent., from £64·5 million in 1913 to approximately £40·7 million in 1928. Table VIII shows the comparative progress of British, American and German export trade.

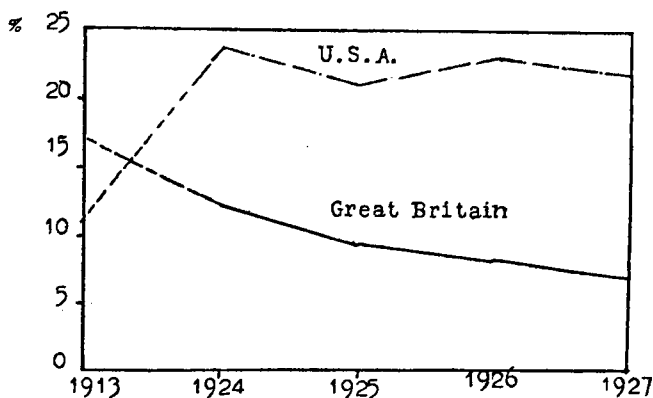
TABLE VIII.—*Exports to Western Europe.*

Year.	Great Britain.	U.S.A.	Germany.
	£ million.	£ million.	£ million.
1913	64·5	64	93·8
1924	92·3	148	29·2
1926	52·1	121	85·5
1927	63·6	113	77·9
1928	66·2	123	90·7

A reversal, similar to that in South American markets, can be seen from the graph below to have taken place in the two chief markets of the Far East, but to an even greater extent. The fact that the import trade of Japan has increased from 1·84 per cent. in 1913 to 3·06 per cent. of world import trade in 1927 implies that Great Britain's loss of trade as measured by her volume of exports has not been so great as would appear from the graph, in fact, in terms of pre-war prices, British exports to China and Japan were, in 1928,

less than £1 million below the 1913 figure. On the other hand, it is evident that the progress of America has been most striking, her exports rising from £16 million to £70 million in 1928 after allowance has been made for the change in price levels.

GRAPH II.



Graph II.—Percentage share of import trade of the Far East taken by Great Britain and U.S.A.

Countries :—China and Japan.

Table IX shows the relative advance of British and American exports to Far Eastern markets.

TABLE IX.—Exports to Far East.

Year.	Great Britain.	U.S.A.
	£ million.	£ million.
1913	38·8	22·5
1924	59·2	108·2
1926	41·9	96·5
1927	37·2	91·6
1928	44·1	111·6

Countries included :—China, Japan, Dutch East Indies, Siam, Philippines.

The United States is not the only country which has gained a very considerable share of the import trade in the Far East at Great Britain's expense. Since 1913 Japan has made great inroads into Far Eastern markets and is well ahead of Great Britain. The percentage share taken by Japan in the import trade of Far Eastern countries rose from 8 per cent. in 1913 to 15 per cent. in 1927 whereas the British percentage dropped 6 points in this period. The way in which Japan has overtaken Great Britain in supplying exports to Far Eastern markets in post-war years is shown by Table X.

TABLE X.—*Exports to Far East.*

Year.	British exports.	Japan exports.
	£ million.	£ million.
1913	24·3	16·7
1924	32·5	43·5
1926	28·0	53·3
1927	22·1	46·0
1928	29·6	48·1

Countries included: China, Siam, Dutch East Indies, Philippines.

It has been shown that, as a result of new forces at work in the changed conditions of the post-war industrial situation, Great Britain is encountering in foreign markets more severe competition than in pre-war years and her relative position is considerably less favourable. Not only has the percentage share taken by Great Britain in the import trade of the groups of countries under consideration declined to a very marked extent, but her exports, measured in terms of 1913 prices, have also lagged behind the pre-war level. The competition from nations whose prosperity largely depends upon a flourishing export trade in manufactured goods is likely to increase in intensity and the gradual restriction of certain markets as a result of the rise of local manufactures under the shelter of a tariff appears to be inevitable.

3. Great Britain's Trade with Empire Countries.

Although competition for trade in manufactured goods has become intensified in every market of the world, it can be shown that the position of British trade is far more favourable in Empire markets than in foreign markets. It has already been stated that in Empire markets, taken as a whole, Great Britain supplies about 36 per cent.

of the imports. With the exception of those parts of the Empire which fall directly within the economic orbit of the United States of America, Great Britain retains a position of definite predominance. In the Empire markets Great Britain's share has tended to decrease since the war; but, as the following pages show, Great Britain is, in most Empire countries, still very well ahead of her competitors.

In Empire markets, the evidence from League of Nations figures is that, although a large share of the trade falls to Great Britain, yet at the same time the United States of America is making considerable inroads. It is interesting to observe the fact that the Empire, including Great Britain, is by far the largest customer for American products, taking over 40 per cent. of America's exports. European countries are making little headway in Empire markets, but, with the exception of Germany, they would appear to have regained the small proportion held in 1913. The position in India is somewhat different from that in other parts of the Empire for, in India, Japan has greatly increased her share of the market since pre-war years and in recent years has vied with the United States of America for second place.

At the commencement of the examination of the position of Great Britain in foreign markets, an attempt was made on pages Nos. 9 to 14 to assess the relative importance of the competitive factors. Great Britain experiences little direct competition in world markets from exports of Empire manufactures, the only source of competition being from certain Canadian industries such as motors and agricultural machinery.

The tendency towards the establishment of local manufacturing industries, which in post-war years became so important a feature in Europe and other parts of the foreign world, has had considerable influence in modifying the economic organisation of countries within the Empire which formerly were almost purely agricultural. Canada is already an industrial power of considerable magnitude. Australia and India, and to a lesser extent South Africa and New Zealand, have developed secondary industries which led to some change in the nature of their import trade. New local manufactures tend to concentrate on the simpler classes of goods for which there is a wide and constant home demand. Concurrently, the establishment of new factories gives rise to a demand for industrial machinery and plant. The main reason why the establishment of manufacturing industries in the Dominions and India is less serious to Great Britain

than is the same tendency among her foreign customers is the fact that the Empire countries purchase their industrial plant and equipment from Great Britain to a far greater extent than do foreign countries. It is probable that the increased purchases of industrial equipment and the higher standard of living resulting from more diversified occupations in the Dominions and India will compensate for the decline in demand for the commoner grades of goods.

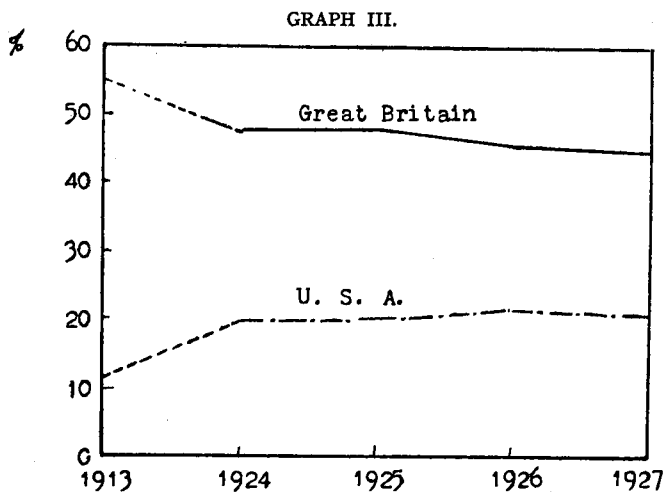
(a) *Dominion Markets.*

Great Britain holds in the Canadian market a much lower share of the total imports than in the case of the other Dominions. This is, of course, due to the proximity of Canada to the great centres of industrial activity in the United States of America. The British share of Canadian imports was 21·3 per cent. in 1913, and 16·8 per cent. in 1927 and 15·6 per cent. in 1928, whereas the U.S.A. share was 64·0 per cent. in 1913, 64·9 per cent. in 1927 and 67·6 per cent. in 1928. The Canadian market is rapidly expanding, her percentage share of world trade shows a very large increase from 2·78 in 1913 to 3·76 in 1927. The total British Exports to Canada have increased in recent years from £27,557,000 in 1923 to £34,267,000 in 1928.

It is interesting to note that each Canadian purchases £3 11s. 10d. of British goods as against 7s. 10d. for each person in the United States of America, and that if Canada purchased British goods only at the same rate as the citizens of the United States of America, the reduction in British exports in 1928 would have been £30,507,000.

In the markets of Australia and New Zealand, the United States has gained to the extent that Great Britain has lost, within the period 1913–1927 the United States share rose by nearly five points, whereas the British share fell by a corresponding amount. The value of U.S.A. exports has nearly trebled within this period. Although Great Britain's share of the Australian market has declined, the value of her exports, making allowance for the change in price, has gradually increased and since 1926 has exceeded the 1913 level by £2 or £3 million.

Graph III should be compared with the one on page 15 which illustrates the trade position with South America. It will be observed that while the tendencies have been largely similar, Great Britain has retained the preponderating share of the import trade of the two Dominions, whereas in South America her share is now far less than that of the United States of America.



Graph III.—Percentage share of import trade of Australia and New Zealand taken by Great Britain and U.S.A.

Table XI below shows a comparison between British and U.S.A. export trade to Australia and New Zealand in millions of pounds sterling.

TABLE XI.—Exports to Australia and New Zealand.

Year.	British exports.	U.S.A. exports.
	£ million.	£ million.
1913	45·3	10·7
1924	81·0	34·9
1926	81·9	43·3
1927	80·7	39·4
1928	74·8	36·5

Table XII shows that the demand for imports into the three Southern Dominions since 1913 shows a considerable real increase. On the basis of 1913 prices, Great Britain has barely reached her pre-war level of exports, whereas exports from U.S.A. have nearly trebled.

TABLE XII.—*Trade of Great Britain and U.S.A. with the Southern Dominions. Values at 1913 price levels approximately.*

Year.	Total imports.	British exports.	U.S.A. exports.
	£ million.	£ million.	£ million.
1913	141	67·5	13·3
1926	180	65·8	40·5
1927	185	68·2	40·5
1928	—	66·4	37·8

Countries included: Australia, South Africa, New Zealand.

In South Africa the United States of America has increased her share of imports from 8·9 per cent. in 1913 to 15·4 per cent. in 1927, while the British share has declined from 56·8 per cent. to 44·8 per cent. Table XIII shows the post-war changes in British and United States exports to South Africa.

TABLE XIII.—*Exports to South Africa.*

Year.	British exports.	U.S.A. exports.
	£ million.	£ million.
1913	22·2	3·0
1924	30·4	8·1
1926	32·1	10·5
1927	30·5	10·8
1928	31·6	12·2

No statistics can be available to show the changes in the position of British export trade since 1913 in regard to the Irish Free State market. The figures for post-war years show a decline in the percentage share of the United Kingdom in the import trade of the Irish Free State from 81·1 per cent. in 1924 to 77·4 per cent. in 1928. The proportion of the import trade taken by the United States of America and Germany has increased but it is clear that the bulk of the trade is in the hands of British exporters.

India's share of world import trade has declined from 3·07 per cent. in 1913 to 2·78 per cent. in 1927. Table XIV shows the position of the export trade from Great Britain and her chief competitors to

India, and is particularly interesting as demonstrating the very similar progress made by America and Japan. The percentage share taken by Great Britain in the import trade of India fell from 64 per cent. in 1913 to 47 per cent. in 1927; British exports, measured at 1913 price levels, also fell from £70 million to £52 million.

TABLE XIV.—*Exports to India.*

Year.	British exports.	U.S.A. exports.	Japan exports.
	£ million.	£ million.	£ million.
1913	70·3	2·2	2·9
1924	90·5	7·9	13·5
1926	81·7	10·3	15·5
1927	85·0	13·0	16·7
1928	83·9	11·0	14·6

(b) *Colonies.*

In a speech on the Colonial Office Vote in the late Parliament, Mr. Amery gave some very interesting information regarding the development of oversea trade in the Colonies. In the period 1924 to 1927, the import trade of the Colonies taken together has increased from £187 million to £247 million and British exports to the Colonies rose from £47 million to £55 million in the same period, with the result that the Colonial Empire taken as a unit now ranks, next after India and Australia, as Great Britain's best market.

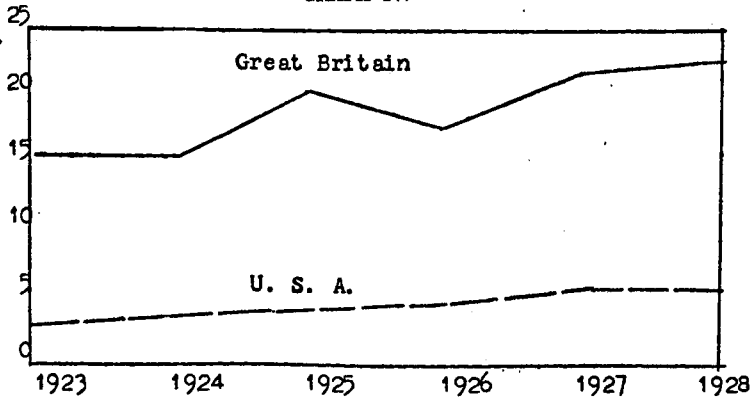
The nature of Colonial trade makes it a particularly advantageous market for Great Britain to develop, for their trade is in the strictest sense complementary. The Colonies are essentially agricultural and producers of primary products and their import trade is largely in manufactured goods. It may be maintained by some that in certain of the Colonies, the production and export of a single primary product plays so large a part in their trade as to put their economic welfare on a precarious footing and lead to great instability and uncertainty in their oversea trade. For instance, in the export trade of Kenya and Uganda coffee and cotton, raw, accounted, in 1927, for 62 per cent. In British Malaya rubber accounted for 49 per cent. of her exports. On the Gold Coast cocoa made up 87 per cent. of the exports and in Ceylon tea and rubber exports were 77 per cent. of the total. It is probable, however, that transport developments, the closer application of scientific research and more detailed studies of the

requirements of overseas markets will lead to the stimulation of the production and export of a greater variety of commodities and that, therefore, a more general and more stable economic development will take place.

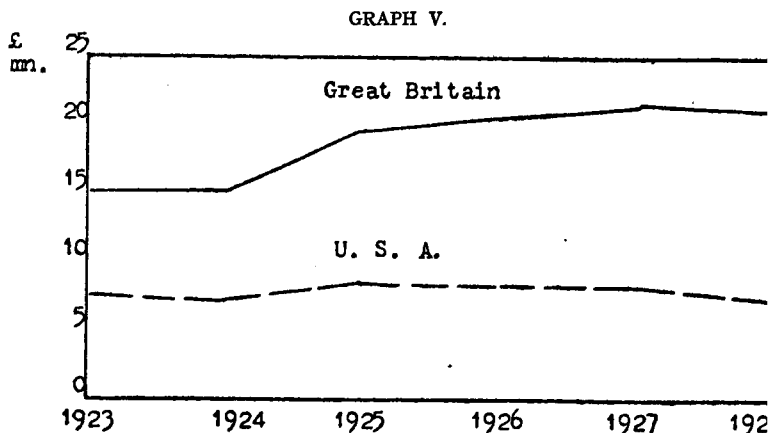
In the general import trade of certain Colonies Great Britain takes a very large share. For the year 1927 the percentage of British imports in the trade of Nigeria was 62; for North and South Rhodesia, 47; Kenya and Uganda, 38·4; other Colonies like the British West Indies have naturally been greatly under the sphere of economic influence of the United States of America and in this group the British share of imports varies but the average percentage is 29. In Malaya, and to a slightly lesser extent in Ceylon, the necessity to import a very heavy percentage of the foodstuffs required results in the British share of total imports representing quite low figures, namely for Malaya 13·2 per cent. and for Ceylon 21·9 per cent. In competitive goods, however, the British share of the supplies to this market is high.

The United States of America is undoubtedly the chief competitor of Great Britain in Colonial as in Empire markets and from the following graphs the relative progress of the United States and British exports to the Colonies can be judged.

GRAPH IV.



Graph IV.—Exports of U.S.A. and Great Britain to British Colonies in Africa.



Graph V.—Exports of U.S.A. and Great Britain to Malay, British West Indies, British Honduras and British Guiana.

Conclusion.

The impression to be gained from a general review of Great Britain's position in overseas markets is in some ways disquieting, but there are specific factors in the industrial situation which afford ground for a more hopeful view of Great Britain's prospects. Of these factors by far the most important is the position which British trade retains in that quarter of the world which is the British Empire.

The predominant position of Great Britain in most of the markets of the Empire is due to a variety of circumstances. In Australia, New Zealand and South Africa, as also in Canada, the influence of sentiment and long established trade relations is reinforced by the system of tariff preferences given to British goods by the Dominions. In India, however, Great Britain holds as large a share of the market as in Australasia. Some Colonies have adopted a preferential system, in others International agreements prevent such action. It is, however, impossible to compare the position of British trade in the Empire with foreign countries without realising that the Empire provides a series of sheltered markets for British industry. India and China buy from the world about equal amounts but in 1928 British exports to India were valued at £83,921,000, those to China at £15,717,000.

Similarly Australia and Argentine import approximately the same value of goods and yet Australia takes £55,698,000 of British exports whereas Argentine takes only £31,212,000. Similarly striking comparisons could be drawn from each Dominion and from most of the Colonies. The existence of, and the further development of these great sheltered markets should provide to the British manufacturer a considerable measure of that security which the home demand of the United States of America afforded to the American manufacturer. Thus the development of Empire markets should enable the British manufacturer to increase his output, to reduce his overhead costs, and thus to place himself in a better position to meet fierce competition in the foreign markets.

It is interesting to note that there is evidence to show that Empire countries are developing more rapidly than comparable parts of the foreign world.

The following table shows the extent to which certain Dominions and Colonies and certain foreign countries have increased or diminished their share of world trade.

TABLE XV.—*Share in World Trade.**

	Empire Group.			Foreign Group.	
	1913.	1927.		1913.	1927.
	per cent.	per cent.		per cent.	per cent.
Canada	2.78	3.76	Argentina	2.66	2.86
Australia	2.00	2.35	D.E. Indies	1.21	1.61
Br. Malaya	1.06	1.85	Brazil	1.70	1.30
Union of S. Africa ..	1.38	1.26	Chile .. ..	.71	.53
New Zealand .. ..	.55	.70	Algeria .. ..	.60	.43
Nigeria .. ..	.17	.23	Uruguay .. ..	.33	.30
Gold Coast .. ..	.13	.22	Morocco .. ..	.11	.16
Kenya and Uganda ..	.03	.10	Foreign West Africa	.14	.15
			Belgian Congo ..	.07	.11
Total	8.10	10.47	Total	7.53	7.45
Area : 8,088,000 sq. miles. Population of Empire Group : 52,554,000.			Area : 7,695,000 sq. miles. Population of Foreign Group: 125,875,000.		

* League of Nations Memorandum on International Trade, Vol. I.

Another factor in which Empire markets seem destined to prove of great value to British industry will be recognised if the competitive position is studied from the point of view of the types of goods exported.

British exports to Empire countries are mainly manufactures. Great Britain has a tradition of excellence in highly finished manufactures requiring highly skilled labour and advanced technique and it is in this class of goods that she has maintained the greatest percentage of the trade in Empire markets.

It is possible that the progress of the newer industries, such as artificial silk, electro-technical products and the manufacture of motor cars and accessories, will, to a considerable extent, relieve the depression in British industry and redress the balance of trade. The percentage of the products of these new industries exported to Empire countries is much higher than the general average for all the manufactured exports; for instance, of the export of electrical goods and apparatus 66 per cent. go to the Empire, of electrical machinery 68 per cent., for artificial silk manufacture the percentage is 61, for motor cars and chassis 81 per cent. and for drugs and medicines 79 per cent.

In 1913 British exports of such manufactures formed 6·4 per cent. of her total export trade and, in 1928, this percentage had risen to 10.

It is probable that the demand for the products of the new industries will continue to increase at a rate higher than the average at home and abroad, but in these commodities, as in industry in general, competition is becoming intensified and Great Britain finds it difficult to maintain her share of the world market. It is essential, therefore, that Great Britain should develop her trade with Empire countries where she enjoys some shelter from competition in markets which absorb from 60 per cent. to 80 per cent. of her exports of these classes of goods.

Mention has already been made of the fact that whereas the export trade of most of her industrial rivals has exceeded the pre-war volume, Great Britain's exports reached in 1927 only 83 per cent. of the 1913 level. It is clear that in foreign markets Great Britain has lost much ground and still finds it hard to compete with exporting countries where lower costs of production prevail. In Empire countries Great Britain's position is more favourable because the result of the shelter she receives is to reserve for her manufactures a high proportion of these markets.

The value to British traders of the preferential treatment accorded to them in Empire markets was much emphasized in the Final Report of the Balfour Committee on Trade. One sentence particularly may be quoted here: "In view of the facts it cannot admit of doubt that the preservation and development of these advantages must be one of the cardinal objects of British Commercial policy."

As the productive capacity of Empire countries increases, a new demand for manufactures will be created and it is to the vital interest of Great Britain to foster trade within the Empire and maintain her predominant position in this group of expanding markets. One of the most serious factors in the post-war industrial situation is the high increase of industrial costs in the great exporting trades. To quote the Report of the Balfour Committee once more: "A great part of the increase of costs is attributable to a decline in production, and a consequent increase in the burden of overhead charges per unit of output." By taking advantage of the increasing purchasing power for British goods operating in the sheltered markets of the Empire, Great Britain should be able effectively to increase the output of her export trades. Development along these lines would lead to a reduction of the burden of overhead costs on industry and thus enable Great Britain to regain a stronger competitive position in foreign markets. It has been shown that here is an opportunity for the steady expansion of British export trade with a lifting of the burden of trade depression and unemployment within Great Britain, and thus, through the development of her great inheritance, Great Britain should be able to remove many of the adverse factors which now hamper her in the full development of her export trade both to foreign and Empire countries.

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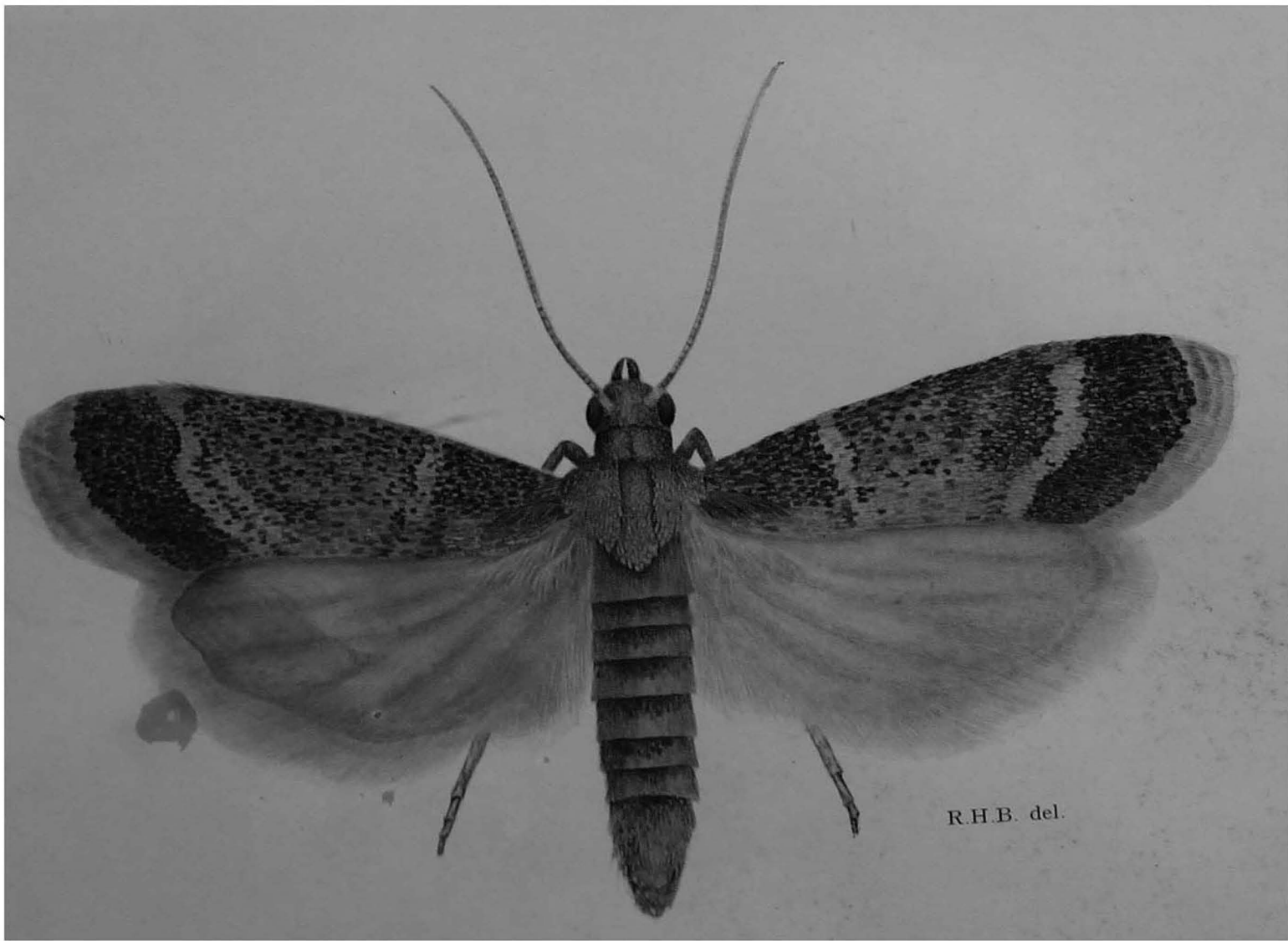


Plate I. *Ephestia elutella* Hb., adult. $\times 9$ (approx.)

E.M.B.24.

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REPORT ON INSECT INFESTATION OF STORED CACAO

Prepared for the Empire Marketing Board's Committee on
Infestation of Stored Products.

By

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CONTENTS.

	Page
Prefatory Note	5
I. Introduction	7
Nature and Extent of the Problem	7
Infestation in the Exporting Country	8
Infestation in Chocolate Factories	9
Infestation at the Wharves and Warehouses in the Importing Country	10
II. Objects of the Present Investigation	11
Preliminary Survey	11
Detailed Survey	15
III. Principal Insects found during the Survey and their Relative Importance :—	16
<i>Araccerus fasciculatus</i> De G.	17
<i>Corcyra cephalonica</i> Staint.	19
<i>Ephestia elutella</i> Hb.	22
IV. Experimental Work in connection with the Survey	32
V. Summary	36
VI. Acknowledgments	37
VII. Bibliography	37

PREFATORY NOTE.

This Report dealing with a preliminary survey of the insect conditions prevailing in cacao stores in certain wharves and docks in London has been prepared for the Empire Marketing Board's Committee on Infestation of Stored Products by Mr. W. S. Thomson, under the direction of Dr. J. W. Munro, Assistant Professor of Entomology in the Imperial College of Science and Technology.

Since the preliminary survey was started, the Board has by a series of grants made to the College enabled that Institution to establish at Slough a research laboratory for the special conduct of Stored Products Research.

At present the research in progress is concentrated on the study of the insect problems affecting cacao and dried fruits and of the problems presented by the occurrence of moulds in cacao and copra, but other products are also receiving attention and the whole field of stored products entomology and mycology will be explored as time and opportunity permit.

The Report affords a useful indication of the nature and extent of the insect problems presented by stored cacao. In particular it shows that the control and prevention of the losses now caused by cacao insects can be attained only by co-operation on the part of all concerned, because insect infestation occurs throughout all stages of the cacao industry.

The most important pest of cacao, the moth *Ephestia elutella*, is now established in the wharves and stores in this country, but even so its numbers are regularly augmented by introduction in shipments from abroad and it is scarcely reasonable to expect wharfingers and warehousemen to take measures to keep their premises free from the moth when every consignment of cacao constitutes a source of re-infestation.

This aspect of the problem is receiving special consideration, and it is hoped that one effect of the publication of this Report will be to call attention to the actual conditions prevailing in the London docks, and to induce the oversea producers and exporters to consider whether all is being done on their part to ensure the shipment of clean cacao. Obviously the general problem will be dealt with by co-operation of all parties, both at home and overseas.

REPORT ON INSECT INFESTATION OF STORED CACAO.

I. INTRODUCTION.

WITHIN recent years the problem of insect infestation of cacao in store in this country has assumed increasing importance. While the direct loss of cacao caused by the depredations of insect pests is small, the indirect losses are sometimes of considerable magnitude.

Cacao insects are transferred from the docks to chocolate factories inland ; this may result in the occurrence of larvae or caterpillars in boxes of manufactured chocolates, a circumstance which would seriously affect the prestige of the firm concerned.

Cacao, of which more than 15 per cent. is infested by insects and is mouldy, is rejected at the U.S. Ports by the Food, Drug and Insecticide Administration of the U.S. Department of Agriculture, who are charged with the enforcement of the Food Laws. The entrance of cacao in which over 10 per cent. of mould is present, is also prohibited. An account of the provisions of the Food Laws is given by Schwarz (38) and by Culham and Scott (8).

Certain cacao insects, notably the *Ephestia* moths, affect other products stored in proximity to cacao, and so are a matter of concern to the wharfingers and brokers. For instance, the wandering of *Ephestia* larvae to such a product as arrowroot sometimes seriously reduces the value of this product, and may in extreme cases cause it to be unmarketable. Although the larvae do not consume arrowroot, they may soil it with web while searching for a suitable place to pupate.

Nature and Extent of the Problem.

The problem of insect infestation of stored cacao has three main aspects :—

- (a) Infestation in the exporting country ;
- (b) Infestation in the wharves and warehouses in the importing country ;
- (c) Infestation in the cocoa and chocolate factories in the importing country.

The object of this survey was to study the second of these aspects ; mention may be made, however, of work which has been done or is now in progress in connection with the other two.

Infestation in the Exporting Country.

Schwarz (38) has surveyed the cacao industry of the Gold Coast, Nigeria, Cameroons and Fernando Po in some detail, with reference to the causes and prevention of mould in cacao. Should the recommendations made by him be carried out, they will probably result also in a distinct diminution in insect infestation.

He deals comprehensively with the industry in West Africa, describing the cacao belt ; the system of land tenure ; forest reserves as a protection for the cacao trees from excessive sunlight ; the work of the Department of Agriculture in educating the natives ; the preparation and handling of the crop ; transportation of the crop from up-country to the ports ; shipping the crop ; experimental work which is being carried out at Aburi on fermentation and moisture-content of the beans ; and finally, proposed legislation.

For drying purposes the fermented cacao is spread out, either on bamboo mats or on tarpaulins, which are raised above the ground. The beans are exposed for about five days, but are protected from the sun for part of the first day in order not to bake the husks ; otherwise drying might be retarded. They are further protected in the event of rainy weather setting in. After drying, the cacao is bagged and sent down to depots, where, if it is found to have been insufficiently dried, it may be further exposed to the sun, and afterwards re-bagged.

In the Gold Coast the bags, when ready for shipment, are stored either in warehouses or, if such accommodation be inadequate, on the beach. When storage on the beach is necessary, the piles are usually supported on a platform raised about a foot from the ground. Tarpaulins are used as a protection from rain.

At the present time, transport from the shore to the ship is effected by means of surf boats, with the result that considerable damage from wetting frequently occurs and gives rise to a high proportion of mould in the consignment. If, however, as seems probable, Takoradi becomes the principal port in the Gold Coast, both storage and shipping conditions will be greatly improved, with consequent benefit to the cacao industry.

It will be seen from the foregoing that there is ample opportunity for insect infestation to occur in the country of origin, particularly on the drying-stages. Mr. W. H. Patterson, Senior Entomologist at Aburi, Gold Coast, in a letter to "Tropical Life" (32) lays emphasis on this point, and states that "the trouble does not start with the stores here; it actually originates in the drying-stages". He is of the opinion that the Anthribid beetle, *Araecerus fasciculatus* De G., is a greater enemy of cacao in West Africa than the Phycitid moth *Ephestia elutella*, Hb., which is the more common pest of cacao in general, and it is with reference to the beetle rather than to the moth that the statement quoted is made. Nevertheless, it is probable that in regard to *Ephestia*, the starting point of the infestation is the same, i.e. the drying-stages. Although sometimes the one insect seems to predominate and sometimes the other, generally *Ephestia* is undoubtedly the more important in relation to the infestation of cacao. It may be that *Araecerus*, which bores into the beans, serves as an auxiliary of *Ephestia*, whose larvae can successfully attack beans only when the shell or husk is broken. In West African cacao, however, the incidence of mould is more widespread and important than that of any insect.

Knapp (21) enumerates several insects, among them three species of *Ephestia*, infesting stored cacao, and mentions not only the drying-stages and storage sheds, but also the cacao trees and pods as possible sources of infestation in the countries of origin. In his opinion the trees and pods are important as providing a possible habitat from which *Araecerus* might infest cacao in the drying-stages. He further mentions the occurrence of *Ephestia elutella* Hb. as a pest of cacao in store in Java; and Granato (16) records the same moth as attacking cacao-pods in Brazil—an interesting point worthy of further investigation.

Apart from the instances just referred to, little work seems to have been done hitherto on the incidence of insect infestation of cacao in the exporting countries.

Infestation in Chocolate Factories.

An investigation of the infestation of chocolate factories by *Ephestia* moths has been carried out by the Cocoa, Chocolate, Jam, Sugar and Confectionery Trades' Research Association, and has shown that no stage of *Ephestia* is able to survive the manufacturing processes which are undergone by the cacao at the factory. This limits the problem

of the manufacturers to one of protecting their goods from risk of infestation between the time of finishing and distribution from the factory. There is, of course, always a possibility that the finished goods may become infested during transport or in the retailer's store through contact with infested material, e.g. cereals, dried fruit and nuts.

In Germany, Zacher (45) has done interesting work in connection with the incidence of infestation by *Ephestia* in chocolate factories, and a short summary of part of his paper on this subject may be of interest. The arrangement of the various processes connected with the manufacture of chocolate from cacao is described as follows—on the top floor of the factory are the raw cacao stores and the husking and winnowing machines ; on the floor below are the roasting and grinding machines ; on the next floor the mixing machines, and below this the finishing and packing rooms. Corresponding to this arrangement, Zacher has found the number of *Ephestia* moths present diminishing rapidly with the increasing distance from the raw material. He states that any larvae which may be feeding in the beans will almost certainly be killed during roasting ; that any eggs which may be laid on the beans after roasting are destroyed during grinding and mixing. He infers that if, in spite of this, evidence of infestation appears in the finished article, it may be put down either to the presence of eggs or other stages of the insect in nuts used in making nut-chocolate, or to the presence of isolated moths in the packing rooms. Having discussed in some detail the points just noticed, he makes the recommendation that where possible special chambers should be constructed, preferably at some little distance from the factory, for the storage of cacao beans prior to roasting. Just sufficient quantities to satisfy the needs of the moment should be brought into the factory, and immediately roasted. The major point which he brings out, however, is that infestation in the factories arises in the first instance from the presence of *Ephestia* in the cacao beans, which may have been infested in the country of origin or re-infested while in store at the ports. This is in accord with experience in this country.

Infestation at the Wharves and Warehouses in the Importing Country.

American literature contains few references to the occurrence of either *Ephestia elutella* or *Araecerus fasciculatus* in cacao, although there are many papers relating to the occurrence of *Ephestia elutella* in other products.

Interest in insect infestation problems has been aroused in Germany. In the "Laboratorium für Vorrats- und Speicher-schädlinge" the incidence of stored-products pests in the warehouses and factories has been studied since 1917, under the supervision of Dr. F. Zacher. As in other countries, the infestation by insects of cacao and of the various types of confectionery manufactured from it, is an important problem in Germany.

Zacher (45) has recently reviewed the incidence of *Ephestia* in Germany in the warehouses, at the ports, and in the chocolate factories. In addition to a brief account of the biology of *E. elutella*, in which he describes the eggs, larvae, pupae and adults, he gives a list of products in which the larvae have been found feeding, and outlines possible control measures. Since frequent reference to his work will be made in this report, further discussion is unnecessary here, beyond indicating that many of his results coincide almost exactly with those obtained during the present survey.

II. OBJECTS OF THE PRESENT INVESTIGATION.

The objects of the investigation were to determine which insects are chiefly responsible for the infestation of cacao; to assess the extent to which infestation takes place at different seasons and in cacao from different countries; to define the extent to which re-infestation occurs in the warehouses in this country; and to ascertain the extent to which infestation is preventible.

It was thought advisable to divide the work into two parts. A preliminary survey was undertaken in order to obtain a general knowledge of the conditions prevailing in wharves and warehouses. This was followed by a detailed survey, in order to study more intensively the insects and storage conditions affecting cacao in particular.

Preliminary Survey.

The various warehouses at which the survey was carried out differ somewhat in size, and, therefore, in the floor-space available for storage purposes, but agree in the main in construction. There are up to five floors in each warehouse; the height of a floor varies from about 8 to 10 feet. In the outer wall of each floor is a "loophole", consisting of a pair of doors which open inwards, and below them a hinged wooden flap which is supported by chains and

which can be opened outwards. When the loop is open, goods can be taken into or out of the floor by means of a block and tackle. The doors leading to landings or from one floor to another are usually of iron, and when doors and loop are open, as frequently happens, there is often a strong draught blowing through the floor. In addition to the loops and doors, there are frequently two windows, portions of which can, in some cases, be opened. In certain floors of one warehouse visited there are also loop-holes in the actual flooring; these admit of internal communication and allow transfer of goods from floor to floor without using the outside loops or the stairs.

In one warehouse where cacao is stored, the stairs leading from one floor to another are placed outside the building; in another, the stairways are within the floors themselves, there being no landings; in a third, except in one section, where a similar internal stair exists, the stairways run up between the sections, and the doors of the various floors open on to landings.

Lighting arrangements differ considerably as between warehouses. In some, the windows of each floor are large, and the walls and ceilings are kept whitewashed. As a result, the lower floors are almost as well lit as the top ones, which possess skylights as well as windows. In others, the windows are smaller, and neither walls nor ceilings are whitewashed, except on certain floors; the top floors are fitted with skylights, and here the light is good, but the lower floors are often very badly lit, some indeed, being almost pitch-dark. As most floors in this type of warehouse are smaller than those in the other, the piles of bags stored tend to be higher. When a floor is full the windows are often obscured, so that the only effective light is that which illumines a small area round the loop, should this happen to be open. In some parts of the warehouse, however, artificial light is provided.

Only one of the warehouses under consideration specialises to any marked degree in the storage of any one product—in this case, cacao. Others specialise to a lesser extent, confining themselves in the main to such products as cacao, spices and coffee, and as far as possible setting aside particular floors for the storage of individual products. It is rarely possible, however, to consider the different floors independently so far as insects are concerned, because the insect conditions found on one floor are usually also to be found on the next. Slight variations in the fauna of different floors are due as a rule merely to the different nature of the products in store at the moment. Cacao and nutmegs have the richest fauna, and coffee the poorest.

In considering the question of the control of insects in these warehouses a number of factors must be taken into account : for example, what species of insects found are those especially associated with cacao ; whether these also attack other products stored with cacao ; whether any insects which attack other products also attack cacao ; whether exotic cacao insects survive the English winter, and if so, in what stage and where they hibernate ; what part is played by dirt and rubbish in insect infestation, and particularly in re-infestation, where this occurs ; in what way infestation is affected by lighting and ventilation ; and whether damage caused by rats has any effect on infestation.

With the object of elucidating some of these questions, general inspections of different products and of the warehouses themselves were made, and during the period October, 1927, to March, 1928, much insect material was collected and many useful observations were recorded.

In this way a knowledge was gained of the fauna of the warehouse in general, and in the course of time many of the insects at first classed only in a general way became assignable to their proper place in the ecology of the warehouse. By this means some of the questions regarding the relationship of certain insects to certain products had been cleared up before the detailed survey was begun.

For example, it has been confirmed that the most important insect affecting cacao is the Phycitid moth, *Ephestia elutella*, Hb. ; that nutmegs are very seriously infested by the Anthribid beetle, *Araecerus fasciculatus*, de G., with which are associated a number of other insects ; and that the beetles *Caulophilus latinasus* (Cossonidae) and *Lasioderma serricornis* F. (Anobiidae) are major pests of ginger. There was an indication, which was afterwards confirmed, that another moth, *Corcyra cephalonica*, Staint, is capable of living both on cacao and nutmegs. It was found that *Ephestia elutella* is capable of withstanding very cold weather, for shortly after the cold spell at Christmas, 1927, larvae were found hibernating under some paper which had not been disturbed for several months. These larvae were in a healthy condition. On the other hand, adult *Araecerus* beetles very soon die unless kept under warm conditions, and it would appear that our winter is too cold for them. In dirt and rubbish, consisting chiefly of dust and particles of various products, including whole

cacao-beans, *Ephestia* species, the beetle *Ptinus tectus*, Boield, and allied species, and small beetles of the genus *Laemophloeus* were found breeding. Although the preliminary survey did not provide any definite indication that re-infestation of cacao actually takes place, nevertheless it showed that conditions on the whole are favourable to re-infestation, in that *Ephestia* larvae are perfectly capable of withstanding an average winter in this country.

Other interesting points were noted during the survey. Two examples may be given to show the extraordinary numbers of insects which are sometimes introduced with an imported product. On one floor where cacao was stored, the walls, ceiling, windows and bags were covered with a thick silken web, spun by thousands of fully-fed *Ephestia* larvae as they left the cacao and wandered through the floor in search of suitable places to hibernate and afterwards to pupate. When frequent cleaning is not carried out, this web, added to by succeeding generations of larvae, attains quite a remarkable thickness and strength. A strip of web some 10 or 11 inches in length by 3 or 4 inches wide was removed from a wall at one pull, and web was seen hanging in festoons from the bags. The other example is somewhat different. In the autumn of 1927, some barrels of dry ginger were stored at one of the warehouses. In October or November of that year, the floor, barrels, and adjacent bags of cacao were found to be swarming with the adults of the Cossonid beetle *Caulophilus latinasus* Say. *Caulophilus*, though probably always present in small numbers, has not appeared in such quantities since.

Many insects which cannot be associated with specific products occur in the warehouses. The preliminary survey has shown that some beetles, such as members of the families Dermestidae and Cleridae, are definitely predaceous on other insects, while others, such as *Cryptophagus* spp., small beetles of the family Cryptophagidae, are associated with the various moulds which occur on damp walls, but may in some cases be attracted by mould in products such as cacao. These two classes are not strictly assignable to any product and are thus best described as "general" feeders. Other insects occur more or less accidentally and come into the warehouses from outside. These include Muscid, Tachinid and Drosophilid flies; the beetles *Lyctus brunneus* Steph. and *Dinoderus minutus* F., which occur in small numbers and which are probably associated with some of the less important products; large tropical species whose habits do

not bring them in any way into contact with stored products (e.g. the Scarabeid beetle, *Phileurus didymus* L.), and which almost invariably occur as isolated specimens and are nearly always dead on arrival in London ; and finally insects which are known abroad as stored products pests but which occur only rarely in England.

Apart from these is a group which comprises those insects which, though not themselves strictly assignable to any product, are parasitic upon other insects associated with some particular product. Of these the Braconid wasp, *Microbracon hebetor* Say., which is an important parasite of *Ephestia elutella*, is a good example.

In all, some thirty species of insects have been found in association with stored cacao, but at present only three of these are known to be of much importance, namely: *Araaccerus fasciculatus* De G., *Corcyra cephalonica* Staint., and *Ephestia elutella* Hb. These three will be dealt with later in the report, but it is not proposed to enter into any further discussion of insects which normally occur in warehouses where cacao and spices are stored, since a detailed account of these insects is at present being prepared for publication.

Detailed Survey.

The Port of London was chosen for the detailed survey, partly on account of convenience and partly because facilities for routine examinations already existed. Detailed records of as many shipments of cacao as possible were kept, and as large a sample of each shipment was examined as circumstances permitted. The details recorded were date of landing, date of examination, country of origin, mark, name of ship, general condition of the beans (presence of broken and mouldy beans, odour), and the estimated extent of infestation by *Ephestia elutella*, *Araaccerus fasciculatus*, and other insects. (It may be mentioned that whenever space permits, the bags of cacao are temporarily stood on end against one another to facilitate sampling ; it is contrary to usual practice to pile the bags before samples have been drawn.)

The detailed survey was begun at the end of April, 1928, and the report deals with the results obtained between that date and December, 1928. During this period some 88 shipments of cacao were examined, and these were distributed between two wharves, except in the case of one shipment of Gold Coast cacao.

TABLE I.
*Number of Consignments of Cacao examined between 24th April and
 19th December, 1928.*

Country.	I. No. of Consignments examined.	II. Total No. of Bags in the Consignments.	III. No. of Bags examined.
Cameroons	4	1,685	136
Ceylon	7	554	143
Dominica	2	27	5
Gold Coast	10	12,439	392
Grenada	12	6,354	1,234
Jamaica	2	38	9
St. Lucia	10	1,078	295
St. Vincent	3	86	12
Samoa	4	1,299	200
Trinidad	7	1,235	292
Brazil	3	1,450	108
Costa Rica	11	371	94
Ecuador	5	1,275	127
Panama	1	52	52
Venezuela	7	1,115	182

The figures given in column III of Table I represent a careful, though limited examination of about 3,270 bags of cacao. In addition to these, small samples from about 750 bags were also examined, in cases where the bags had to be piled and could not be completely opened up. (When the bags are piled a small semi-circular cut is made at any convenient point ; from the hole thus formed the sample is extracted by means of a scoop, the cut being sown up again afterwards.)

III. PRINCIPAL INSECTS FOUND DURING THE SURVEY AND THEIR RELATIVE IMPORTANCE.

There are three insects to be considered in relation to cacao :—

- (i) *Araecerus fasciculatus* De G.
- (ii) *Corcyra cephalonica* Staint.
- (iii) *Ephestia elutella*, Hb.

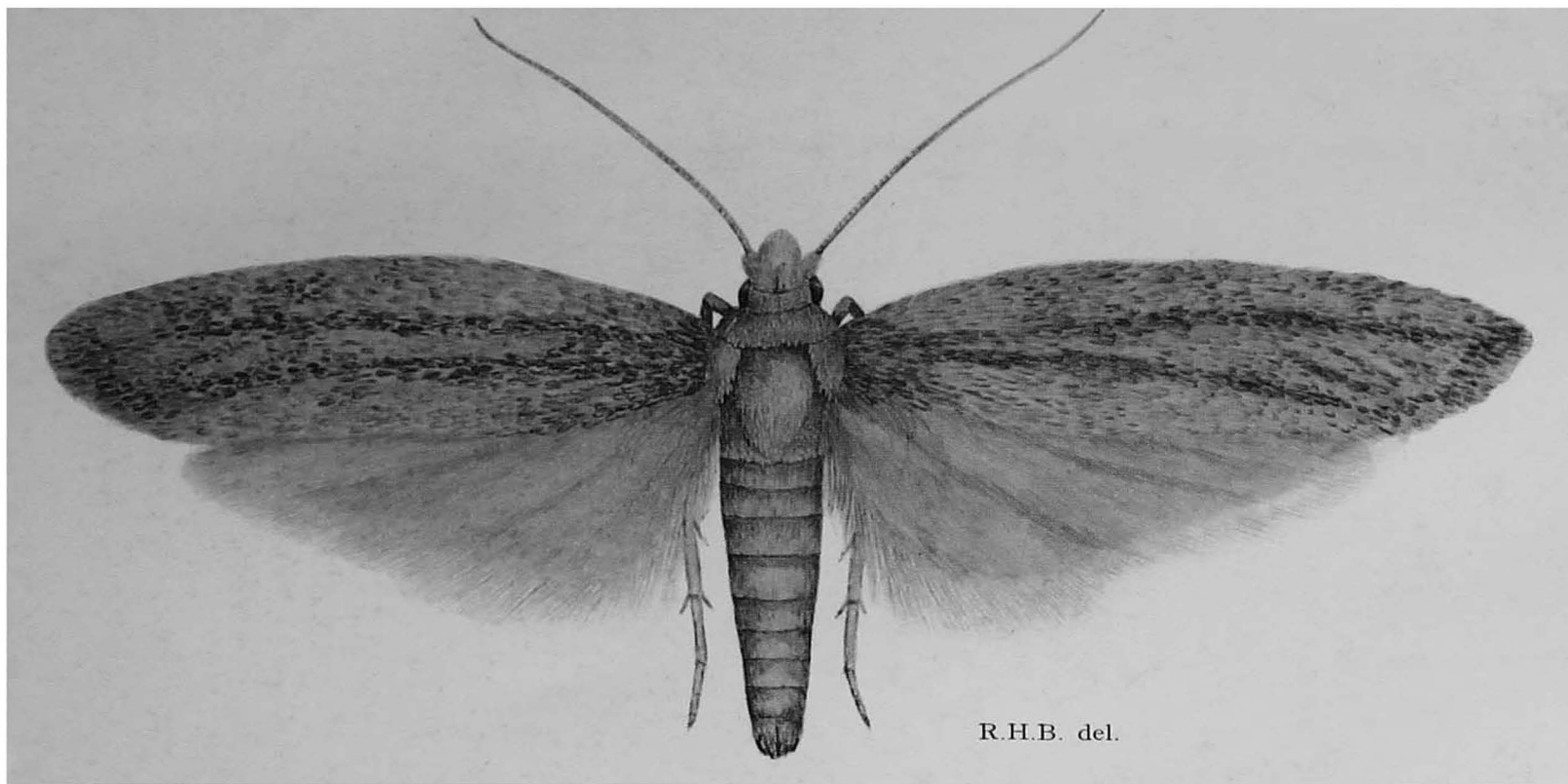


Plate II. *Corcyra cephalonica* Staint., adult. $\times 8$ (approx.)

(i) *Araecerus fasciculatus* De G.

Belonging to the family Anthribidae, this beetle is chiefly of importance in relation to cacao because of its occurrence in beans from the Gold Coast, where, it will be remembered, Patterson (*loc. cit.*) records it as causing considerable damage on the drying stages.

It is widely distributed in tropical countries, but appears to possess little resistance to cold, and very soon becomes sluggish and dies when it arrives in England during the cold weather. It survives the summer months, although on a cool day it is very much less active than usual; and if the windows of a spice warehouse are examined after a few frosty nights, numbers of the beetle will be found lying dead on the sills. It is most improbable, therefore, that *Araecerus* can maintain itself without re-importation under our conditions of climate.

The preliminary survey revealed the occurrence of *Araecerus* in African cacao and in nutmegs from Grenada and the East Indies. It is a serious primary pest of nutmegs, often causing severe damage to them; but, apart from cacao, its presence has not hitherto been detected in products stored in the warehouses under consideration. Reitter, however (34), records it as imported into Germany with exotic fruits; Bridwell (4) has found it in pods of *Pithecolobium (Samanea) saman* Benth. in Hawaii; it is recorded by Tucker (42) as attacking maize stems in America, and the same writer states that in warm countries it is omnivorous; MacGillivray (22) and Brown (5) both record its occurrence in strychnine; Frederichs (13) notes it as a minor pest of coffee; Ogilvie (30) gives records of it on papaw trees, in stored corn (probably maize), and associated with "black tip" disease of bananas; Mayné (26) has found it attacking cacao pods on the trees in Belgian Congo; and Zacher (46) records it in cacao and coffee beans, areca nuts, ginger, all kinds of drugs, dried fruit, maize, nutmegs and many kinds of seeds.

It is singular that while *Araecerus* was found abundantly in Grenada nutmegs, it occurred in only one of about a dozen consignments of Grenada cacao examined; moreover, cacao and nutmegs from Grenada are often shipped together, sometimes in the same hold of the ship. It seems from this that *Araecerus* exhibits a very distinct preference for the nutmegs. In this connection it is interesting to note that in West Africa, where nutmegs are not grown, at any rate in sufficient quantities for export, *Araecerus* is quite content with a diet of cacao.

During the survey, *Araecerus* has also been noted in an isolated consignment of cacao from Panama; and occasionally in cacao from

Ecuador, Venezuela and Ceylon. In some Samoan cacao the beans showed injury resembling that caused by *Araecerus*, but no beetles were found. Table II shows the extent of infestation of cacao by *Araecerus*, and the relatively considerable damage caused by it to cacao from the Gold Coast.

TABLE II.
Infestation by Araecerus fasciculatus De G. of Cacao from different countries.

Country.	No. of Bags examined.	Number of Bags containing traces of <i>Araecerus</i> .*
Cameroons	136	—
Ceylon	143	4 (3 doubtful)
Dominica	5	—
Gold Coast	392	205
Grenada	1,234	16
Jamaica	9	—
St. Lucia	295	—
St. Vincent	12	—
Samoa	200	5 (doubtful—one consignment)
Trinidad	292	—
Brazil	108	—
Costa Rica	94	—
Ecuador	127	3
Panama	52	52
Venezuela	182	8

* "Traces" includes larvae, pupae, adults or damaged beans.

It is quite evident from Table II that as yet the only country in which *Araecerus* has to be considered as a serious cacao pest is the Gold Coast, where a study of the beetle has recently been commenced by the Senior Entomologist at Aburi (Mr. W. H. Patterson). At the same time it is always possible, though perhaps unlikely, that in the future *Araecerus* may become important in other cacao-producing countries; for example, in Panama. All the cacao from this country which was seen, though admittedly only a small quantity, showed damage by *Araecerus*.

The damage caused by *Araecerus* larvae to cacao beans is characteristic. There is usually a large exit-hole, while inside the bean a varying proportion of the cotyledons is replaced by the frass of the larva. The frass takes the form of a rather fine dust, often yellowish

in colour, and is entirely distinct from that of *Ephestia* larvae, whose frass appears as small nodules the colour of the cacao itself, adhering to strands of webbing exuded by the larvae as they move about. The beans are often considerably hollowed out by *Araecerus* larvae, not more than one of which is generally found in a single bean. Pupation as a rule takes place within infested beans, whereas in *Ephestia* the reverse is usually the case. The survey has demonstrated that *Araecerus* is introduced into Great Britain in larval, pupal and adult stages ; whether the eggs are also introduced is not yet known.

The question arises as to the possibility of re-infestation by *Araecerus* of cacao stored in the same warehouses as nutmegs, which, as has been shown, are often seriously infested by the beetle. From present knowledge of the incidence of *Araecerus* in this country, it seems that such infestation might be possible in the summer months, but that it is extremely unlikely to occur during the winter season, because of the apparent inability of *Araecerus* to withstand low temperatures. Whether the beetle breeds at all under British conditions of climate ; whether re-infestation of cacao from nutmegs does in fact occur, and whether, if so, it is likely to be serious, has yet to be discovered.

(Note.—Reh (33) gives a description and bibliography of *Araecerus* ; the eggs are described by Swezey (41), and the larvae and pupae by Cotton (7).

(ii) *Corcyra cephalonica*, Staint.

Unlike *Araecerus*, this moth (family Galleriidae) has a comparatively wide distribution as a cacao pest. Although generally speaking it is found only in small numbers, its occurrence to a somewhat greater extent in one or two cacaos is interesting and important, because, as its English name of Rice moth implies, it probably occurred originally as a pest of rice, adapting itself later to other products.

There are very few records of its occurrence in England ; Meyrick (27) records it, however, from Kent, Middlesex and York, and states that it is an introduced species. Abroad, Zacher (46) notes its occurrence in the Mediterranean region, in India, Ceylon, Java, Western Sudan, Nyasaland, Réunion, Brazil, Cuba, Grenada, Porto Rico, Mexico, the United States, Hawaii, Germany and France ; de Seabra (12) records it from San Thomé ; Simonds (39) from Fiji ; Vayssière and Mimeur (43) from French West Africa ; and Ritchie (35) from Tanganyika.

Regarding its food, it appears to be fairly catholic in taste. Zacher (45) has taken it in large numbers from rice of various kinds, and records its occurrence in Germany in currants and other dried fruits; Meyrick (27) notes it in England in dried currants; Chittenden (6) records it in the United States in stored rice, all forms of cocoa and chocolate whether sweetened or not, ships' biscuits and sesame seeds, and is of the opinion that its habit of feeding on cacao-beans is probably an acquired one; Hutson (19 and 20) mentions its occurrence in stored rice and stored cacao-beans in Ceylon; Bedford (2) gives a record of its feeding on stored cotton-seed in the Sudan; Simmonds (39) has found it in cotton-seed, linseed, cacao-beans, chocolate and rice in Fiji; Roepke records it in husked rice and maize in Java; and Ritchie (35) states that it is attracted to bulrush millet already damaged by the moth *Sitotroga cerealella* Ol.

The incidence of *Corcyra* in cacao imported into London and inspected during the present survey is best shown by Table III, which in its arrangement is exactly comparable to Table II.

TABLE III.
Infestation by Corcyra cephalonica Staint. of Cacao from different countries.

Country.	No. of Bags examined.	No. of Bags containing traces of <i>Corcyra</i> .*
Cameroons	136	11
Ceylon	143	6
Dominica	5	1
Gold Coast	392	1
Grenada	1,234	11
Jamaica	9	—
St. Lucia	295	34
St. Vincent	12	—
Samoa	200	8
Trinidad	292	5
Brazil	108	1
Costa Rica	94	2
Ecuador	127	—
Panama	52	—
Venezuela	182	—

* "Traces" includes larvae, pupae, adults and damaged beans.

It will be seen that except in the case of St. Lucia cacao, infestation by *Corcyra* is as yet almost insignificant. That *Corcyra* is an insect potentially dangerous to cacao is, however, demonstrated by the numerous records given above, wherein it is noted as of frequent occurrence in all forms of cacao in widely distant parts of the world.

Corcyra larvae damage cacao in the same way as *Ephestia*, and the description of damage to beans, given when discussing the infestation of cacao by *Ephestia*, applies equally to this species, except that the frass-nodules of full-grown *Corcyra* larvae are larger than those of full-grown *Ephestia* larvae. The life histories of the two species are very similar, but it is not yet known whether *Corcyra* is capable of withstanding the winter in Great Britain.

The cocoons of *Corcyra* are easily distinguishable from those of *Ephestia*; they are constructed by the larvae when about to pupate, and consist of strong, thickly woven, very white silk, whereas those of *Ephestia* are smaller, thinly woven, greyish, sometimes almost transparent, and much less conspicuous. *Corcyra* larvae seem to be somewhat gregarious in their habits; cocoons are frequently found not merely in close proximity to one another, but actually matted together, so that it is a matter of some difficulty to separate individual cocoons. Indeed, Zacher (45), in describing a bad infestation of cacao-powder by *Corcyra*, states that in this instance the surface of the powder was covered so thickly with cocoons, which formed almost a solid mass, that it was extremely difficult for the moths in the underlying cocoons to emerge from them at all. In the case of the comparatively mild infestation of cacao beans noted during the present survey, it was often by no means easy to disentangle the cocoons from the sacking upon which they were spun without injuring the enclosed pupae.

In regard to the incidence of *Corcyra* in the warehouses generally, it has been found in varying, but on the whole small, numbers in Grenada nutmegs, and is distinctly one of the less common of the warehouse insects. Its larvae have not been seen crawling over bags, walls, floor, etc., in large numbers in the autumn, as in the case of *Ephestia* larvae, nor was it recorded in the winter months, except as infesting newly arrived consignments of cacao or nutmegs.

Thus with *Corcyra* there is the same problem awaiting solution as with *Avaccerus*, i.e. to determine whether it is capable of surviving the winter in this country; whether it will breed here; whether it will re-infest cacao in the warehouses; and following from this, whether its incidence in nutmegs is of material importance to cacao.

(iii) *Ephestia elutella* Hb.

The Phycitid moth, *Ephestia elutella* Hb. is by far the most important of the various insects which infest stored cacao generally, though Patterson (32) considers that *Araecerus fasciculatus* De G. is the more important in West African cacao.

Ephestia elutella is found in varying and often large, numbers at the London wharves and warehouses, in cacao from all parts of the world. No cacao is immune from its attacks, though it appears to prefer some cacaos to others.

The geographic distribution of *Ephestia elutella* is very wide ; Zacher (45) mentions the moth as occurring throughout the warmer parts of Europe and extending as far north as the southern part of Sweden ; it has established itself widely in both Canada and the United States ; and Myers (29) has recorded it from Australia. During the survey it has been noted in cacao from many tropical countries including Costa Rica, Panama, Brazil, Gold Coast, the Cameroons, Nigeria, Nyasaland, Ceylon, Java, Samoa.

It is, of course, the larvae which are responsible for the damage to cacao ; the moths themselves are incapable of taking solid nourishment. The types of food which these larvae will eat are most diverse, and it is this catholicity of taste which constitutes one of the chief reasons why *Ephestia elutella* is so important an insect economically.

Apart from cacao-beans, the larvae of *elutella* have been recorded in biscuits, figs and chocolate in England by Meyrick (27) ; in Australian currants by Myers (29) ; in ground-nuts in Nyasaland by Mason (25) ; in shelled walnuts in California by Maskew (23 and 24) ; in sugar in France by Smits (40) ; in cocoa-powder in Germany by Andres (1) and by Zacher (45 and 46) ; in earth-nuts, dried vegetables, rice, rhubarb-roots, bread, cakes, grain, pearl barley, dried apples and pears, orange-peel and all kinds of seeds and cereals in Germany by Zacher (45 and 46) ; in grain in England by Dendy and Elkington (10) ; in pea-nuts in America by de Ong (11) ; in different kinds of nuts in Canada and in linseed in British Columbia by Curran (9). Finally, Vecchi (44) avers that the larvae have been found feeding on dead but not yet desiccated individuals of the bee, *Apis ligusticus*.

Ephestia elutella is continually being introduced from abroad into the London warehouses, although it is not yet possible to state definitely that such introduction takes place throughout the year.

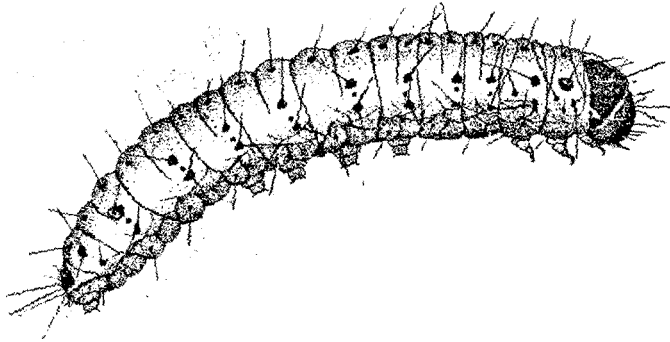
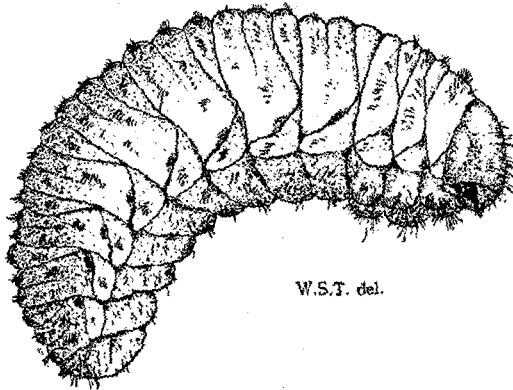


Fig. i.—*Ephestia chetella* Hb. larva. $\times 12$ (approx.)



W.S.T. del.

Fig. ii.—*Aracerus fasciculatus* de G. larva. $\times 12$ (approx.)

PLATE III.

Table IV shows the number of bags of cacao examined, which were infested by *Ephestia* in the larval and pupal state in each month.

TABLE IV.

Month.	No. of Bags examined.	No. of Bags infested by Larvae.	No. of Bags infested by Pupae.
April	48	9	7
May	434	65	37
June	506	155	114
July	570	230	212
August	258	98	67
September	289	39	159
October	175	39	36
November	28	5	4
December	240	31	46

During the period April to December, 1928, careful records were kept of the occurrence of larvae and pupae of *Ephestia elutella* in cacao arriving at the warehouses. These records show that the proportions of larvae and pupae were increasing at about the same rate, but that there was a constantly higher proportion of larvae. The larval peak was reached in July-August, after which there was a sharp drop. There was a slight drop in the pupal figure in August, followed by a high peak in September. By October, the proportion of pupae had fallen again till it was almost equal to that of larvae. From October to December the proportions fluctuated but at the same time approximated. There was thus a larval peak in July-August, followed by a pupal peak in September, which might be expected; what takes place between December and April is of course, not yet known.

The succession of larvae and pupae, however, is not quite so simple as the foregoing appears to indicate. Within the period of the survey, *Ephestia* has been found to arrive in London most commonly as full or nearly full-grown larvae and as pupae. Sometimes infested beans on being opened have contained half-grown and occasionally quite young larvae, and sometimes a few adult moths have flown out when the bags were cut open, but these instances are comparatively rare.

On the other hand, large numbers of empty cocoons and pupa-cases have often been found on opening the bags. The inference is that the moths emerged from these cocoons during the voyage, and very probably laid eggs.

Now it is usually not until a considerable period of time has elapsed after egg laying that an infestation of cacao is noticed. The eggs and newly-hatched larvae, though visible to the naked eye, are so minute that in the ordinary way their presence is never detected. Moreover, almost the first act of a newly-hatched larva is to secrete itself within a crack in a cacao-bean, from which base it proceeds to eat its way into the centre of the bean, where it generally remains until fully or nearly fully-fed, unless circumstances demand its migration to another bean. Consequently, the cacao often appears clean until frass (excrement) is seen extruding from beans or until the larvae themselves are seen round the seams of the bags or crawling over the outsides in search of suitable places for pupation.

Thus moths which have emerged during the voyage, as evidenced by the empty cocoons seen round the seams of the bags, may very easily have given rise to a further infestation (re-infestation) which in fact commenced on board ship, but which, on account of the time that elapses before such infestation becomes apparent, is often attributed to conditions in the warehouses. That moths do emerge during transit was shown on 3rd September, 1928, when an inspection of cacao was made on board a ship immediately on arrival in the Thames; on that occasion moths were noted flying above the bags of cacao in the hold.

It is apparent that primary infestation of cacao by *Ephestia* takes place abroad, and that the introduction of the moth to the London warehouses may take place by means of eggs, larvae, pupae or adults, but most obviously by means of larvae and pupae. It would appear that the first re-infestation of the cacao may take place on board ship during transit from abroad to the United Kingdom. The question of the incidence of *Ephestia* in cacao from different parts of the world now arises.

Table V shows the infestation of cacao from the various countries.

TABLE V.

Country.	No. of Bags examined.	No. of Bags showing infestation.
Cameroons	136	34
Ceylon	143	49
Dominica	5	5
Gold Coast	392	180
Grenada	1,234	298
Jamaica	9	6
Samoa	200	101
St. Lucia	295	202
St. Vincent	12	6
Trinidad	292	132
Brazil	108	9
Costa Rica	94	7
Ecuador	127	45
Panama	52	52
Venezuela	182	134

There is little information regarding variation in the duration of the life-cycle of *Ephestia* in the warehouses, but several important points have been brought to notice.

Ephestia seems capable of withstanding a considerable degree of cold. In the course of a visit paid to one of the cacao-warehouses about a fortnight after the intensely cold spell in December-January, 1927-28, a number of living *Ephestia* larvae were found hibernating between some sheets of brown paper which had been left lying on the window-sill. The larvae were fully grown and had spun cocoons, but had not pupated; they seemed quite healthy, and when brought to the warmth of the laboratory soon began to leave their cocoons and to crawl about in a lively manner. Eventually they pupated and produced moths. On the same occasion many living larvae were found on the wall of one floor, where they had taken advantage of cracks in the mortar between the bricks. These larvae were also full-grown, and were evidently hibernating.

Waste products and rubbish of all kinds quickly collect in corners and along the bottoms of walls; mingled with this refuse are nearly always some cacao beans, and the larvae of *Ephestia* have been found

feeding, not only in these beans, but also upon refuse generally. It is interesting to note that the larvae so found during February, 1928, were not yet fully-grown, nor did they appear to be definitely hibernating.

The evidence of the survey, and the long experience of the warehouse staffs, show that from about the end of June to about the middle of August, but particularly during July, the adult moths of *Ephestia* occur abundantly, often in such numbers as to become a serious nuisance. For example, at a warehouse visited frequently in July, 1928, and in succeeding months, there was stored on one floor a parcel of Guayaquil (Ecuador) cacao which arrived only the previous month. This parcel was the only one stored on that particular floor, and while the moths were common in most of the other floors, they occurred here in vast numbers. The females oviposited freely on the bags, and watch was kept on the pile. From the beginning of September and for a period of some weeks following, very large numbers of larvae emerged from the bags, crawling first to the top of the pile, which speedily became covered with a thick silken web, then down the sides to the floor, and across it to the walls, up which they climbed till they found suitable crannies for pupation, often among the rafters of the ceiling. There is little doubt that these larvae were the progeny of the swarm of moths noticed in July. If, as seems probable from finding healthy, hibernating larvae in mid-winter, these larvae from the Guayaquil cacao pupate in the spring of 1929, the resulting moths may prove the source of a definite warehouse re-infestation of cacao in the following July.

Questions have often been raised as to whether cacao which has been in store for a long time becomes seriously infected by *Ephestia*, and whether the degree of infestation increases in direct proportion to the period of storage. It is not yet possible to give satisfactory answers to these questions, because sufficient data are not at present to hand; what evidence there is, moreover, is somewhat conflicting. Judging from the evidence given in the previous paragraph, it would appear that the longer cacao remains in store, the more liable it becomes to infestation from moths which have accustomed themselves to a warehouse habitat. A special survey was carried out in October, 1928, in order to throw some light on this theory at a time when the larvae were still leaving the bags in search of suitable places for pupation; but the evidence obtained was inconclusive. In some cases 1927 cacao seemed to be more heavily infested than 1928; in

others the reverse. It must, of course, be recollected that there was variation as between cacao from different countries, but in the main it seemed to be cacao which had arrived at the warehouse between about January or February and July, 1928, that was the more heavily infested.

In considering these somewhat negative results, certain possibilities should be taken into account. It may be that after a certain time in store the moisture-content of cacao falls below that preferred by *Ephestia*, and so such cacao becomes distasteful. When selecting some cacao for experimental work on one occasion, a bag of Grenada cacao which had been in store for nearly three years was examined, and although abundant evidences of damage by *Ephestia* were present, there was no sign of life.

Further, a small wasp, *Microbracon hebetor* Say (Braconidae, Hymenoptera), which is a parasite of *Ephestia*, undoubtedly plays a large part in reducing the number of *Ephestia* larvae which are able to complete their life-cycle in the warehouses, and as Hase (17 and 18) points out, is a most useful auxiliary to mechanical control measures. *Microbracon hebetor* is referred to in greater detail later.

It is perhaps significant that the maximum infestation occurred on the whole in 1928 cacao which arrived at the warehouse up to July, while that stored after July seemed in general to be considerably less heavily infested, with exceptions in both cases however. It will be remembered that July is the month when the adult moths are most abundant in the warehouses. From the occurrence, already referred to, of the heavy larval infestation of Guayaquil cacao at another warehouse, following the July peak, it is not unreasonable to suppose that the bulk of the larvae seen during the special survey to be leaving the cacao stored from January to July, 1928, were the direct result of the July flight of moths.

Thus it may be that serious warehouse infestation is liable to occur mainly in cacao stored say from January or February to July or August in one year, while older and more fresh cacaos, the former through lack of moisture and the latter through escaping the July flight of moths, tend to remain more free from infestation.

Turning now to the habits of *Ephestia*, the most noticeable characteristic of the moths themselves is perhaps their aversion from light. Almost always they seek out the darkest parts of the floors ;

during the flight period in July, 1928, large numbers could be seen resting on the more shaded walls of the floor on which the Guayaquil cacao already referred to was stored, but very few indeed were to be found upon an adjacent window. This habit, however, is probably modified to some extent by the position of the cacao. In the case of the Guayaquil cacao, no other product was stored on the same floor, and not more than a fifth of the total space available was occupied. Only one side and the back of the pile were sheltered from light. The moths, while preferring the darker portions of the walls nearest the cacao, and the darker sides of the bags themselves, never flew far away from the pile, and took no advantage of a distant but even more shaded corner of the floor. When not resting on the bags or on the adjacent walls they hovered about in the immediate vicinity of the cacao.

The same habit of shunning light is also characteristic of the larvae. When these leave the bags to pupate or hibernate as the case may be, they immediately seek those surfaces which face away from the light; for every larva crawling over a surface exposed to light, a dozen or so may be found on a sheltered surface.

When wandering, the larvae often try to reach a comparatively high altitude. Many are not satisfied merely with the top of a pile of bags—probably, of course, owing to lack of suitable accommodation—and laboriously descend to the floor, crawling over it until some perpendicular surface is reached. At the same time, they do not appear to exhibit much consistency in regard to the height to which they finally ascend. Some are content to make their cocoons between the bags in the top two layers in a pile five or six feet high, sometimes lower; others, having reached a wall, do not climb very high should a suitable cranny present itself; others, again, climb to the ceiling, some ten feet or so above the floor, and might go higher if they could; but all agree in showing the climbing and wandering instincts. Hence in considering warehouse hygiene, no part of a floor can safely be deemed immune from intrusion. It is possible that there may be a fairly well-defined period during which the wandering and climbing instincts assert themselves, and that after this period has passed, the larvae make use of the nearest suitable cranny, irrespective of its position. If this is so, the distance to be covered by each larva would be a limiting factor in regard to the ultimate height attained, and would explain the inconsistency just referred to.

As to the feeding habits of *Ephestia* larvae, it has already been said that on hatching from the egg, the young larva's first instinct is to hide. Having once secreted itself within a crack in the husk of a cacao bean, it seems rarely to leave its shelter until fully-grown, and not always then. When an infested bean is opened, the larva is nearly always found lying in the centre, and this seems to be the normal position. The cavity made by the larva becomes filled with small excretory nodules, which are characteristic, and which are usually loosely bound together by silken webbing. The presence of these nodules extruding from the end of a bean is a sure sign that *Ephestia* has been at work, though at this stage it is unusual to find the larva in situ, except in certain cases where, contrary to usual habits, pupation takes place inside the bean. It is of common occurrence to find beans which consist only of husk, excreta and webbing, the whole of the contents having been devoured.

Length of Life Cycle of Ephestia in the Warehouses.

This is a question concerning which there is still much uncertainty. Mention has already been made of the re-infestation of cacao on board ship during transit, resulting sometimes in the introduction of comparatively young larvae into the warehouses ; of the July flight of moths followed by the appearance of wandering larvae in abnormal numbers in September and October ; of the hibernation of fully-grown larvae in the warehouses during the winter ; and of the detection, also during the winter, of younger larvae subsisting on refuse and waste cacao, and, in a few instances, in bags of cacao. Very much more evidence than this is necessary before any definite statements can be made ; it is by no means certain what effect British climatic conditions have upon larvae introduced from abroad at different times of year, save that these conditions probably retard development.

The problem is a very complicated one. From the evidence at present to hand it might be assumed that the larvae resulting from the July moths, having passed the winter in hibernation, pupate in the spring and produce large numbers of moths the following July. But enormous numbers of these larvae are destroyed before hibernation by parasites, and the numbers which survive do not seem high enough to correspond with the numbers of moths seen in July. Again, as in the case of the Guayaquil cacao referred to, many of the moths comprising the July flight are undoubtedly of very recent introduction.

Moreover, moths were observed continuously from May to October, though mostly in comparatively small numbers. Some of these are introduced, but it is possible that some are the result of warehouse infestation, perhaps indeed that of the previous July. This suggestion is put forward on the grounds that, as biological experiments now in progress show, there is a quite definite inconstancy in the rate of development of individual larvae. Some feed up much more quickly than the majority, others much more slowly. Hence some of the progeny of the July infestation may feed up quickly and emerge in October, the majority may emerge in the following May, June or July, while others may take longer still to complete the cycle.

As stated when discussing the extent to which infestation by *Ephestia* takes place at different times of the year, larvae and pupae are being continually introduced. It is not known to what extent the development of these is hindered by the cool climate of Great Britain, but it is conceivable that those introduced in the autumn and winter are retarded long enough to swell the ranks of the next July flight, while those introduced in spring and summer may form not only the greater number of the July moths but also the majority of those seen in May, June, late August and September.

Until, however, the effect of climate upon *Ephestia* has been studied further, no exact information as to the life-cycle of the moth in this country can be given. Such study, of course, will have to be pursued at the warehouses, since the conditions prevailing in them cannot be properly imitated in the laboratory. Meanwhile experiments are in progress to observe and record in detail the life-cycle of *Ephestia* at a fairly constant temperature and humidity. Even under these favourable conditions the variation in the rates of development of individual larvae is surprising, and it may be that under warehouse conditions this variation is still more pronounced. Further work on the problem just set forth is, therefore, imperative.

As stated previously, *Ephestia elutella* is liable to severe attacks by a small wasp, *Microbracon (Habrobracon) hebetor* Say (Braconidae Hymenoptera), which often destroys large numbers of the larvae. According to Hase (17)* the larvae of *Habrobracon* are either biophagous or necrophagous, and larvae which are more than half-grown

* Hase worked with *Habrobracon brevicornis* Wesm., using *Ephestia Kühniella* Zell. as his host, but it has been shown by Muesebeck (28) that "references in literature to *Bracon* or *Habrobracon brevicornis*, *hebetor* or *juglandis* as parasites of the Mediterranean Flour Moth, *Ephestia Kühniella* Zell concern this species", i.e. *Microbracon (Habrobracon) hebetor* Say.

are preferred to smaller larvae. When fully-grown, the *Microbracon* larvae spin small, oval, white cocoons, which are often seen in large numbers near the shrivelled remains of their hosts.

The adults seem to be most numerous in September and early October, when the fully grown *Ephestia* larvae have commenced wandering. Many which have not already been parasitised are then stung, but oviposition does not appear to take place, for the host larvae die almost at once. So badly, sometimes, does *Microbracon* attack *Ephestia* larvae at this time, that their dead, flaccid bodies appearing as if their backs had been broken may be seen in hundreds, adhering to bags of cacao and to the ceilings. As a further example of the destruction sometimes wrought by *Microbracon*, the case may be cited of a considerable quantity of *Ephestia* larvae which were collected at the warehouses in the early autumn of 1928, and brought to the laboratory. Almost every one of these was parasitised, and only a very few eventually pupated.

From these instances it becomes apparent that when *Microbracon* occurs in large numbers, not only are its larvae instrumental in reducing the proportion of *Ephestia* larvae which would otherwise pupate and produce moths, but its adults play an even more important part by stinging and killing fully-grown, wandering larvae. Thus *Microbracon* may sometimes be a potent factor in reducing warehouse infestation in the spring and summer following its attacks in the previous autumn.

Much work is necessary before definite statements can be made upon the life-cycle and many of the habits of *Microbracon* under British climatic conditions; moreover, the possibility of its use as a biological control against *Ephestia* in the warehouses is as yet an unexplored field of research.

Microbracon is probably parasitic on many moths belonging to the family Phycitidae; it has been recorded by Myers (29) and Parker (31), as attacking *Plodia interpunctella* Hb. and *Ephestia cautella*, Walk., both of which infest dried fruits.

Another insect which seems to attack both *Ephestia elutella* and *Corcyra cephalonica* Staint. is *Holepyris hawaiiensis* Ashm. (Bethy-
lidae, Hymenoptera), adults of which have been taken in bags of cacao which were infested by the larvae of these moths. *Holepyris*, however, is by no means common, as compared with *Microbracon*, and at present cannot be considered important, whatever it may become in the future. It is interesting to note that Bridwell (3) records *Holepyris*

as abundant in warehouses in Hawaii. The same author also records that in captivity it will oviposit in the larvae of *Plodia interpunctella* Hb. and *Corcyra cephalonica*, Staint.

IV. EXPERIMENTAL WORK IN CONNECTION WITH THE SURVEY.

Biological.

Work is now in progress upon the biology of *Ephestia elutella*, and two lines of research are being pursued ; one, a study of the structure of the adult moths, in relation to other species of the genus, concerning which there exists much confusion ; the other, a study of the life-cycle of *elutella*, both in relation to that of other species of the genus and to varying types of food. It is hoped eventually to publish the results of these investigations in the appropriate journals.

Large stocks of *Ephestia elutella* and other insects are being built up for experimental purposes, since much of the research necessary for a solution of the problems in connection with stored products insects entails experimental work bearing on sterilisation and fumigation methods, and biological experimental work in relation to temperature, humidity and food.

Since the main object of the survey was to study the incidence of *Ephestia* in cacao arriving in London, no experiments on control measures have been specially planned at this stage. The two following experiments were conducted under special circumstances and are cited merely to give an indication of the nature of control work generally.

An experiment was arranged in June, 1928, to test the efficacy of hydrocyanic acid gas (HCN) in the form known as Zyklon B, as a fumigant against *Ephestia*. At the invitation of Messrs. Weber, Smith and Hoare, Ltd., the experiment was carried out in one of their warehouses in collaboration with the London Fumigation Co. and with the Cocoa, Chocolate, Sugar, Jam and Confectionery Trades' Research Association. The scope of the experiment was limited by insufficient supplies of the various stages of *Ephestia*.

The objects of the experiment were to test penetration of the gas into bags of cacao beans when stacked in piles ; to test the effect of the gas on warehouse insects in general and on *Ephestia elutella* in particular, and to test its effect on various foodstuffs.

It was proposed at first to fumigate a ground floor, but on account of the difficulty of satisfactorily ventilating this floor afterwards, a higher and more easily ventilated floor was selected.

For purposes of fumigation, circulation of air between the floor and the outside atmosphere was prevented by pasting strong paper over all window, loop and other door joints, ventilators and cracks. The actual floor and the ceiling were of concrete, the walls of brick, and there were double doors of iron.

In regard to interior arrangements, in order to restrict the circulation of air as much as possible, the cacao was piled in a corner formed by a side-wall and a buttress to which the doors were attached. Because infestation in the cacao used was on the whole slight, and because this infestation consisted almost entirely of larvae and pupae, nine bags were specially selected and labelled. Into the centre of each bag a small cage containing living *Ephestia* moths was introduced, together with a small tube in which was a test paper soaked in a solution of benzidine acetate and copper acetate (Siefert's and Hermsdorf's Test). Five of the bags so treated were from St. Lucia, and arrived in 1928; the other four were from Grenada, and had been in store since 1925. These nine bags formed part of the inner base of the pile, being placed at and near the corner before mentioned.

To test penetration of the gas, three other bags of cacao were placed in a convenient position, and each was fitted with an aspirator, the receiving tube thereof being driven into the centre of the bag. To the outlet tube of each aspirator was attached a length of rubber tubing, which was passed through the latch-holes of the double doors, outside which was arranged apparatus for testing the amounts of gas present in the bags while fumigation was still in progress.

In addition to these arrangements one bag of cacao infested by *Ephestia* larvae was divided into two parts which were re-bagged. One part was fumigated, the other retained as a control. Both were afterwards sent to the laboratory for examination.

Immediately the fumigant had been applied the operators left the floor, the doors at once being closed and pasted up from outside. Fumigation commenced at 11.30 a.m.; tests of the penetration of the bags by the gas during the experiment were made at 5 p.m. by means of the apparatus described above, when the gas was found to have penetrated to the centres of the bags. The floor was re-opened at 8.30 p.m. the same day, after fumigation had continued for 9 hours. The concentration of gas in the warehouse was approximately 1.5% by volume.

In estimating the effect of the gas on *Ephestia*, it should be noted that it was not possible to examine every infested bean from the nine bags of cacao referred to. Accordingly about 1½ lbs. of infested beans were removed from each bag, and the number of larvae and pupae found in each of these samples was recorded. It is interesting to note, in view of the theory put forward when discussing the question of the relation between the age of cacao-beans and the degree of infestation by *Ephestia*, that examination of the samples from the four bags of Grenada cacao, which had been nearly three years in store, revealed no larvae or pupae at all. These results are embodied in Table VI, and those of absorption of the gas by various products in Table VII.

TABLE VI.

Result of Fumigation of Cacao-beans. (Based on 1½-lb. samples.)

Bag. Country.	Larvae.		Pupae.		Adults.		Percentage Kill.		
	Living	Dead	Living	Dead	Living	Dead	Larvae	Pupae	Adults
1 St. Lucia	-	59	-	2	-	-	100	100	-
2 Grenada	-	-	-	-	-	8	-	-	100
3 "	-	-	-	-	-	33	-	-	100
4 "	-	-	-	-	-	3	-	-	100
5 "	-	-	-	-	-	6	-	-	100
6 St. Lucia	-	49	-	2	-	5	100	100	100
7 "	3	49	-	3	-	5	94	100	100
8 "	-	61	-	3	-	6	100	100	100
9 "	-	34	-	4	-	8	100	100	100
10 "	-	133	-	4	-	1	100	100	100

TABLE VII.

Absorption of HCN by Cacao in comparison with other Products.

Amounts of HCN in parts per million found in materials immediately after ventilation of premises.

Cacao Beans	12	Marshmallows	6
Cacao Powder	63	Dates	5
Agar Agar	3	Brazil Nuts	13
Gelatin	2.5	Walnuts	50
Chocolates (Liqueur)	2.5	Desiccated Coconut	15
Chocolates (Assorted)	1	Fruit Jellies (Sweets)	7
Chillies	15*		

* This figure represents the amount retained a fortnight after the experiment.

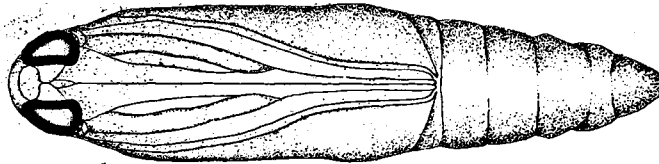


Fig. i.—*E. elutella*, pupa. $\times 12$ (approx.)

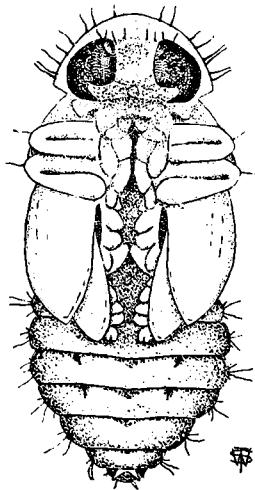


Fig. ii.—*A. fasciculatus*, pupa.
 $\times 12$ (approx.)

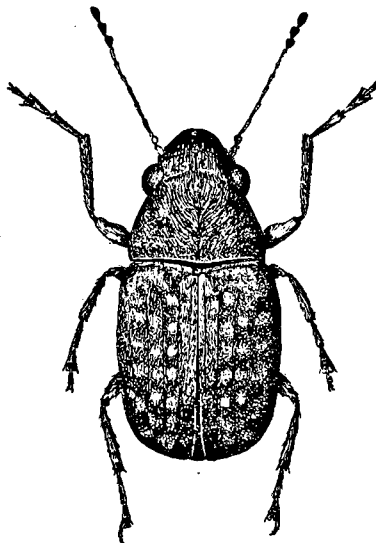


Fig. iii.—*A. fasciculatus*, adult.
 $\times 12$ (approx.)

PLATE IV.

Cacao beans, it will be noted, absorb a relatively low amount of HCN. Even if this were not so, it is probable that the use of HCN would be safe as a control measure against *Ephestia* because the roasting undergone by the beans during manufacture into cocoa or chocolate would eliminate any gas absorbed. In connection with this experiment brief mention should be made of work done in America by Griffin and Back (15) and by Griffin, Neifert, Perrine and Duckett (14), on the absorption and retention of HCN by fumigated products, as a result of which work much interesting and valuable information has been obtained.

Further experiments, designed to provide a means of dealing with sudden outbreaks of *Ephestia* in warehouses over a limited period, were carried out in September, 1928, in collaboration with the warehouse authorities. The infestation upon which these experiments were made occurred in the warehouse during June, 1928, in Guayaquil cacao referred to in this report when discussing the July flight of moths and their offspring.

While the larvae were leaving the bags in September, the warehouse staff kept one man employed almost continuously in sweeping the floor and walls, but the larvae were present in such numbers that by the time the whole wall had been swept down it was necessary to begin the operation afresh. Even so, many larvae escaped through having already reached the beams in the ceiling. Moreover, this method of reducing the numbers of the larvae could only be used through the day.

Spraying with a proprietary wash was also employed, but while destroying such larvae as it actually touched, it did not seem to possess much power as a deterrent, since walls which had recently been sprayed offered no obstacle to other larvae, which climbed them freely. Continual spraying was, therefore, necessary. It was not considered safe to spray the bags themselves in case of damage to the cacao.

Again, the warehouse staff placed numerous pans of water in suitable positions round the pile. Larvae falling into them were drowned, but it was impossible to provide sufficient pans to make any real impression on the numbers of the larvae. In this connection it is interesting to note that one pan, measuring approximately 8 inches in diameter by 4 inches in depth, and placed at the corner of a bag where a strand of webbing used by the larvae in their travels reached the floor, was after 24 hours completely filled with drowned larvae.

Experiments were then made with a form of grease-banding analogous to that used for fruit trees. At first a mixture of three parts of resin to one part of linseed oil was used. The mixture was smeared on strips of paper which were fixed round the walls in a continuous band. This mixture proved unsatisfactory, because when cold it tended to harden, and thereby allowed the larvae to negotiate it successfully.

Another attempt was made with a second preparation smeared on grease-proof paper which was pasted to the walls in a continuous band, and which was also placed round the pile of bags. In regard to adhesiveness, this preparation was successful, but its very success became a serious disadvantage, because the bands became after a time so clogged with bodies that fresh larvae were able to cross with impunity, and so to escape. This method of trapping the larvae has the merit of being relatively inexpensive, but the question of re-application has to be considered when the infestation, as in this case, is a particularly bad one.

V. SUMMARY.

The survey of insect conditions prevailing in the London wharves and warehouses shows that there is considerable infestation of the cacao on arrival.

The chief insects found infesting cacao are *Ephestia elutella* Hb., *Araecerus fasciculatus* De G. and *Corcyra cephalonica* Staint. Of these *E. elutella* is the most important.

Cacao from all exporting countries shows evidence of insect infestation, which takes place in these countries. Infested cacao arrived during each month of the period covered by the survey, and the period of maximum infestation extended from July to October.

It should be noted that the Anthribid beetle *Araecerus fasciculatus* De G., though frequently found in West African cacao, is absent from most other cacaos. It occurs abundantly in nutmegs from Grenada (B.W.I.), but Grenada cacao is apparently almost free from its attacks.

It is difficult, if not impossible, at this stage of the investigation to assess the loss caused by insect infestation of cacao. It can be said, however, that while the wharfingers and brokers are affected to a relatively slight extent, the merchants, and particularly the cocoa

and chocolate manufacturers, sometimes suffer considerably. Apart from the actual loss caused by cacao-beans being destroyed or eaten by insects, indirect loss caused by fouling of the cacao is important, and there is the serious risk of loss of prestige incurred by manufacturers who inadvertently sell chocolates or other goods harbouring insect larvae. The attitude of the Food, Drug and Insecticide Administration of the U.S. Department of Agriculture shows the attention paid to insect and fungus infestation of cacao imported into America.

Remedial and control measures to be effective must begin in the exporting country. In this country only palliative measures can be adopted pending further knowledge of the habits and life history of *Ephestia* under the peculiar climatic conditions prevailing in the London wharves and warehouses.

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INDIAN (SUNN OR SANN) HEMP

Its Production and Utilisation

MEMORANDUM

prepared by

THE IMPERIAL INSTITUTE

with the co-operation of its Advisory Committee
on Vegetable Fibres,

and issued by

THE EMPIRE MARKETING BOARD



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INDIAN (SUNN OR SANN) HEMP.

INTRODUCTORY.

THE name *hemp* was first given to a plant (*Cannabis sativa*) native to parts of Europe and Asia, belonging to the same botanical family as the common stinging nettle, and used from remote times as the source of the fibre of the same name. Grown in hot countries the hemp plant produces the well-known narcotics *bhang*, *ganja* and *hashish*, and its cultivation, like that of the opium poppy, is often prohibited, e.g., in India. The fibre, known in the trade as Italian, Russian and Hungarian hemp, is used very largely for the manufacture of cordage and textiles.

Several other fibres, suitable for similar purposes, are also termed *hemps*, e.g., Manila, Sisal and Mauritius *hemps*, and New Zealand hemp or Phormium fibre. The nearest of all, however, in its characters to the common or true hemp is the Sunn or Sann Hemp of India, called also Indian or Bombay hemp. It has been used in India as a fibre plant from very early times, and also exported, so that it is well known commercially. It is employed in Great Britain for many of the same purposes as ordinary hemp, viz., the manufacture of ropes, cables, twines and nets. Recently it has begun to be used on a larger scale as a substitute for Russian hemp (*Cannabis sativa*), which is difficult to obtain owing to the great decrease in production since the War and the consequent, increased utilisation of the smaller output by Russia itself. As was pointed out at the conclusion of the evidence given on behalf of the Imperial Institute before the Royal Commission on Agriculture in India in 1927 (see Appendix I, p. 37), the time has now arrived at which Sunn hemp may be dealt with. Much discussion of the subject took place over a century ago, when the East India Company endeavoured to introduce the fibre to British consumers but found the existing interests in this country so opposed to it as to prevent its entry into the market. Now for the first time is coming an opportunity for India to increase the consumption of the product if it really desires to do so. Sunn hemp may now perhaps secure for itself a sound position as against Russian hemp, a chance which it never had before and may never have again. Once established in the market it would be very difficult to dislodge.

The object of this publication is, in the first place, to point out that in Sunn hemp there is available for the use of manufacturers a fibre capable of taking the place of ordinary Russian hemp, the supply of which has greatly decreased during recent years.

At the same time it has to be admitted that whilst much of the hemp exported from India is of satisfactory quality, there is also a great deal which does not meet the best commercial requirements. This is due, not to any natural defect in the fibre itself, but to the careless conditions under which it is prepared and marketed. Careful consideration has therefore been given to indicating how the general standard of the Indian output might be raised with benefit both to the manufacturer who naturally demands a reliable supply of standard quality, and to the grower who would obtain a better price for his product.

Recent work has shown that first class Sunn hemp can be produced in other countries. Full particulars are accordingly given of the best known methods of cultivation and manufacture in the hope that, should India be unable to meet fully the requirements of the trade, the export of supplies of good quality may be encouraged in other parts of the Empire. It is important to note that the Sunn hemp plant can be used for the dual purpose of renovating the soil and smothering weeds, and at the same time of yielding a cash crop. This should greatly enhance its value to the tropical cultivator who must take measures to maintain the fertility of his soil to prevent a falling off in the production of his staple crop, but often finds it difficult to put land for a lengthy period under a crop, which, although of direct benefit, entails some outlay and yields no immediate financial return.

THE PLANT.

The plant which produces this useful fibre is a member of the Pea and Bean family (*Leguminosae*), known botanically as *Crotalaria juncea*, which occurs wild, or apparently so, in various parts of India,* and is also grown as a cover crop or green manure in many tropical countries.

* Dr. Clouston (Agricultural Adviser to the Government of India) in a letter (September, 1929) says : " I collected seeds of the wild type in the Central Provinces many years ago and tested it in a varietal series of experiments, in which I had also other leguminous crops under trial as green manures. It gave a much smaller yield of green manure than the cultivated variety."

Sunn hemp is a stiff, shrubby annual, usually about 4 to 7 feet high, with rather narrow leaves 2 to 3 inches long. When in flower it is quite decorative, bearing fairly large bright yellow flowers, in upright sprays of about one foot in length. These are succeeded by tough-skinned pods each containing numerous small seeds.

Like so many other leguminous plants it is able to utilise directly the nitrogen of the atmosphere, and being also a plant of very rapid growth, capable when sown thickly of smothering many tropical weeds, it is of value as a cover crop and as a soil renovator. For these reasons Sunn hemp is often grown in India as a rotation crop immediately before such crops as sugar-cane, tobacco, potato, jute, etc., and also on lands newly brought under cultivation, as it will thrive even though the tilth is not good. When sown in fields reclaimed from *kans* grass (*Saccharum spontaneum*), a persistent weed which has overrun many thousands of acres in India, it grows luxuriantly and helps to smother any *kans* plants left. In other parts of the tropics it is already used as a cover and green manure crop on sugar, rubber, cotton and other estates, and it should prove one of the best crops for cleaning and preparing land for arable cultivation or permanent crops. Usually in such cases the whole plant is cut down and ploughed in as a manure and is not utilised for the preparation of fibre. Comparatively recent investigations in India indicate that it may well be practicable to attain both objects at the same time.

The Agricultural Adviser to the Government of India* states that the Sunn hemp plant "plays an important part in the economics of Indian agriculture as it is also largely used as a green manure. The extension of its cultivation is therefore important, supplying as it does both a cheap but valuable organic manure and a marketable fibre. It is thus a dual-purpose crop. The hemp fibre exported for the year under review fetched Rs. 83 lakhs (£622,500). At present Sunn hemp is grown either for fibre or for conversion into manure; experiments at Pusa have, however, conclusively shown that the same crop can be used economically for both the tops as a manure and the stems for fibre". (See also under "Time of Harvesting", p. 9.)

As a green manure crop the plant has in India proved to be one of the very best. It is hardy and grows rapidly so that if sown in June it can be ploughed under in early September, by which time it should

* *Review of Agricultural Operations in India, 1926-27, p. 34.*

yield 10 to 12 tons of green dressing per acre. The land thus manured is ready for another crop in the beginning of November. Few plants lend themselves so effectively to double cropping as Sunn hemp.

Even when grown for fibre a large quantity of green material is added to the soil. If cut when seeding most of the leaves are left on the field. They begin to drop off early in the seeding stage of the plant and the layer of leaves on the ground forms a valuable organic manure for the next crop, as analyses have shown that most of the nitrogen of the plant is stored in the leaves. It has been proved by experiment that the quality of the fibre does not suffer to any appreciable extent when the harvesting of the stalks for fibre is thus delayed until the seeding stage of the plant.

Should there be any likelihood of stock having access to fields of Sunn, it is desirable to point out that the stems and foliage are not poisonous or otherwise likely to cause injury if eaten. The plant is, as a matter of fact, often described as a fodder for cattle, etc. Dr. Clouston states (in correspondence) that in India "it is not as a rule fed to stock. Cattle eat it when hungry but do not relish it, owing to the leaf having a bitter taste. Buffaloes eat it, but not with any great relish".

It has been stated by a Rhodesian planter that "cattle seem extremely fond of the dried leaves which cover the ground, after removing the crop for seed; they stay contentedly on it for hours, greedily eating the leaves". This observation was confirmed at the Experiment Station, Salisbury, the Agriculturist reporting "both cattle and sheep greedily ate the dried leaves off the ground".* From the Gwebi Farm, also in Rhodesia, it is reported that two sheep showed no ill effects when green Sunn was included in their fodder over a period of sixteen weeks.† The seeds might, however, be injurious.

CULTIVATION.

Choice of Locality.—With most crops grown for financial profit, various factors other than the requirements of the plants themselves play their part in determining the most suitable localities. Cost of transport from the place of production, availability and price

* J. A. T. Walters, "Deccan Hemp and Sunn Hemp." *Rhodesia Agricultural Journal*, XVII, 1920, 522-528.

† S. D. Timson, "Sunn Hemp," *Rhodesia Agricultural Journal*, XXVI, 1929, 668-682.

of labour, are always important and need not be further dwelt on. In the case of a fibre plant such as Sunn it has to be carefully borne in mind that, after the crop has been grown, it has to be retted to obtain the fibre which is the marketable product.

For this, water is essential and the presence, or absence, of sufficient water at the right season thus becomes a determining factor. The position is well put by the Director of the Institute of Plant Industry, Indore, who in discussing the question why so little increase in the production of Sunn hemp has taken place in India during recent years, says* :—

“ The answer becomes apparent when the root system of the plant is examined. Sunn hemp only thrives on permeable, well aerated soils ; water logging is harmful for fibre purposes and still more so for seed production. These requirements have helped to drive the cultivation away from the deltas towards the higher and better drained parts of the country. This is satisfactory so far as growth is concerned, but a difficulty at once arises in retting. In the drier parts which suit the crop, there is apt to be a shortage of water in the autumn for retting. This circumstance has naturally limited production and, in all probability, accounts for its stationary condition in spite of the excellence of the fibre”.

With these general considerations in mind, and also the fact that the production of Sunn hemp in India is essentially a peasant industry, we can turn to the actual agricultural operations.

Soil.—Sunn hemp will grow on almost any kind of soil ; on heavy clays and low-lying damp soils it may make vigorous growth, but gives a poor yield of coarse fibre. For fibre production a fairly light, well drained soil should be chosen.

Sowing.—The plant is grown from seed which germinates very rapidly. The amount of seed required per acre varies greatly with the mode of sowing. In any case it is important that the plants be closely spaced, in order to ensure upright single stems without much production of side branches. It is stated† that when sown broadcast about 40 lb. per acre is necessary.

* A. Howard, “ *Crop Production in India* ” (1924), pp. 140-141.

† Mukerji, *Handbook of Indian Agriculture*.

A Deccan method of double drilling, the first lengthwise and the second across the field, to ensure an even stand, takes about 70 lb. per acre.* Probably about 60 lb. per acre may be regarded as the usual quantity employed.

As a general practice the establishment of plants evenly spaced at about 3 to 4 inches apart should be aimed at. For this a soil with a good surface tilth is essential, and with moderately light soils this can usually be obtained by two ploughings followed by such harrowing as may be needed.

Beyond that necessary to prepare the land for sowing very little cultivation is required. Sunn sown thickly, as is essential in growing it as a fibre plant, is itself effective as a cover crop for smothering weeds and is so used in many parts of the tropics. The all-important point is thus to prepare the land thoroughly at first to ensure a uniformly close stand and rapid growth. (See Figs. 1 and 2).

In India, Sunn is most commonly sown about the beginning of the rains, i.e., April to June. It can also be sown in September to October. In either case it is ready to reap in about four to five months. (See Fig. 3).

Diseases and Pests.—The plant is apparently usually free from serious diseases and pests. The caterpillars of some moths may at times do a good deal of harm by eating the foliage. In Trinidad, where the plant has comparatively recently come into use on a considerable scale as a cover and green manuring crop on sugar-cane lands, very little good seed is obtained in the wet season owing to the caterpillar of a moth (*Utetheisa ornatrix*) which attacks the young seed in the pod, but does no harm to the foliage. In the dry season this difficulty is not experienced.

A Lygaeid bug has been reported as causing similar trouble in Nyasaland.

A few fungoid diseases, e.g., wilt and anthracnose, have also been noticed in various places, but the plant is usually reported as being free from serious trouble of this nature.

* G. Watt, *Dictionary of Economic Products of India*.



FIGURE 1.

Sunn Hemp. Grown for Fibre. Seed Rate, 40 lb. per acre. Sown June 12th, 1929.
Photographed August 13th. Height 6 ft.



FIGURE 2.

Sunn Hemp. Grown for Fibre. Seed Rate, very heavy, 120 lb. per acre.
Photographed August 13th. Height 5 ft.

Sown June 12th, 1929.

PREPARATION OF THE FIBRE.

Having reached the stage for harvesting, the plants are cut down or pulled up, dried, retted, and the fibre then separated.

Time of Harvesting.—There is considerable diversity in opinion, and accordingly in practice, as to the best time to harvest Sunn hemp, whether when in flower, in seed, or after the seed has ripened.

Some experiments were carried out by the Indian Imperial Department of Agriculture at Pusa, and the results reported on by a firm of fibre merchants in London. The best fibre in this series was produced by plants which had been harvested when the fruits were fairly mature. In the report it is stated that "there is not a very great difference between the strength and quality of the fibre retted at flowering as compared with the plant retted when fairly mature (i.e., the seeds ripe), but we estimate that the latter process is one which should be encouraged as it would permit the gathering of the seed as well as securing the fibre, and as judging by these tests this can be done without any great detriment to the value of the fibre, it should be more profitable than to ret after flowering and before the seed has been gathered". If it is necessary to prepare the land quickly for a following crop and at the same time to use Sunn hemp both for its value as a green manure and as a source of fibre, the results of experimental work in India already referred to (p. 5) should be borne in mind. In this case the leafy tops of the plants are cut off and together with the roots ploughed in as manure, the stems being retted for fibre. "Though this necessitates the cutting of the crop three weeks earlier than is ordinarily done when fibre alone is in view, neither the quantity nor the strength of fibre is affected thereby".*

Method of Harvesting.—The actual harvesting is simple. The standing plants are pulled or cut close to the ground, and allowed to remain on the ground for two or three days to lose their green colour and for the leaves to fall. The leaves left on the ground are of considerable manurial value. If the seeds have matured before harvesting the plants and are required, the pods should be stripped off or the seeds threshed out by beating piles of the harvested plants with sticks.

* *Agricultural Operations in India, 1926-27, p. 34.*

Retting.—The stems have next to be retted preliminary to separating the fibre (see Fig. 4). At this point there is a good deal of variation in practice dependent on the available supply of water. "In some localities the stems are buried in mud, while in others they are submerged in water and weighted down like jute. Running water or stagnant water is used according to availability. In dry regions the stems are tied in bundles and left in the fields until they are quite dry. By postponing the time of retting until the hot weather, a much shorter period of immersion in water is found to be sufficient."* Such storage is, however, not practicable in wet districts, as the fibre deteriorates and also the peasant cannot afford to postpone the time of getting the monetary return from his crop. Usually four days to a week is sufficiently long for the stems to remain in the water. Experience is necessary to determine the actual period, which depends on whether the water is stagnant or running, its temperature, etc. *It is important to avoid oversteeping, which weakens the fibre.* When the stems have softened they are removed bundle by bundle, pounded with stones, then resoaked, and so on until the fibre strips off easily. (See Fig. 5).

In a paper published in "The Agricultural Journal of India," Vol. III (1908), p. 2, Dr. Clouston gives the following details of the usual practice in the Central Provinces and Berar :—

"In retting, the bark is partially removed by drawing a handful of the stalks between the thumb and first finger. The stems are then stripped one by one. The retter, having broken the lower end of the stalk so as to get a free end of the fibre, grasps this end of the stalk with his left hand and removes the fibre in strips by running up the thumb and first finger of the right hand between it and the stalk. The cost of retting is considerable. Day labourers on the Experimental Farms produce about 4 lb. of fibre per day only. Cultivators commonly pay one pice per bundle for retting. If a suitable machine could be secured, which would extract the fibre at cheap rates, a great impetus would be given to the cultivation of Sunn."

As pointed out in Appendix I (para. 4) over-retting results in a fibre so weak that it will not withstand scutching, 25 to 40 per cent. of "stick" being in consequence retained in the fibre, baled up and

* Note on Hemp Cultivation in India, by the Agricultural Adviser to the Government of India, *Indian Trade Journal*, July 31, 1924, Supplement.

exported. Retting in mud or muddy water, as in some districts, results in so much dust and dirt in the product that factory workers in some countries decline to spin it. Such dustiness is most marked in the grades known to the trade as "Philibit" (see p. 14) and, owing to lack of facilities for washing the hemp in the producing districts, is difficult to remedy other than by hackling or combing the fibre before export.

Washing and Drying.—The separated hanks of fibre are finally washed if possible and hung up in the sun or laid on the ground to dry, for which in fine weather two or three days are sufficient.

Hackling or Combing.—Most of the fibre is exported in a raw state but part is subjected to a hand hackling or combing process in order to free it from dirt and separate the short fibre or tow. Hackling is already done on a fairly extensive scale at Bombay and Calcutta and the industry has received an impetus from the improved prices obtained for combed hemp.

The results of this combing are :—

- (a) The fibre is freed from dust and short fibre.
- (b) The short ends of the hemp are combed out, and are known as tow. This article is mostly used for twine, but can also be employed for caulking ships' decks.
- (c) Tonnage space is saved to the extent of the dust and stick removed.
- (d) The tow obtained in the process is readily saleable at something under the price of raw hemp whilst the dressed fibre fetches a considerable premium.

Baling.—The cleaned fibre is finally baled for export. (See Fig. 6). In India the making up of the bale and the pressure to which it is subjected vary greatly, and it is very desirable that the best method should be generally followed, to secure uniformity and a product put up in the condition most convenient for the user.

It is recommended that the fibre in the bales should be put up in bundles, about 4 or 5 inches in diameter and tied about 6 inches from the butt end. At present the fibre is commonly made into small plaits with both ends tied. This is an objectionable practice,

as much labour and wastage is entailed in undoing the plait before the fibre can be used by the spinners. The bales (about 3 cwt.) are usually compressed up to about 50 cubic feet to the ton.

Yield.—The yield of fibre is stated to range from 200 to 1,200 lb. per acre. About 500 to 800 lb. (or 5 to 7 cwt.) may be expected as a fair average under good conditions and to be obtainable from 3 to 5 tons of dry stems which yield about 8 per cent. of their weight as fibre.

CHARACTERS OF THE FIBRE.

Some grades of Sunn hemp resemble ordinary or Russian hemp in appearance, but are not quite so strong. The fibre of commerce consists of narrow ribbon-like strands about 4 to 5 feet long. The fibre is only slightly lignified or woody. The ultimate fibres are approximately 0·2 to 0·4 inch long and have an average diameter of 0·0012 inch. They do not taper to a point but the ends are thickened and rounded.*

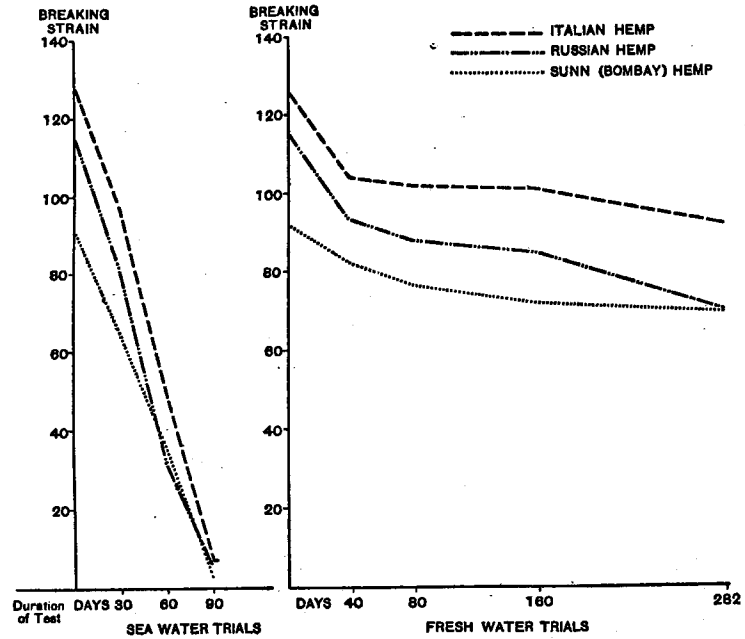
Experiments which yielded interesting results were recently made by the Imperial Institute to test the resistance to water of Bombay or Sunn hemp in comparison with Italian and Russian hems (two varieties of ordinary or true hemp). The details of the experiments (which were carried out with twines) are given in the attached report (Appendix II, p. 38).

A graphic representation of the results is shown in the accompanying diagram.

It will be seen that the Sunn or Bombay hemp twine was originally weaker than either the Italian or the Russian hemp twine. Under the conditions of the test all three deteriorated so much in strength after three months' alternate wetting with sea water and drying as to be practically worthless. In the fresh water trials the deterioration was much less rapid; the Sunn hemp actually suffered less loss of strength than the Italian or Russian and can be looked on as of equal value to either of these for use under such conditions.

* E. Goulding, *Cotton and other Vegetable Fibres*, pp. 123-124.

13



EXPORTS AND GRADES.

The principal areas of India in which Sunn hemp is produced are Madras, the United Provinces, Bombay and Sind, and the Central Provinces and Berar.

The following account of the various grades exported is taken from Dr. Clouston's *Note on Indian Hemp*.*

Calcutta.—The Sunn hemp exported from Calcutta is classed in the trade under three grades, viz. :—(1) Benares Sunn, (2) Green or Raigarh hemp, and (3) Bengal Sunn. It is estimated that in normal times about 100,000 bales (350 lb. each) of all grades are exported annually from Calcutta, the approximate quantities of each grade exported being as specified below :—

- (1) Benares Sunn.—Normal exports about 85 per cent. or 85,000 bales ; obtained from Benares and certain other districts in the United Provinces.
- (2) Green or Raigarh hemp.—Normal exports about 10 per cent. or 10,000 bales ; obtained from Raigarh and the Central Provinces generally.
- (3) Bengal Sunn.—Normal exports about 5 per cent. or 5,000 bales ; obtained from certain districts in Bengal.

The bulk of the export trade is handled between October and May.

The standard qualities of each grade as exported from Calcutta are as follows :—

- Benares Sunn, Nos. 1, 2, 3.
- Green hemp, Nos. 1, 2, 3 and tow.
- Bengal Sunn, Nos. 1, 2, 3, 4.

Bombay.—About 80,000 full pressed bales of 3½ cwt. each are exported annually. The following descriptions are exported :—

- Philibit.
- Central Provinces and Raigarh.
- Dewghuddy (Devgad).
- Gulburga and Warangal.
- Khandeish.
- Godra.

* *Indian Trade Journal*, May 30, 1919, Supplement.

They are classified under the following grades :—

Philibit .. .. .	..	Fine. No. 1. No. 2.
Central Provinces	..	Fine Itarsi. Fine Sewnee. Extra fine Jubblepore. Fine Jubblepore. No. 1 " No. 2 "
Dewghuddy .. ..	..	Extra fine. Fine. No. 1. No. 2. Salsi P.L.
Gulburga.. .. .	..	Fine. No. 1. No. 2.

Grades Nos. 1 and 2 of Jubblepore, Dewghuddy and Gulburga are rarely exported.

Madras.—The following varieties or descriptions of hemp are exported in small quantities from the Madras coast :—

Upper Godavery from Sirivansa and Dumugudem Districts.		
Gopalpore	..	Gopalpore
Warangal	..	Warangal.
Cocanada	..	Districts South of the Lower Godavery.
Singarem	..	Rajahmundry.
Palinara	..	Narsapur.

Upper Godavery varieties are usually packed separately ; the hemp from Sirivansa District being both longer and of lighter colour than that from Dumugudem. Dumugudem hemp is a good variety but usually short. Gopalpore in cleaning usually gives :—

White .. .. .	..	75 per cent.
Brown .. .. .	..	15 per cent.
Shorts or tow .. ..	..	10 per cent.

under which descriptive marks the hemp is usually packed.

Warangal, Cocanada, Singarem and Palinara varieties are not assorted in cleaning, the colour being very uniform, but the tows and shorts are packed and shipped separately.

The following table gives a list of the principal commercial grades of Sunn hemp and indicates their values per ton (October, 1929) in comparison with those of true hemp.

Sunn or Indian hemp.

Benares Sunn :—

No. 1 .. ..	..	£25 to	£27 c.i.f. Antwerp.
No. 2 .. ..	..	£17 ..	£24 .. "
Bengal Sunn No. 2	..	£35 ..	£37 .. "
Prime dressed hemp	..	£40 ..	£50 .. "
Prime Jubblepore tow		£28 ..	£31 .. "

Bombay hemp :—

Fine Dewghuddy	..	£34 ..	£36 .. "
Fine Itarsi ..	..	£31 ..	£33 .. "
Fine Sewnee ..	..	£28 ..	£30 .. "
Fine Jubblepore	..	£27 ..	£29 .. "
Fine Philibit ..	..	£22 ..	£24 .. "

True Hemp.

Italian hemp £53 to £68 c.i.f. United Kingdom.

Russian hemp :—

Rein hemp .. ..	..	£57 ..	£64 .. "
Siretz .. ..	..	£38 ..	£50 .. "
Tow .. ..	..	£30 ..	£40 .. "

Hungarian and Yugoslavian hemp :—

Hackled hemp ..	..	£65 ..	£70 .. "
Scutched hemp ..	..	£47 ..	£52 .. "
Tow .. ..	..	£30 ..	£45 .. "

The following table gives the official returns of the exports of raw hemp (chiefly Sunn) from India during recent years :—

	1923-24.	1924-25.	1925-26.	1926-27.	1927-28.	1928-29.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom ..	5,280	7,900	5,188	3,485	3,859	3,108
*Other Countries ..	64	35	42	37	23	(a)
Total, British Empire ..	5,344	7,935	5,230	3,522	3,882	(a)
Belgium	9,644	14,757	15,094	13,299	12,407	14,851
Germany	1,669	4,265	3,752	1,691	2,504	2,734
Italy	2,021	1,857	1,207	303	1,423	3,261
France	2,365	2,737	2,128	904	876	1,226
United States of America	551	576	2,728	855	1,488	776
†Other Countries ..	1,348	1,309	1,058	1,418	1,628	(a)
Total, Foreign Countries	17,598	25,501	25,967	18,470	20,326	(a)
Total	22,942	33,436	31,197	21,992	24,208	28,055

(a) Figures not available.

* Mainly Ceylon and Aden.

† Mainly Greece, Denmark, Sweden, Egypt, Arabia, Netherlands, Spain, Portugal.

CONCLUSION.

It will be seen that most of the grades of Sunn hemp command at present lower, and in some cases much lower, prices than Italian, Russian and Hungarian hems. This is due to faults which could in large measure be corrected, and not to the fibre being intrinsically so much inferior to true hemp as the difference in price might suggest. The prices of the various grades of Sunn hemp coming from different districts vary greatly, e.g., No. 2 Benares at £17 to £24, compared with No. 2 Bengal at £35 to £37. It was shown several years ago at the Sibpur Botanic Gardens that when seed of Sunn hemp from the various districts was obtained, the plants grown under identical conditions at Calcutta, and the produce prepared by a man from a district which turned out good fibre, there was no material difference in the value of the hemp produced in the opinion of a commercial expert in England to whom the samples were

submitted. The faults common to many of the grades of Sunn hemp are :—(a) Irregularity in quality due to difference in growth conditions and cultural care, variation in retting, scutching, etc. ; (b) admixture of dust and dirt due to retting in mud or even deliberate addition of such impurities ; (c) unreliability of packing, i.e., admixture of various grades, faulty baling, etc. The attention of the Indian authorities has been directed on various occasions to these defects, and considerable effort has been made to remedy them through the Agricultural Departments. Improvement in Indian methods is however slow, largely owing to the fact that Sunn hemp is a peasants' crop against which there is a certain amount of caste prejudice. Its cultivation is relegated mainly to the lower castes, and to the smaller cultivators of these castes. The grower cannot afford to build tanks or vats in which to steep his bundles of Sunn stalks ; the steeping is therefore done in the nearest pool, often a dirty muddy pool in which the village buffaloes wallow. Such fibre when retted is muddy and discoloured and brings a poor price. The existing market arrangements, too, leave much to be desired ; the small middlemen who purchase the fibre do not give an adequate premium for quality. The cost of labour involved in preparing the fibre is considerable, and the price of labour has almost doubled in India during the last twenty years. The result is that Sunn hemp yields a smaller net profit than many other crops which do well under similar soil and climatic conditions. There is, however, the renovating effect on the fertility of the soil, but this is usually not fully recognised by the grower who looks only to the immediate economic return.

The Agricultural Adviser to the Government of India has recently suggested that the new Jute Committee should deal also with other Indian fibres, including Sunn hemp. Should this suggestion be accepted the Committee will be in a position to stimulate research on this crop and to improve the conditions under which the fibre is prepared and marketed. It is very necessary that such improvements should be made, as there is an increasing demand for a fibre to take the place of the diminishing supplies of Russian hemp, and good quality Sunn hemp can supply this want. It has been proved that entirely satisfactory "Indian hemp," i.e., from the Sunn hemp plant, can be produced in India and also in tropical Africa, e.g., Nyasaland, and doubtless could also be grown in other parts of the tropical Empire. As already emphasised the plant is particularly suitable for growing as a rotation with cotton, sugar-cane, maize,

and other tropical and sub-tropical crops. It is admirably suited for smothering weeds either on new land or land already under cultivation. It is hardy, free from serious pests, requires no weeding or irrigation, and seeds freely. Sunn hemp is one of the few plants available to the tropical planter for use as a really valuable green manure and smother crop which will yield him a cash crop as well, often an important desideratum in tropical agriculture.

There is thus an opportunity for India to set its house in order and produce, from all or most of the hemp-growing districts, a fibre up to the commercial standard at present reached by but few. On the other hand, other parts of the Empire may find, after due consideration and preliminary experimental work, that in Sunn there is a plant which can be used as the source of an addition to their list of exports and the basis for the establishment of a new and profitable industry. Seed could be obtained from any of the following :—

The Director of Agriculture, Poona, Bombay Presidency.

The Director of Agriculture, Nagpur, Central Provinces.

The Director of Agriculture, Lucknow, United Provinces.

The Secretary, Imperial Council for Agricultural Research,
Delhi.

Mr. A. L. Godden, Agent for the Sale of Government seed,
Narainganj, Dacca.

From the manufacturer's point of view there is already available in the better grades of Sunn hemp a fibre which can take the place of the diminishing supply of Russian hemp. It is hoped that this publication may be of assistance in leading to an increasing production of this Empire fibre and to its more extended utilisation.

APPENDIX I.

Mr. Alfred Wigglesworth, of Messrs. Wigglesworth & Co., Ltd.; Lt.-Col. Sir David Prain, C.M.G., C.I.E., F.R.S., Chairman of the Advisory Council for Plant and Animal Products at the Imperial Institute; Capt. S. E. J. Brady, M.B.E., Board of Trade; Mr. E. J. W. Buckpitt, J.P., representing the Rope, Twine and Net Manufacturers' Association; Mr. H. A. F. Lindsay, C.I.E., C.B.E., Indian Trade Commissioner; Dr. Goulding, Secretary; representatives of the Advisory Committee on Vegetable Fibres, Imperial Institute.

MEMORANDUM ON THE PACKING AND GRADING OF EAST INDIAN HEMPS.

(1) East Indian hemp has recently begun to be used on a larger scale as a substitute for Russian hemp (*Cannabis sativa*), which is difficult to obtain, owing to the great reduction in production since the War and the consequent increase in the consumption of the smaller output by Russia herself.

(2) A prejudice has always existed that the wear of Indian hemp exposed to water is less satisfactory than Russian. Recent tests at the Imperial Institute tend to dissipate this prejudice, and these are being carried further.

(3) The consumption of Indian hems is limited by :—

- (a) the great irregularity of quality;
- (b) excess of dust and dirt in the fibre; and
- (c) the unreliability of the packing.

(4) As regards (a), this is due to differing conditions in the cultivation in different Provinces; some growing the crop in the cold weather season and others in hot weather; some retting the material in water under satisfactory conditions—others, such as in the Benares area, over-retting the material and making the fibre so weak that it will not stand the scutching, resulting in about 25 to 40 per cent. of stick being retained in the fibre and baled up and shipped to Europe.

(b) Some districts, such as Philibit and Chandausi, ret the fibre in mud, and even put mud into the dried fibre after retting, resulting in so much dust and dirt in the material that the factory workers in many countries decline to spin it.

(c) Relates to unreliability of packing, the grades shipped not always representing what is sold, and fibre of various districts being mixed in the same bale.

(5) It is of paramount importance that hemp should be shipped under the name of the Province or district by which it is currently known in the trade, and that no substitution of inferior grades or mixing should be permitted.

The following are the customary trade designations and they indicate fairly accurately the provinces or districts from which the hemp is drawn :—

Dewghuddy (Devgad).	Bengal.
Itarsi.	Coconada.
Sewnee (Seoni).	Gopalpore.
Jubblepore.	Warangal.
Philibit.	Godavery.
Benares.	Palinara.

(6) Since the dressing or hackling of hems (a process of purifying by passing through pins and extracting the tow and some of the dust) has been adopted, a fairly steady and growing demand has set in, and in this form the material makes a better substitute for Russian hemp than in the raw state. It has been stated, however, that the material is not baled in a satisfactory way. In some cases the heads of the material are much too small—scarcely more than an inch in diameter, in place of four or five—and instead of being tied about 6 inches from the butt end they are turned into a plait and both ends tied together, thus entailing considerable labour and wastage in undoing this plait before the fibre can be used by the spinners. Furthermore, the material is put into a powerful hydraulic cotton press and is baled to about 50 cubic feet to the ton, thus flattening the fibre to such an extent that when it comes from the bales it has lost its loose and spinnable character and is flattened beyond recognition. To obviate this, it is suggested that the practice of other producing countries should be adopted, and that such material should be baled more loosely. In order to ascertain the best cubic capacity an experiment would have to be made to ascertain whether 60, 70 or 80 cubic feet to the ton would be most suitable so as to permit the material to come from the bales in a way which would satisfy the consumers. It is admitted that the freight would be higher, but this should be more than counterbalanced by the enhanced value of the fibre.

(7) Some years ago, Sir David Prain—when he was Director of the Sibpur Gardens, Calcutta—instituted an experiment in sowing under identical conditions seeds obtained from the various *sunni*-growing districts of India, with the result that the produce was almost identical and not more than £1 or £2 per ton difference in value could be ascertained. This is to be contrasted with the wide differences in quality to-day, which range from £16 for No. 3 Benares—which probably contains approximately 35 per cent. of stick and dirt—to £35 for Fine Dewghuddy. A still further improvement in value is obtainable as the result of dressing and hackling the raw material in India, such material realising a price of £40-45 for prime dressed.

(8) A recent visit to His Majesty's Naval Dockyard at Chatham enabled the Committee to ascertain the requirements of the Navy in regard to Indian hems, and they were able on the spot to verify the defects alluded to in the above report. It is considered that no obstacle stands in the way of a remedy of these defects, and it is thought that the improvements could best be effected within the trade itself, without necessitating direct action on the part of the Government. In connection with possible action by Government, reference is invited to the Committee's letter of May 9 addressed to the Secretaries of the Royal Commission.*

(9) It is realised that the Agricultural Departments throughout India might assist considerably in improving the preparation and growth of hemp by disseminating accurate information on the cultivation, quality of seed, time of sowing, pulling of the hemp at the correct moment so as to obtain the best results, drying the hemp in the sun before immersing in the retting pits, carefully instructing the growers as to the correct period of retting so as to get the best results, and general instructions for preparing the material for the market. The practice obtaining in Italy on these and other points is a model which might well be investigated in the interest of Indian cultivators.

* See Appendix.

(10) A leaflet recently issued by a Department of Agriculture in India on the subject of the cultivation of *sunm*, conveyed instructions which would not be helpful to the production of good fibre, but it is understood that these instructions were intended to apply to the cultivation of the crop for seed purposes. It is important that no misunderstanding should arise and that instructions which may be issued for the cultivation of *sunm* should clearly indicate the best means of producing a good fibre.

(11) With regard to marketing, we are of opinion that the existing system of marketing *sunm* in India might be considerably improved at origin. The small dealers who collect up-country are undoubtedly responsible for prices paid for superior material being low in comparison with those paid for the inferior. In Bombay, better control might be exercised in the selection, so as to keep separate the fibres from the various districts. Certain well-known houses take great care in this respect and their marks are recognised as high standards, but there are certain other houses on whom no reliability can be placed.

(12) With regard to marketing in Europe, we are of opinion that since the organisation of the London Hemp Association, which has formulated a definite and carefully thought-out Contract and has established a panel of arbitrators to assess differences in value, the existing houses are capable of carrying out the distribution of the fibre in the European markets in a satisfactory way.

(13) The following samples are submitted :—

- (a) Sample drawn from hemp showing the result of over-tight packing.
- (b) Sample of *sunm* (*Crotalaria juncea*) as cultivated experimentally in Africa by the Empire Cotton Growing Corporation.
- (c) Sample of Russian Siretz (i.e., uncleaned hemp) (*Cannabis sativa*).
- (d) Samples of yarns spun by Messrs. J. & E. Wright, Ltd., from various qualities of *sunm* hemp.

APPENDIX.

LETTER FROM THE SECRETARY, ADVISORY COMMITTEE ON VEGETABLE FIBRES,
TO THE SECRETARIES, ROYAL COMMISSION ON AGRICULTURE.

Imperial Institute, London, S.W.7.

May 9, 1927.

Advisory Committee on Vegetable Fibres.

Dear Sir,

With reference to Imperial Institute letter of November 17 forwarding a memorandum on Indian hemp which had been prepared by the above Committee, I have to inform you that at a meeting of the Committee on February 23 further consideration was given to this subject. Attention was drawn to the difficulties which are encountered in attempting to secure any improvement in the preparation of the fibre and to the need for research in this connection. After discussion it was decided to bring the difficulty to the notice of the Indian Agricultural Commission and to enquire whether it might be possible to impose a small cess (similar to that imposed on cotton under the Cotton Cess Act) on all the hemp produced in and exported from India, on the understanding that the cess should not be large enough to affect the price of

the fibre. The Committee were further disposed to think that the fund so created should be applied to research on methods of improving the production and preparation of the hemp and should be administered by an organisation constituted on lines similar to those of the Indian Central Cotton Committee.

I am instructed to add that if the Commission intend to take evidence in England this Committee will be glad to arrange for evidence to be given on the subject of the condition in which hemp is marketed in this country, together with recommendations for its improvement.

ORAL EVIDENCE.

54,735. *The Chairman* : Mr. Wigglesworth, you are of the firm of Wigglesworth & Company, Ltd., and you are Chairman of the Advisory Committee on Vegetable Fibres and for the Packing and Grading of East Indian Hems ?—That is so.

54,736. You are supported here, to-day, by some of your colleagues on that Committee ?—That is so.

54,737. Perhaps you will decide who amongst you will answer particular questions ?—I shall be very glad to answer any question or refer them to my colleagues if necessary.

54,738. We have a note of the evidence you wish to give us ; would you like to make any statement at this stage ?—I propose to enlarge on that statement a little, though I think, perhaps, further information will be elicited in the course of our statement. I wish to say a few words briefly about hemp as hemp. Europe was dependent entirely upon *Cannabis sativa*, that is the real hemp, for centuries until other areas developed, such as East India, New Zealand, the Philippine Islands and Mexico, where indigenous fibres were discovered, which, though not of the real hemp plant, were fibres strong enough to be manufactured into ropes where strength and size were essential. These became known and gradually, to a large extent, supplanted the use of hemp which at one time was grown in this country, which later was obtained almost exclusively from the Baltic Provinces and the interior of Russia, being shipped from Riga. Latterly the tendency has been for material grown in other countries to take the place of this European fibre, and the War accentuated the movement, because the change of conditions in Russia and the substantial increase in the cost of agricultural produce there since the Soviet regime, has brought the fibres of India and other countries once more on to a more competitive basis than before. The work of my Committee is mainly to enable us to direct the energies of the fibre producers in various parts of the Empire to producing a quality of fibre which will be more suitable and more competitive with these varieties grown in Europe—Italy, Hungary and Russia—which are admittedly the very best. India has latterly come to the fore with this fibre, produced from a plant known botanically as *Crotalaria juncea*, which really has nothing at all in common with this *Cannabis sativa* or real hemp, except that it produces a fibre which, when it is carefully prepared and compared with real hemp, is such that it would be very difficult to find any visible difference. Our Committee realises that India can go a long way further than it has gone in the preparation of this material, firstly, by better agricultural methods ; secondly, by intelligent research as to the times when the seed had best be sown ; thirdly, by research as to when the stalk should be pulled, because the strength and quality of a fibre depends very largely on whether you take it in an immature condition, whether you take it dead ripe, or whether you take it after the plant has seeded and has

parted with a very large proportion of its natural strength and quality ; and, fourthly, if the Government of India assists the Committee in co-operation on these lines and we succeed in improving the production of the material, we have to make further inquiries as to how far that production may be prepared by selection and baling for the European consumers so as to give them the greatest possible satisfaction. Now, briefly, we have proof that there are many practices in India which might be vastly improved, both as regards agriculture and the date at which the seed is sown, the time and method of retting, the selection and grading, and even the baling. In every respect my Committee will be in a position to give valuable counsel if we have the support of the Indian Government and its Agricultural Department to help us to get these ideas carried out, and I have no hesitation in saying that, within the next 10 years, we might double the consumption of Indian products in the European market.

54,739. What exactly is the constitution of your Committee ?—The Committee consists of the Director of the Imperial Institute, Sir David Prain, Director of Kew, Captain Brady of the Board of Trade, a representative of the Overseas Trade Department, the Trade Commissioner for India and other men drawn, as far as possible impartially, from those who are engaged in every process concerning hemp ; that is from the merchanting to the spinning, and rope-making and twine-making, and the various processes for which hemp is used. There are various associations connected with each of these processes from whom we were lucky to secure the services of one of the members nominated by the Chairman of that particular association, so that you may regard our Committee as by far the most representative Committee in this class of material that has ever been got together in this or any country.

54,740. When was the Committee constituted ?—Roughly a year ago ; it is the result of the reconstruction which is going on at the Imperial Institute.

54,741. What channel of communication is open to the Committee between this country and India ? How do you bring information and advice to the proper quarters ?—I am sorry to say that the channel of communication has not yet been definitely established. There has been, during the time of this Committee and before, a certain unofficial correspondence going on between myself and certain sections in India, such as Dr. Clouston, the Agricultural Adviser to the Government of India, whom I know personally and with whom I stayed in Pusa during a visit to India in 1925, and occasionally with different Departments of Agriculture ; for instance, that of Bengal at Dacca where they have the all-important jute preparation and a very considerable trade in the hems which we are now discussing, shipped from Calcutta.

54,742. Indian hemp stands in a class by itself, does it not ?—Distinctly, but Indian hemp, in certain of its grades, is remarkably similar in appearance and strength to Russian hemp ; that perhaps is the nearest substitute.

54,743. Do you regard the world demand for Indian hemp as more or less stable and fixed ?—By no means ; you have only to regard the figures of imports to see how very unstable it is. I think you may account for that by the fact that, so far, Indian hemp has been used as a substitute fibre, and that if we could establish its use as a permanent article used by itself, we should stabilise demand and price.

54,744. In order to do that, would it be necessary both to improve the quality and to narrow the range of quality ?—To improve the quality, yes ; to narrow the range of quality, if you mean by that eliminating the worst and bringing the lower grades up to the better, yes.

54,745. Has your Committee, or have you, ever considered the possibility of organising the hemp interests in India from the grower upwards through those interested in distribution as far as the ultimate consumer, on some such plan as that on which the Indian Central Cotton Committee is organised?—We have not on our Committee considered that so far, perhaps because we have not had time to. Personally I have never considered it, because I should have thought the problem was far too vast to be undertaken by any one individual. (*Captain Brady*): Might I interpose here to say that the Committee has drawn your Commission's attention to the suggestion of the Indian Central Cotton Committee that a similar cess should be levied for the improvement of hemp, and a copy is attached to the memorandum submitted to this Commission of the suggestion they make as to a similar organisation. (*Mr. Wigglesworth*): I rather think we might ask Mr. Lindsay to tell us how far they have got with regard to that.

54,746. *The Chairman*: Certainly.—(*Mr. Lindsay*): I may say I had been in close touch with the Agricultural Departments in India before this Committee was formed. I wrote on several occasions to them, pointing out the difficulties in methods of collection and preparation of hemp for this market; so that the work of this Committee fits in very well with the clearing of the ground which has already been covered in consultation with Agricultural Departments in India. This idea of imposing a cess on exports in order to improve local production is an idea which, I know, has been before the Government of India for some years past. Actual effect was given to it in regard to cotton by the imposition of the cotton cess; the tea cess has been in force for some time past, but I do not think any step has been taken in India with regard to hemp for the introduction of a similar cess. I should like to add that I think, if funds could be collected in that way, they could be very profitably spent in India with a view to assuring the cutting of the crop at the right time and with a view to improving the conditions, particularly of retting and preparation in India for the market. (*Mr. Wigglesworth*): I should just like to say in connection with that that only this morning I received, from Dr. Clouston, samples of Indian hems which had been pulled and retted at different periods in the life of the plant, and the result is most illuminating. There is, undoubtedly, a very considerable difference in the value of the material as between the plant which has been pulled immediately after flowering and others which have not been pulled until the material was fully ripened. Those are technical points which it is an early date to discuss and which I would rather submit to my whole Committee for a general discussion with other experts; but, briefly, much greater strength, to my surprise, was visible in the fibre which was mature, but the fibre was bolder and harsher to the feel and would not spin so fine as the immature material; it would be for the experts to decide whether the whole output should be prepared so as to attain the maximum strength, even at the cost of some coarseness, or whether a proportion of it might very well be made in a finer degree for other purposes. That is a technical point which would have to be considered and which shows the necessity of the closest possible collaboration between our Committee and the authorities in India.

54,747. *Sir Thomas Middleton*: You are referring now to the *Crotalaria juncea*?—Precisely; we do not refer at all to the real European hemp; as Sir David Praeger knows, its cultivation is prohibited in India, except by Government.

54,748. *The Chairman*: Are any standards of quality and purity in vogue in London?—Since the coming into existence of the London Hemp Association, founded

I think in 1906, they have established a contract which stipulates for certain prescribed qualities. The standardisation which is the direct result of that work, has unquestionably added immensely to the popularity of Indian hems and, I should say, greatly increased their consumption.

54,749. Are you satisfied with the terms of that contract?—The terms of the contract are satisfactory as far as the commercial terms are concerned; the establishment of grading which is not directed from London, further than saying that it should be Grade No. 1, No. 2 or No. 3 of Bengal or Benares, for instance, might be considerably improved.

54,750. Have you considered, at all, the feasibility of there being instituted, in India, standards for exports, so that if a particular lot of hemp destined for export did not come up to the necessary standard, export in the case of that lot would be prohibited?—I am inclined to think you would have to go a long way before it would be advisable to establish a regulation of that nature; the preparation is so diverse that you might have to exclude whole districts if you did that. I would instance a district in Philibit where the material is prepared by retting in mud, and it is stated, and I believe it to be true, that frequently the growers actually put mud into the centre of the material before they ship it. Of course, Government can take stringent action in cases like that, but I think, before starting any penal clauses, it might be advisable greatly to improve the preparation of the material, and we should come to that at a later point. The sample which I now produce illustrates material containing a great deal of foreign matter which should not be in it.

54,751. *Dr. Hyder* : Does that come from Chandausi?—Yes.

54,752. Do you know Chandausi?—Yes.

54,753. Does it occur to you that there is not much water available in Chandausi, and it may be that the people have to dip it in the mud?—I have considered that, and for that reason have never cared to give any definite opinion as to whether the Government ought to prohibit it or not, because I realise that if they did they might be interfering with an established industry. I agree with you, it is possible there is not sufficient water there.

54,754. Where does this shiny hemp come from that you have here?—That I am going to show you later. It comes from Africa; that shows you what can be done in a country which has never grown it before.

54,755. *The Chairman* : In the case of your own firm where do you buy as a rule?—In Calcutta and Bombay.

54,756. Up country as well?—We have our agents up-country in the control of the Bombay house and the Calcutta house.

54,757. Do you carry out any grading?—Everything is graded before shipment.

54,758. At what stage is the grading carried out?—In the case of raw hems, selection is made into three qualities; then there will be about ten different districts, so that there will be about thirty qualities.

54,759. But in the case of hemp bought by your buyers up-country, is any grading attempted at the up-country centres?—No, not as a rule until it comes down to Bombay or Calcutta.

54,760. Would it be possible to grade it up-country?—Yes, I see no reason why it should not be done. For instance, I remember when the whole of the Benares crop was graded in Calcutta, but now it is graded just outside Benares.

54,761. Would grading at the up-country centre facilitate giving growers an adequate premium for quality?—There is one difficulty about up-country grading: in Calcutta and Bombay, but especially in Calcutta, they have a number of Europeans who are highly expert men and who can control the quality, but these men do not reside in the mofussil districts, where they would be dependent upon the Indians who have less experience of the European markets.

54,762. Is it your view that the cultivator is, at this moment, receiving a sufficient premium for quality?—The general view is that he does not receive the premium for quality. The view I have always taken with regard to that is that seeing that the premium is actually paid by the buyers and consumers in Europe, it is the result of some system of purchase there through many different hands, so that the first man who buys tries to get the best material at the price of the worst. If the grower who produces the best were in touch with the actual house of shipment, he would get better prices.

54,763. Have you any concrete proposals to make for the improvement of the Bombay market in regard to shipping and grading there?—I do not think so.

54,764. Or as to any other matter?—The baling might be very much improved. For instance, in Bombay we frequently find that the grades from Philibit or Chandasi may be mixed with those from Jubbulpore or Itarsi; my feeling is that if each district were kept strictly separate and sold under its own proper designation, you would certainly get the real values and you would get a higher ultimate value for the whole crop; because, if you have only 10 per cent. of inferior grade mixed with the better very likely you will only get the price of the lowest grade for the whole lot, because the buyer cannot take the risk of selecting it himself and must pay you a lower price correspondingly. Then again, we have a statement in our memorandum about baling; it is so tightly packed that if the material is the least damp, when it comes out of the bales it is like a board. This sample illustrates that, though this has been beaten and it is much worse than that when it comes out of the bale. (*Producing a sample of hemp.*) If, instead of baling to fifty cubic feet to the ton, it were baled to eighty cubic feet to the ton, there would be more freight to pay, but the compensating price would more than make up for the increased freight.

54,765. Have you made representations on that point?—I have personally instructed our shippers to bale to fifty, sixty and eighty cubic feet to the ton.

54,766. And, in the course of time, you will be able, I suppose, to come to a firm view as to the appropriate tightness of these bales?—Yes, I can tell you that at once on opening the bales.

54,767. You say you have to make up your minds whether the ton should be sixty, seventy or eighty cubic feet; you are not quite clear yet as to what is the proper pressure?—Yes, I would rather see it in practice. I think it should be 80 cubic feet, but it would be far better to reserve an opinion until we actually receive the goods. There is another matter of small practical detail. When material is tied round the head like this sample, it obviously involves a great deal of labour to tie it and it involves labour which costs two or three times what it does in India to untie it. These are small details which there should not be the smallest difficulty in overcoming, and yet, in the twenty or twenty-five years in which I have been interesting myself in Indian hemp, I have found it almost impossible to get instructions like that carried out; they seem to be absolutely wedded to habits centuries old and unwilling to make any change.

54,768. Have you got the exact particulars of your contract with you to-day or could we have those?—One has been sent attached to our statement. It is a very well thought-out contract dealing with lateness, unavoidable delay, declarations of the contract, method of insurance, quality conditions, weight, provisions in the case of default, arbitration and so on.

54,769. Is that in line with the contracts in force in New Zealand and the Philippines?—It is more in line with the contract in force for Indian jute, because being an Indian product, we have as far as possible adopted the practice of the Jute Association, with the necessary variations for the hemp trade. I would like to mention that, some years ago, I had Indian hemp sown in Italy under the same conditions as Italian hemp, which is the best hemp in the world; the result was better than it had ever been grown in India. The improvement in the quality was due, first, to the land being properly nourished, secondly, to its being deeply ploughed and very well cultivated; thirdly, to its being sown in the appropriate season, which in Italy is the month of March just when the sun is getting stronger; fourthly, to its being pulled exactly at the right season; fifthly, to its being retted in exactly the right number of days, because if you ret a material two days too long you rot it, while if you ret it one day too little you cannot clean it; sometimes a few hours will make a difference. Sixthly, it was due to the grading and packing being done on the Italian method. That experiment convinced me that what could be done in Italy by intelligent work could be done equally well in India.

54,770. There is nothing in the climatic conditions?—There is nothing in the climatic conditions.

54,771. *Professor Gangulee*: What are the chief methods in Italy which we in India could not adopt?—I cannot think of any which you could not adopt; but may I point out that in Italy, beginning at the top, the Agricultural Departments give gratuitous information to all farmers, firstly, with regard to the germination of the seed, the percentage of germinability of the seed; secondly, they will analyse and give information regarding the fertilisers required for certain kinds of soil; thirdly, they supply co-operative assistance, if necessary, with certain machinery which is expensive and which is required for the preparation of the crop. I sent one of those machines to India some time ago to Sinclair Murray & Company, and that was sold, I believe, by Sinclair Murray to the Government of India. Unfortunately, it was destroyed by fire, and I was told they could not get the necessary vote to put up the £200 to replace it, so that the experiment ended.

54,772. *The Chairman*: Is your Committee concerned with the British aspect only or with the European?—European.

54,773. How does the reputation of Indian hemp stand on the Continent?—Rather low; it contains so much dirt and inferiority that in some countries they have actually legislated against its consumption.

54,774. Has there been a change in the quality, and so the reputation, of Indian hemp? Is it improving or deteriorating?—On the whole improving; it is improving in this respect, that materials are being hackled or dressed in Bombay and Calcutta, and that knocks out a great deal of the dust and dirt. That trade has grown; it produces two classes of material; one the long dressed hemp and the other the tow, and it eliminates ten or twenty per cent. of dust. The proportion of dressed is low as compared with the total export.

54,775. Of the various factors that make for good or bad hemp, is it the case that retting is by far the most important?—I am inclined to think that the preparation of the soil is just as important, and the proper class of soil. It is exactly like cooking: if you leave your beefsteak on the fire for 10 minutes too long you do not want to eat it. Retting is a thing which can be more easily corrected than any other fault.

54,776. Is it necessary that the retting process should be begun very soon after the hemp is pulled?—The very best practice in regard to retting is to dry the material out before it is put in the water at all; if it is bundled straight away from the field into the water, it is full of chlorophyll, that green material will not be removed in the retting process and you will never get as good a fibre. By drying, the plant turns to a normal yellow colour, loses a great deal of its natural moisture, and obviously absorbs the moisture in the retting process much quicker, and gets retted quicker and better.

54,777. What is the usual practice in regard to that in India?—I could not say because it varies in every district. Though I have been in India various times, I have never been able to time my visit to be in any hemp district just as they were doing this process.

54,778. Do you do any retting in your up-country stations?—We have supervised a good deal of retting in Yorkshire in connection with flax some years ago.

54,779. But never in India?—No, that is all done by the peasant grower; there is no retting whatever of jute or hemp in India under European supervision; the whole thing is a peasant industry. In my opinion proper co-operation between the Agricultural Department of India and the peasants would be invaluable. I do not say a large number of demonstrators should be appointed; we must go slowly, but probably the appointment of a larger number of men with sufficient knowledge and experience, not merely students, to tell the peasant what to do, would be very helpful. I think, if in any particular district only one cultivator were converted to improved methods, the fact that his material would sell at a better price than the material of other peasants, should lead the others to follow his example.

54,780. *Mr. Noyce*: If it were merely done by one man, would he be able to sell his material at a better price than the others?—Yes, I think so; the difference would be very great in quality. I may say we are establishing more up-country agencies for the very purpose of enabling the producers of better quality to get the real value of the material, because it is not the desire of the merchant houses of Bombay that a man who produces good material should get a low price.

54,781. *The Chairman*: Of course it is hard to say, but if a substantial improvement could be effected, is it your view that a very considerable improvement in demand for Indian hemp might result?—If you could get Indian hemp used permanently for the production of certain standard articles, you would get an improved demand.

54,782. So that this is a direction in which successful work by the agricultural departments would be followed, at a very short interval, by an important advantage to the cultivators growing hemp?—Yes, decidedly.

54,783. *Professor Gangulee*: On the question of the standard article that you propose, would you attach a great deal of importance to grading?—Yes, I attach great importance to grading.

54,784. Some time ago, I think, the Board of Trade recommended that the grading should be controlled by legislation. Do you favour such a measure?—(*Mr. Lindsay*) : No, I do not think so, on the whole. (*Mr. Wigglesworth*) : I think it is premature, and I think the system would break down almost at once. What I am pressing and urging is to leave the grading and the packing in the hands of the men who are doing it at present, who are not doing it very badly. Improve the production and the grading will improve itself.

54,785. Would you leave it entirely to the trade?—Yes.

54,786. In what way can the Government Departments assist?—(*Mr. Lindsay*) : That is rather a point of contact between ourselves and the Committee. The suggestion is that Government should enter for the purpose of helping the industry to organise itself. The only method by which organisation is possible is by means of funds; you cannot see these improvements materialise except by means of improved methods, demonstration, improved seed and so on, and right through that whole process of organisation is the need for funds. What we believe, on the Committee, is that Government can help in thus helping the industry to organise itself; that is to say, to subscribe and collect its own funds, and utilise those funds through the expert departments. May I just add one word on the subject of mixing, because it is a very important point: as you know, the mixing question has been very serious in India in regard to cotton. The fundamental principle is this, that, to take the cotton industry as an example, your short staple cotton can secure a higher price if sold in a district where long staple cotton is grown, for the purposes of mixing, than it can secure in the ordinary market under its own name. Now, that is the tendency which, somehow, under the ordinary laws of economics we have got to controvert. In the cotton industry they have overcome that difficulty by prohibiting the transport of short staple cotton into long staple areas which require protection. But whether you can go as far as that in regard to the hemp industry, I should think is very doubtful; I should think some measures might be taken at the point of baling to prevent the mixture of inferior with superior grades. That is to say, at the point of the baling press you might ensure the isolation of the two.

54,787. So that the chief directions in which the departments of agriculture in India could usefully direct their attention would be the cultivation of hemp?—The cultivation, and then, as in the case of cotton, you might proceed up to the point of baling; in fact, up to preparation for market.

54,788. Referring to the deterioration of the Manila hemp, I think you, Mr. Wigglesworth, wrote an article in the "Times" Trade and Engineering Supplement?—(*Mr. Wigglesworth*) : Yes.

54,789. In that article, you referred to the awakening of the Philippine authorities in this matter of grading, and you say that it has resulted in the scrapping of the old grading institution and the formation of a new Board of Graders constituted on wide lines, with the representatives carefully selected from officials, experts, producers, traders and thus combining all interests. Knowing the Indian conditions as you do, do you think the volume of Indian trade in hemp would justify the formation of such a Board?—I think it is premature in India to consider that; but it illustrates the point we made before, that I do not advocate Government interference because it was through Government interference in the grading of Manila that the whole thing went wrong. It is an industrial Board of technical men now.

54,790. It is not an official Board?—No, the majority are non-official. Yesterday I had, by chance, a visit from one of the leading men on that Board and had an opportunity of discussing the production methods with him. He accentuated very strongly the point that as long as it was an official organisation it was a complete failure, but as soon as you brought technical men into it the results were very different.

54,791. Then you think we should have in India a non-official organisation?—I think the trade itself would have to do that; I do not think that should come from Government, except as a recommendation. (*Mr. Lindsay*): On the lines of cotton.

54,792. The fluctuation in prices has been, I understand, too excessive to ensure steady cultivation of Indian hemp; is that criticism correct?—The tendency over the last few years has been for the fluctuations of prices on all articles to be very excessive; in fact, they were far too great. That is because of certain economic causes we are not here to discuss to-day; but under normal conditions, given the production of an article which is well prepared and honestly packed, you do not get those fluctuations. I should compare the results as regards sisal which is produced in East Africa on the most up-to-date lines, mechanically prepared, supervised, properly graded, not official grading at all but grading by private people. During the times when Indian hemp was fluctuating more than fifty per cent. of its value, the East African has not fluctuated more than fifteen to twenty per cent., with the same economic causes in operation, showing that a great deal of the fluctuation is due to an article being so inferior that, the moment trade gets bad, it is the first to suffer. In general, in any depression the inferior, whether they be inferior workmen or inferior goods, are the first to suffer: inferior workmen are out of employment while other workmen are still employed, and inferior goods cannot be sold while better goods keep on going into circulation.

54,793. I understand from your answers to the Chairman that the Russian hemp at the present time is not coming into the market very much?—Very little; it is almost impossible to get it. We know nothing whatever about the acreage and production in the last three or four years: we are absolutely at sea. Mr. Buckpitt, who is a prominent consumer of that article, will be able to support me in this: the consumers will be very glad to find something upon which they can depend as to export and know they will not be left without material when they require it.

54,794. Suppose Russia has come into the market, Canada is trying to grow hemp: when all these countries put hemp on the market, do you think India can hold her own?—Does India hold its own in jute?

54,795. There is a monopoly?—Yes, but why is it a monopoly? Because you have the most ideal conditions for producing that fibre in the world; the same is true with regard to hemp. With your enormous population in India of highly intelligent people—I repeat, highly intelligent people—capable of learning, capable of doing really good work when properly directed, willing to work for moderate wages with whole families engaged in the operation, not reckoning so much an hour for their work, you have ideal conditions for the production of a material of which, if found satisfactory, the consumption could be five or ten times what it is to-day.

54,796. *Mr. Calvert*: Could you tell us whether any commercial use can be made of wild hemp?—What is wild hemp?

54,797. Wild *Cannabis* that grows all over the Northern Punjab?—I am afraid not; I regard nothing that you can get for the picking as of the slightest value. To illustrate the point; I remember, some years ago, there was great excitement

when a man was offered a vast concession in India of the fibre growing on the sides of the railways 200 miles long ; he wanted to get up a company with a capital of £200,000 ; and he was terribly astonished when I told him it was not worth a half-penny. You must concentrate, you must have fibre properly looked after, grown where there is labour available and where conditions are right.

54,798. Have you anything to say about Indian flax ?—Indian flax has been experimented with, I believe in Bihar, and I think near Cawnpore, and a very successful quality was produced. Why it was not proceeded with I am unable to say.

54,799. *Sir Ganga Ram* : Do you deal with any other kind of fibre imported from India, rhea, for instance ?—On so small a scale that it is not worth mentioning ; most of the rhea is imported from China, not from India.

54,800. But at one time there was a great demand for Indian rhea ?—Yes, but there never was a great production of it.

54,801. Is there any limit to the altitude on the hills at which hemp can be grown ?—Yes, distinctly, there is, of course, a limit.

54,802. Up to what height does it grow ?—It is a crop for the plains ; it should not be grown on the hills.

54,803. It will not grow on the hills ?—No.

54,804. *Mr. Calvert* : About 3,000 feet ?—That is the very extreme.

54,805. *Sir Thomas Middleton* : Have you any information as to the total crop available in India ?—Yes, we have full statistics of it.

54,806. Both of that exported and that used internally ?—No, not that used internally ; we have tried to get that, but it has been impossible to get either the acreage or the actual production. The reason given was that, frequently, *Crotalaria* is used for the purposes of manuring the successive crop, as green manure.

54,807. That is its common use in the Bombay Presidency ?—Yes, and the peasants when they sow it do not know, depending on the rainfall, whether they are going to mature all of it or none of it or part of it. I think that makes the statistics with regard to acreage almost impossible and certainly unreliable.

54,808. What is the price of hemp coming from India at present ?—The cheapest quality coming in to-day is worth £19 a ton ; that is from the Chandausi districts ; the best, from the Dewghuddy districts, sells at £34 a ton. That really represents a difference, not in the length or anything of that kind, but in the treatment of the material.

54,809. That difference in value arises almost entirely from the retting, does it not ?—Yes, to a very large extent ; the colour and cleanliness is due to that.

54,810. Is there much difference in the strength ?—Yes, the Dewghuddy is distinctly stronger than some of those from Chandausi.

54,811. Are the weak fibres due to over-retting ?—In the case of Benares over-retting is the cause of the weak fibre ; that is very light in colour. Where you over-ret you get a very white colour. Why I suggested the departments of agriculture intervening in this is that you strike an exact medium where you get both good colour and good strength ; carry your retting too far and you will sacrifice the strength.

54,812. Are there any circumstances leading you to suspect that the strength of the fibre has suffered from poor cultivation ?—No, what would happen from bad cultivation would be that you would get a short fibre instead of a long. If you were to pull the material before it is mature, then you would get a weak fibre, or if you were to over-ret it you would get a weak fibre.

54,813. *Dr. Hyder* : You have spoken about Chandausi ; it appears to me that much of this loss of quality is due to the fact that there are no water ponds available ; you know the mud is about knee deep ; in a district where you have plenty of water, you have a better kind of fibre after retting ?—May I ask if there is much dew in Chandausi ?

54,814. Always in September ?—If the fibre were dew-retted it would have no dust or dirt at all in it, but they would get a rather darkish material. The whole of the American crop is dew-retted and not water-retted at all, for the same reason, that they have insufficient water ; but their material does not contain dust and sand and dirt.

54,815. I have seen it myself ; they actually dip it in the mud ?—Dew-retting means laying the stalk flat on the ground after it is cropped and turning it over every two or three days, so that the effects of the alternate dew at night and the hot sun in the day extract the material which makes the fibre adhere to the stick and so enables them to clean it.

54,816. Your Committee is concerned with vegetable fibres of all sorts, is it not ?—Yes.

54,817. Has the West African thistle any economic importance ?—Do you mean thistle or *sisal* ?

54,818. No *sisal* is different. I was talking to a man, in Mülhaus, who is in this business of hemp and jute ; I asked him about substitutes, and he mentioned the West African thistle ?—Are you sure he did not mention nettle. Sir David Frair is an authority on the subject. The rhea fibre is of the nettle family. (*Sir David Frair*) : Yes. (*Mr. Wigglesworth*) : Nettles in this country also contain fibre, and that fibre was extracted by the Germans during the war as a substitute for flax, but it is not an industry and never will be.

54,819. Is there anything by way of a substitute growing in Madagascar ?—Nothing that will take the place of this ; Madagascar is far behind.

54,820. Is there anything by way of a substitute coming from French Indo-China ?—Nothing at all.

54,821. They are doing something at Mülhaus ?—There are specimens and samples coming all the time, but we keep records of all the imports and exports of fibre, and they are not coming in any quantity. The French are trying certain fibre developments in Indo-China, but they are succeeding very badly ; they are not keeping pace with us.

54,822. *Mr. Noyce* : I understand your Committee consider that hemp is a suitable crop for an organisation such as the Indian Central Cotton Committee ?—I think it is.

54,823. Have you given any consideration to the question of getting a satisfactory personnel for such a committee in India ? One of the reasons why the work of the Indian Central Cotton Committee has been so successful has been the interest the Indian mill industry, generally, has taken in its work ?—(*Mr. Lindsay*) : I should think the agricultural experts and the exporters between them would form a satisfactory nucleus ; and I should think also the agricultural representatives, that is to say, the growers' representatives, could also be available. The Cotton Committees, as you know, are composed of growers as well as millowners and exporters.

54,824. Do you think exporters really take a great interest in quality ?—I think so. I think on the Cotton Committee, for example, the cotton brokers and cotton shippers do play their part.

54,825. The amount which has been suggested as a suitable cess for Indian hemp is four annas per cwt. ; that is, 7s. 6d. a ton. I presume the price of a ton of hemp is such that that would have no serious effect ?—(*Mr. Wigglesworth*) : I think it is far too much ; my own idea would be one or two annas a bale or something like that.

54,826. I thought you said the price of hemp was about £19 a ton ?—That is the price of the lowest quality.

54,827. Surely 7s. 6d. would not make much difference to that ?—It would make an enormous difference.

54,828. That is the point I wanted to get at. If you consider that four annas per cwt. is a great deal too much, there would be extremely little in the way of funds for this committee to administer, as with four annas per cwt. the total proceeds of the cess would be only a lakh and a quarter ?—That is a great deal of money.

54,829. But if you say that is a great deal too much and you would put it at about one anna per cwt., they would only have about Rs. 30,000 a year ?—I think Rs. 30,000 a year is the nucleus of a very considerable sum, and I would far sooner see the thing grow gradually, instead of having a lot of money before they know how to spend it.

54,830. Do you not think general revenues could put up Rs. 30,000 a year without causing the dislocation to the trade which would be involved in the levy of a cess, however small ?—(*Mr. Lindsay*) : The trouble is that general revenues are liable to reconsideration at every Budget time. (*Mr. Wigglesworth*) : Another thing is that I believe in contributory interests : I think it is only right that the trade should contribute a cess of this kind. When I was in East Africa, about a year ago, I was very strong on having a cess on coffee there, because the coffee people were getting money from one of the public departments, and in that case could very well afford to pay a small cess as they are doing in tea and cotton. I think it is a much sounder principle than taking money from public revenues, even though it is very small in India.

54,831. Who would pay the cess if it were imposed : the cultivator or the importer ?—I do not think you could collect it from the cultivator ; I think the cess should be imposed in the same way as it is done with regard to cotton. Who pays it in the case of cotton ?

54,832. It is actually collected from the mills or the exporter. What I am referring to is the question of the ultimate incidence : is it actually paid by the consumer or the exporter ?—Every charge is paid by the consumer ultimately. I thought you meant who would collect it.

54,833. No, I wanted to know what your views were as to who would pay ultimately ?—I think that is a question to ask an economist.

54,834. *Dr. Hyder* : Supposing the price went up by 7s. 6d., do you think the 7s. 6d. would remain on the back of the cultivator ?—No, I think about 21s. would come on to the ultimate consumer, because obviously you will have five or six different people, each taking a profit on that 7s. 6d.

54,835. You mean, it will come on to the back of the consumer ?—Yes, it always does.

54,836. If you have no more hemp and no substitutes for hemp and your demand for hemp remains unaffected, then perhaps it might all go on to the back of the consumer, but not otherwise ?—(*Mr. Lindsay*) : Might I suggest for the consideration of my Chairman on this point that it seems to me that, in the matter of hemp, the

market is fairly large and that Indian supplies do not cover the whole market ; therefore it is not likely that a 7s. 6d. cess would affect the volume of India's contribution towards the general pool. I do not see how, in those circumstances, the general price of hemp would rise ; that is to say, that this cess would become an addition to the particular charges inherent in the trade from India. It would be as much a market charge as the cost of transport, i.e., the cost of rail from the field to the port, or the cost of steamship freight from the port to London ; it would be a charge inherent in the cost of marketing, and I do not see how one can avoid the conclusion that that cess would really be paid by India in the case of a commodity which is so extensively satisfied in London from other sources than India. (*Mr. Wigglesworth*) : That is exactly my view.

54,837. *Mr. Noyce* : In that case it would be the cultivator, who would pay and not the consumer ?—I have taken precisely the other view.

54,838. I think *Mr. Lindsay* suggests that the cultivator would pay. One of the points *Mr. Lindsay* mentioned in connection with the cess is that the imposition of a cess would ensure the cutting of the crop at the right time ; I should like him to explain that.—(*Mr. Wigglesworth*) : If that 7s. 6d. a ton is going to get one or two pounds more a ton price for us, it is an investment ; if the charging of a cess of 7s. 6d. is going to improve the quality so that you get one or two pounds a ton more in the price, that will be an advantage to us. In mentioning that figure I am suggesting something very small, because I have just shown that it is quite possible to convert the £19 quality into a quality worth £34. When I am asked who is going to pay it, I say again it is the consumer who is going to pay it ; in any case, he will be getting a better quality and will be pleased to pay more for it.

54,839. *Dr. Hyder* : So that the effect of the cess might be that you might have an improvement, and benefit the producer, the consumer and the trade ; is that so ?—Yes.

54,840. *Mr. Noyce* : *Mr. Lindsay* has not answered my last question. You have mentioned, as one of the objects which would be secured by the imposition of a cess, that it would ensure the cutting of the crop at the right time ; I was wondering how it would have that effect ?—(*Mr. Lindsay*) : By demonstration.

54,841. You mean if the cess were spent on demonstration ?—Demonstration is one of the most important items in the scheme.

54,842. You say in your note : " A leaflet recently issued by a Department of Agriculture in India on the subject of the cultivation of *sun* conveyed instructions which would not be helpful to the production of good fibre." What were those instructions ?—(*Mr. Wigglesworth*) : The instructions were that they should sow the seed three feet apart, whereas you cannot produce a good crop unless it is sown three or four inches apart.

54,843. In the circumstances we had perhaps better not ask which Department of Agriculture it was ?—I purposely did not state it.

54,844. The ordinary distance is about six inches ?—Yes, three to six inches ; four inches is the usual thing, I think. I want to accentuate the point about the tying of this material. It is a very small matter. To twist and plait and tie this material in that way must take a great deal of time, and, as I pointed out, a great deal more time to undo. By simply twisting it once and putting it in the bale, and then not pressing it so tight, it can be taken out and put straight on to the machine, thus saving anything from £1 a ton in expenses.

54,845. *The Chairman* : You have shown us hemp from other sources which is tied in a better way ?—Yes, this is a sample of Russian hemp, that is perfectly all right ; all the sisal which comes from Africa, all the hemp which comes from Italy, is packed like that ; all that comes from Hungary, Mexico, New Zealand and the jute from Calcutta is properly packed. It is a mystery why they should adopt this practice of tying it in tiny hanks and twisting and plaiting it ; there is no object in doing so. It may be for transport purposes when they are selling it originally, or it may be to conceal what is inside ; I cannot tell.

54,846. *Sir Thomas Middleton* : You do not class *Hibiscus* as a hemp at all ?—No, it is not a real hemp.

54,847. Do you class it with jute ?—Yes. In America they do not use the word " hemp," because they have a duty on hemp, but none on *sunm* ; it is really a *sunm*.

54,848. But *Crotalaria* is *sunm* ?—I thought you were talking of *Crotalaria*.

54,849. No, *Hibiscus* ?—That is jute ; I have already answered that question.

54,850. Do you class it with jute ?—Yes, as jute. (*Sir David Prain*) : I suppose that would be appropriate. The name " jute " is not known in Bengal, as you know, except among brokers ; the cultivator never calls it jute, or they did not 40, 30 or 20 years ago. I have to thank our friend Mr. Wigglesworth for having ascertained, though he probably does not know that he did, what the real jute was. The real jute is the fibre of *Hibiscus cannabinus*, but now it has come into favour again in India, and you have got to call it Bimlipatam jute to distinguish it from the thing which usurped the name " jute."

54,851. *The Chairman* : Has colour for its own sake an important bearing on value ?—(*Mr. Wigglesworth*) : The appearance always helps to sell ; it is generally regarded as a sign of purity when a thing is white and it is tolerably correct.

54,852. *Professor Gangulee* : Is the Department of Agriculture in Bengal aware of the experiment which Sir David Prain conducted ?—(*Sir David Prain*) : That was in the days when the Department of Agriculture was the Department of Land Records. What happened in that particular case was this. I have to look at these things not from the agricultural point of view at all ; I am not interested in that so much as in the botanical point of view. One knew that there were various ideas with regard to the different kinds of hemp that come from India, and it was my desire to show that certainly it was not in connection with the plant itself, which is as familiar to you as it is to me. I could not therefore ask any Government servant, but I seized the opportunity of a visit to India of a man who was interested in these things. He was making a tour of India to get for himself seeds of the *sunm* plant in every Province that he visited. When he had done this and sent these seeds to me, I got a friend of his who was a fibre broker in Calcutta to come down to the Botanical Gardens at the week-end and see how the plants were growing. Then I got him to select for me one of those men who retted the fibre of *sunm* in Delgarshir district ; you know how good that is and what a price it gets. That man cut, retted and prepared the fibre on all those different plots of plants that came from different parts of India. The fibre thus prepared was sent out, as chance would have it, to Mr. Wigglesworth, and he was the broker who was good enough to write and say there was not more than £2 a ton difference in value, and I think there were about fifteen or sixteen samples. So that clears up the possibility of there being any great difference in the varieties of the plant. Therefore, it must be something in connection either with the time of cutting and retting or with the nature of the retting, and these are two processes,



FIGURE 3.
Sunn Hemp. Fully Grown. Ready to reap for Fibre.



FIGURE 4.
Retting Sunn Hemp.
The stalks are immersed in water, being weighted down by heavy stones



FIGURE 5.
Cleaning out Sunn Hemp from the stalks after retting.

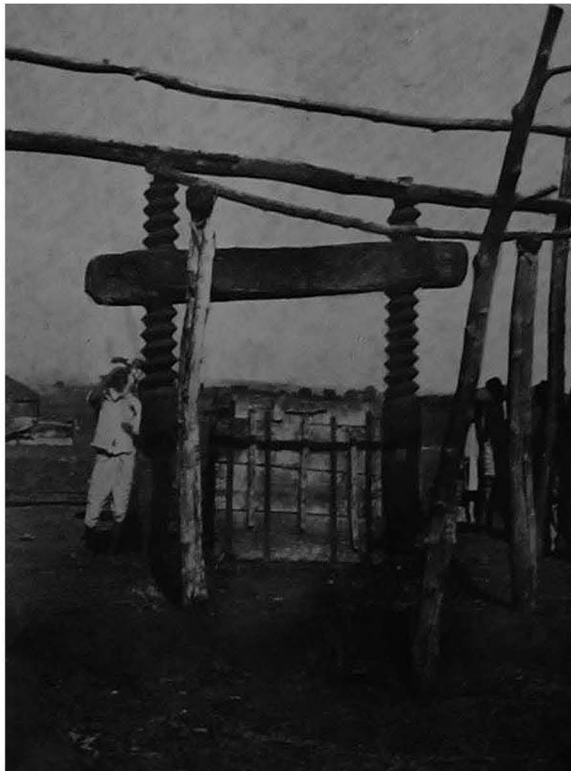


FIGURE 6.
Baling Press for Sunn Hemp. Central Provinces, India.

as you can understand, about which an Agricultural Department, and only an Agricultural Department, can advise you. I would like to say that, although accident has made me a member of this sub-committee that you have honoured by asking to speak to you to-day, I cannot divest myself of the feeling that I have as Chairman of the Advisory Council for Plant and Animal Products at the Imperial Institute. In that capacity I have listened with great interest to the evidence put before you and to the very wise questions that have been asked. My feeling is that we have before us, at this time, an occasion on which this fibre may be dealt with. As most of you know, this fibre was very much discussed at the end of the 18th century and at the beginning of the 19th century, when the East India Company did its very best to get it taken up by the interests in this country, but found the interests in this country so opposed to it that it never made its way in the market at all. Now, for the first time, is coming an opportunity when it can come in if India is anxious and willing to take an interest in the thing herself. It may now perhaps establish a sound position as against Russian hemp which it never had before and may never have again. If it is once established in the market it will be very difficult to dislodge in the future. Another thing I should like to say is this: if India refuses to do it, these samples will show what Nyasaland can do, and Africa will do it. (*Mr. Wigglesworth*): That is a very strong point; we have only to set the ball rolling in Africa, and it will go very rapidly, because it happens that we have discovered that this *Crotalaria* plant is the very best thing to grow as a between-crop with cotton; a weevil is destroyed by this *Crotalaria*; it cannot live in the presence of that fibre. That is a great discovery.

54,853. *Mr. Noyce*: That might also apply to India?—It will certainly apply to India.

APPENDIX II.

IMPERIAL INSTITUTE.

ADVISORY COMMITTEE ON VEGETABLE FIBRES.

REPORT ON THE EFFECT OF SEA WATER AND FRESH WATER ON TWINES MANUFACTURED FROM ITALIAN, RUSSIAN AND BOMBAY HEMPS.

The hemp twines which form the subject of this report were obtained from a firm of manufacturers by the kind offices of Mr. E. J. Wotton Buckpitt, J.P., in order that comparative tests might be made on their resistance to sea water and fresh water.

The samples each consisted of about 3 lb. of twine and were respectively labelled "302 Italian," "302 Bombay," and "302 Russian," and were composed of the following mixings:

Italian hemp.—One-third T.B.S.; one-third S.M.; one-third S.P.

Russian hemp.—Diamond Siretz.

Bombay hemp.—One-third Itarsi; one-third Philibit; one-third Dewghuddy.

I.—Effect of Immersion in Sea Water.

Portions of the twines were exposed to sea water at Southend under such conditions that they were completely immersed at high tide and completely exposed at low water, and thus received alternate wetting and partial drying twice a day. The tensile strength of each twine was determined (1) before immersion in sea water, and (2) after being exposed for one month, two months and three months, and subsequently washed with fresh water. Before carrying out the strength tests all the twines were dried in the air and conditioned in a humidity chamber for 24 hours. The following results were obtained, 30 tests being made in each case. (A graphic representation of these results is given on page 13.)

<i>Breaking Strain in lb.</i>				<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
<i>Before immersion.</i>						
Maximum	..	..	..	160·5	173·5	124·0
Minimum	..	..	..	106·0	94·0	69·5
Maximum variation	..	..	..	54·5	79·5	50·5
Average	..	..	..	126·9	116·6	91·8
<i>After one month's exposure.</i>						
Maximum	..	..	..	140·5	100·5	104·0
Minimum	..	..	..	67·0	63·0	39·0
Maximum variation	..	..	..	73·5	37·5	65·0
Average	..	..	..	96·4	81·9	66·1
Average decrease	..	..	..	30·5	34·7	25·7
<i>After two months' exposure.</i>						
Maximum	..	..	..	74·0	48·0	58·0
Minimum	..	..	..	32·0	20·0	20·0
Maximum variation	..	..	..	42·0	28·0	38·0
Average	..	..	..	50·5	31·4	35·9
Average decrease	..	..	..	76·4	85·2	55·9

				<i>Breaking Strain in lb.—cont.</i>		
				<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
<i>After three months' exposure.</i>						
Maximum	..	..	..	14.5	13.0	9.0
Minimum	..	..	..	2.0	1.0	1.0
Maximum variation	..	..	..	12.5	12.0	8.0
Average	..	..	..	7.1	4.7	3.2
Average decrease	..	..	..	119.8	111.9	88.6

				<i>Average Decrease in Strength, per cent.</i>		
				<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
One month	..	..	..	24.0	29.7	27.9
Two months	..	..	..	60.2	73.0	60.9
Three months	..	..	..	94.4	96.0	96.4

II.—Effect of Immersion in Fresh Water.

In these experiments portions of the twines were immersed in fresh water for 16 hours and then allowed to dry in the air for three days, these operations being repeated continuously throughout the whole period of the trial. The tensile strength of each twine was determined before immersion and after treatment for 40 days, 80 days, 160 days, and 282 days, the twines in all cases being previously air-dried and then conditioned in a humidity chamber for 24 hours. The following results were obtained, 30 tests being made in each case. (See diagram p. 13.)

				<i>Breaking Strain in lb.</i>		
				<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
<i>Before immersion.</i>						
Maximum	..	..	..	160.5	173.5	124.0
Minimum	..	..	..	106.0	94.0	69.5
Maximum variation	..	..	..	54.5	79.5	50.5
Average	..	..	..	126.9	116.6	91.8
<i>After treatment for 40 days.</i>						
Maximum	..	..	..	135.0	113.5	100.5
Minimum	..	..	..	85.0	70.0	62.0
Maximum variation	..	..	..	50.0	43.5	38.5
Average	..	..	..	103.9	94.0	83.3
Average decrease	..	..	..	23.0	22.6	8.5
<i>After treatment for 80 days.</i>						
Maximum	..	..	..	130.0	110.0	99.0
Minimum	..	..	..	82.5	65.0	54.5
Maximum variation	..	..	..	47.5	45.0	44.5
Average	..	..	..	101.9	88.0	77.1
Average decrease	..	..	..	25.0	28.6	14.7
<i>After treatment for 160 days.</i>						
Maximum	..	..	..	130.0	108.0	91.0
Minimum	..	..	..	81.0	64.5	53.0
Maximum variation	..	..	..	49.0	43.5	38.0
Average	..	..	..	102.0	85.2	72.1
Average decrease	..	..	..	24.9	31.4	19.7

Breaking Strain in lb.—cont.

<i>After treatment for 282 days.</i>	<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
Maximum	109·0	100·0	90·0
Minimum	74·5	62·5	51·5
Maximum variation	34·5	37·5	38·5
Average	92·2	70·1	70·3
Average decrease	34·7	46·5	21·5

Average Decrease in Strength, per cent.

	<i>Italian.</i>	<i>Russian.</i>	<i>Bombay.</i>
40 days	18·1	19·3	9·3
80 days	19·6	24·5	16·0
160 days	19·6	26·9	21·5
282 days	27·3	39·9	23·4

Remarks.

The results of these trials have shown that of the three twines the Italian was strongest and the Bombay the weakest. It is noteworthy that the twine made from Russian hemp was more irregular in strength than the others.

In view of the statements that have been made regarding the inferiority of Indian hemp in respect of its resistance to the action of water, the results of the immersion tests are unexpected and remarkable.

In every test in the sea water the Bombay hemp twine suffered a smaller reduction of strength than the others, although the average decrease *per cent.* of the original strength was approximately the same in all cases.

The results of the fresh water tests are somewhat similar. At the end of each period the actual loss of strength suffered up to that point by the Bombay hemp twine was less than that of either the Italian or Russian hemp twines. A comparison of the *percentage* decreases shows that on the whole the Bombay hemp twine resisted the action of fresh water better than either of the others.

March, 1929.

E.M.B. 26.

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6

BRITISH INDUSTRIES AND EMPIRE MARKETS

By

PROFESSOR A. J. SARGENT, M.A.,
London School of Economics.



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PREFACE.

The geographical distribution of the United Kingdom's export trade in manufactured products and the changes both in that distribution and in the relative importance of the different commodities exported are facts of great moment in the development of our commerce. In particular, the extent to which the output of each of our great exporting industries has been taken by other parts of the Empire and by foreign countries at various times is of considerable interest.

The Empire Marketing Board has rightly considered a study of this complex problem to be an essential part of its documentation. A complete analysis of Empire and foreign markets and of their significance in the development of our oversea trade would be an enormous task. Mr. McDougall, the Australian representative on the Board, has recently given us a general study of the distribution of the total exports of the United Kingdom. In this book Professor A. J. Sargent has carried the analysis a stage further in his account of the changes which have taken place during the present century in the relative importance of the main groups of manufactured articles in our exports to other parts of the Empire and to foreign countries respectively. Like Mr. McDougall's paper it is issued by the Board as a personal contribution by the author, who is himself responsible for the accuracy of the facts and figures he presents.

As one not unfamiliar with the laborious and exacting character of statistical investigations, such as have gone to the making of Professor Sargent's valuable study, I commend this book to all those who are concerned to get at the basic facts of our oversea export trade.

PASSFIELD.

March, 1930.

INTRODUCTION.

THE following pages are designed to show, in brief and consistent form, the meaning of the Empire to-day as a market for the manufactures of Great Britain, and to illustrate some of the changes in its relative importance in recent years. To explain the facts and the changes fully, several volumes would be needed. Such have yet to be written, though most of the relevant material exists already, in scattered shape in official publications.

The figures in the tables are approximations ; percentages fail to add up to a hundred and the sum of a series of values or quantities differs frequently from the total given. Arithmetical accuracy, to two or three places of decimals is unnecessary for the purpose in view ; the extra figures convey little or nothing to the mind of the ordinary reader and for the most part correspond to no real facts in matters of trade.

The schedules are not constructed on any basis of theory, but are merely convenient sections cut from the monthly Accounts of Trade, since these offer the only material which can be kept up-to-date and is not too costly to procure. As illustrating the method of selection, the heading " structural " in the tables dealing with iron and steel, includes all items in the monthly Accounts from ingots to steel pillars. The schedule " miscellaneous ", however, includes all items not dealt with specifically in the table above it, and, therefore, is not equivalent to " iron and steel, other sorts ", in the Accounts. The same principle applies to machinery.

In the use of the tables, it must not be forgotten that comparative figures of total quantity are less accurate as guides to the movement of trade than figures for the separate items constituting the total, particularly when there has been a marked variation in the relative importance of these items. Thus, the same total weight of agricultural and electrical machinery and boilers may have an entirely different significance in two years separated at all widely, if the relative proportions of the three trades have changed in the interval. Hence the need to qualify the totals by the details. Some error is inevitable, but less probably than in any attempt to measure progress by values, while the process of measurement is more simple. In some of the textile schedules, quantitative comparison involves special difficulties, owing to changes in official methods of measuring ; the conversions used in such cases are those accepted by recognized

authorities, and errors in these are not likely to affect seriously either the particular purpose for which the following figures are intended, that is a comparison of *rates* of progress, or the broad conclusions reached. Actual, as distinct from relative, changes in the volume of particular trades and in particular parts of the Empire must be dealt with elsewhere; the figures are far too elaborate for inclusion in a short description. The figures of values at the end of each table are intended to show the relative importance of the various sections of the trade and of the group as compared with other groups; though closely related to them, they are not the actual bases of the percentages, since the latter are mainly calculated on quantities.

The year 1913 has been used in comparisons purely for convenience, and to save much labour. The year was marked by considerable prosperity and the average figures for 1909-13 would indicate a generally lower level in most exports. The effect of taking measurement from the higher level is merely to reduce the apparent gains, while exaggerating the losses in 1927 as compared with pre-war years. This must be borne in mind, but it need not concern us greatly since our purpose is to compare *relative* movements and not to discuss the progress of British exports as such.

The term "Empire", throughout, excludes Great Britain, the Irish Free State, Egypt and Sudan, Iraq, Hong-Kong, and mandated territories; while Great Britain includes Northern Ireland.

Egypt, etc., are included under "foreign countries", while the Irish Free State is omitted from all calculations. Great Britain, in the text, is used as a short and convenient title for the United Kingdom of Great Britain and Northern Ireland; the adjective British refers to this area, except in phrases such as British North America, where it has obviously a more general significance; the "Southern Dominions" comprise Australia, New Zealand and South Africa, while "British America" includes Canada, Newfoundland and the British West Indies.

In calculations of British manufactured exports coke is excluded.

When exports of goods are classified according to groups of countries, exports to countries not shown separately in the Trade Returns are classed under "other countries", even though they may belong to the specific groups. This may not affect the percentages materially, but the broad result is that the percentages for the specified groups of

countries will tend to be smaller, and those for "other countries" greater, than would be the case if more complete information were available.

The diagrams are intended merely to give to the eye a broad impression of the relative importance of the different groups of exports at the two periods, and, more particularly, to emphasize the share in each trade credited to the Empire; they are not to be used as a substitute for the more accurate and detailed figures in the text and tables.

In preparing this sketch, I have received valuable criticism and assistance from officials of the Board of Trade and the Empire Marketing Board, but they are in no sense responsible for the accuracy either of the statements in the text or of the statistics on which these are based.

A. J. S.

BRITISH INDUSTRIES AND EMPIRE MARKETS.

Great Britain lives, and must for the most part continue to live, by the sale of her manufactured products to countries overseas. Apart from coal and some iron ore, and the output of her quarries and brickfields, the only native resources of any magnitude are to be found in agriculture ; yet, of the nineteen million people in England, Scotland and Wales, recorded in 1921 as employed in industry of some kind, rather less than seven per cent. are assigned to agriculture. Agriculture might, under different conditions, employ more, but there are physical as well as economic limits to such increase, and the fact remains that Great Britain can no more feed its present population from native resources than a modern city can support itself from the produce of fields and market gardens within its boundaries. Like a city, it must obtain supplies from without and pay for them either by goods produced within its frontiers or by services which can be exchanged for goods. Moreover, the production of goods implies raw materials, and these again must as a rule be imported from abroad. In short, apart from that section of its people employed in agriculture or mining, or in carrying the products of these industries, Great Britain is merely a gigantic urban area, dependent for its very existence on the supply of food and raw materials from without, and these are purchased largely by the products of its manufacturing industries. The only native resources of the city are to be found in its labour, skill, capital and organization, which together form the basis of its industrial activity and of the production, for use or sale, of manufactured goods. For some of these goods, such as cotton, sale abroad is even more important than consumption at home.

The population of Great Britain has grown up under this special system ; it can continue to exist, at its present size and with its existing standard of life, only by the perpetuation of the conditions of its growth. It must sell a large part of its manufactured products abroad. Even if a greater share of the domestic market could be reserved for the native manufacturer, there would still remain, owing to the economic specialization of industry, a vast surplus which could not be utilized internally. There is a limit to the quantity of any particular kind of goods which an individual or group of individuals can consume, apart altogether from the question of price. Moreover, most of the goods consumed in Great Britain itself depend on imported

raw materials for which payment must be made in some form. We may reduce our imports somewhat, but we shall need always a large export in the form of manufactured goods.

Great Britain depends, and must depend, for its existence on the continued export of manufactures ; but it has no monopoly of production, and other countries also export in competition. Though the world as a whole is not overburdened with material wealth, the world-market for the particular kinds of goods produced in Great Britain is not unlimited. Certain goods sell best in certain markets, and such markets must be cultivated. On a long view, a market which is favourable to a manufacturer, and tending to expand, may be more worth cultivating than a much larger market which, for reasons, economic or political, is tending to contract.

The British Empire, or rather that section of it which is outside Great Britain, is, on the whole, a favourable and growing market for British manufactured exports. Many foreign countries also buy largely of these exports, but the relative importance of their purchases is generally declining. May we then argue that an increase in the wealth and prosperity of countries within the Empire is of more importance to Great Britain than a similar increase in foreign countries ? On the political side, the advantage of increased wealth in any part of the Empire organization is evident ; are we, however, justified in assuming that the economic growth of any part of the Empire will necessarily benefit the manufacturer in Great Britain and is, therefore, a matter with which his interests are intimately connected ? History, supported by much cumulative statistical evidence, proves that there is such connection in fact, and that it is very close ; it may be explained, partly by reference to the type of economic development in important sections of the Empire and the stage through which that development is passing, and partly as the result of definite policy.

The British Empire, on the map, consists of many countries, great and small, with every possible type of climate and products, distributed all over the globe ; from the view-point of trade, however, the Empire consists of people, of many races and in various stages of economic development. During the past generation there have been additions to the map, and, therefore, to the size of the market, but the really important increase has been in the numerical growth and economic advance of the population in the great regions which have not changed their boundaries vitally in recent years.

In 1891, the purchasing power of the Empire was represented by about 308 million people; in 1901, by 345 million; in 1911, by 375 million. In 1927 it was not far short of 400 million. This increase in numbers, large as it is, fails to give a true idea of the expansion of the market. We shall find that the growth in exports from Great Britain to the Empire is more rapid than the growth of population in the Empire. The facts are illustrated in the following table. For ease of comparison we will call the population and the volume of trade in 1901 a hundred, and will limit our survey to the present century, since the earlier figures are of doubtful validity.

Exports of Manufactures from the United Kingdom to the Empire.

Year.	Population of Empire. Index No.	Exports at Prices of 1900. £ Million.	Index No.	Per cent. of Total Exports of Manufactures.
1901 ..	100	90.9	100	39.5
1913 ..	109	155.6	171	41.3
1925 ..	114	122.5	135	42.4
1927 ..	115	147.2	162	45.8

Owing to statistical changes, the figures in the third column are liable to considerable error; it is, also, not possible for every year to obtain exact figures of population to correspond to the exports. It is clear, however, from these approximate figures, not only that the proportion of British manufactured exports credited to the Empire increased over the whole period, but also that the volume of trade increased more rapidly than the population constituting the real market. In other words, each individual in the Empire, on an average, accounted for a much larger part of our total sales at the end than at the beginning of the period, though the trade has not yet recovered the high level of 1913.

This average is based on the Empire as a whole, but individuals in that whole differ widely in buying-power. Let us consider this point. In 1927, on the basis of the declared values of our exports, we sold to India and Ceylon manufactured goods only to the extent of about 5s. 3d. per head of their population, whereas for Australia and New Zealand the figure was about £10. Changes, therefore, in these markets have a different implication and must be measured by a different standard. Australia already buys heavily; if she is to buy more, this is

likely to result only from an increase in the number of her people, and a very moderate increase is likely to have a marked effect on trade. The market is small in size, but each unit is extremely valuable. On the other hand, the same absolute increase in the population of India would have little effect on trade, since the buying power of the unit is small. India owes her importance to a small individual demand multiplied by the many millions of her population. A considerable growth in absolute numbers would have little commercial significance ; whereas, a very slight improvement in the economic condition of this vast mass of purchasers would result in an enormous addition to their total demand for goods. The development of this market depends not on growth of population, but on growth of prosperity and improvement in the internal condition of the country as a whole. An increasingly prosperous India will buy more goods, of some kind, and her chief purchases at present are from Great Britain. We have thus two means of measuring the value of a market ; we may consider the total amount of our manufactures which it takes, or the amount in proportion to its size, that is, its numbers. Both methods are necessary to correct and supplement each other, more particularly when we are estimating future possibilities.

We have considered the Empire in isolation, as a market for British manufactures, but this is not enough ; to find its place in our general system, we must make some comparison with foreign countries or groups of countries.

The real importance of Empire trade is a matter of the last thirty or forty years. In that period, not only has the Empire grown in population and wealth, but many foreign countries, formerly among our best customers, have developed their own manufactures behind a growing wall of protective tariffs, while the development of manufacturing industries in Empire countries overseas has not yet progressed very far. The number and elaboration of such protective tariffs in Europe have tended to increase rather than to decrease since the war. We have seen, in the table above, the general result on the distribution of our manufactured exports : more to the Empire, less to foreign countries generally. The Empire, it is true, has changed its content since 1900 ; it has grown by the addition of certain areas with their inhabitants ; such addition, however, is not sufficient to affect seriously the statistics of trade or the conclusions for which they provide a basis. The figures fairly represent the growth of manufactured exports from Great Britain to

those areas which now constitute the British Empire. The Irish Free State is excluded, as in this case no comparison with the past is possible. It must not be forgotten, however, in this connexion, that one of the most important of all markets is that of Great Britain itself. Figures strictly comparable to those of exports are not available, we can only guess at the value of this market from the estimates put forward in the census of production of 1924. These seem to indicate that of our manufactures about one-third are for export. If we assume that the same proportion holds in 1927, then the purchases by the home market in 1927 would be about £27 per head of the population of Great Britain as compared with £10 per head, calculated on a similar basis, by Australia and New Zealand combined.

The "world" is a somewhat vague and unsatisfactory unit for comparison; let us try a closer method. We may compare the Empire as a whole with Europe, the new market with the old, or we may compare selected parts of the Empire with certain foreign areas to which they bear some kind of resemblance. Let us attempt both methods, and see what results. For this purpose we will define Europe as excluding the area covered by the former Russian Empire, since the majority of the inhabitants of this area were never purchasers of British manufactures on a scale comparable to that of the rest of the Continent. Also, we shall thus avoid certain statistical difficulties. If Russia were included, the figures given in the fourth column of the following table would be lowered considerably. In Europe, thus defined, we have a population in 1927 of about 230 million, in part highly industrial, in part purely agricultural. In the Empire we have 390 to 400 million, most of whom can be classed as agricultural, in the broader sense of the term. The market consists of those people; let us compare their purchases of British manufactured exports.

Exports of Manufactures from the United Kingdom.

Year.	To Europe (excluding Russia). £ Million.	Index No. of Exports.	Per Head of Population.		To Empire. £ Million.	Index No. of Exports.	Per Head of Population.	
			s.	d.			s.	d.
1901	62	100	5	1	88	100	5	1
1913	101	163	7	7	170	193	9	1
1925	141	227	10	1	250	284	12	9
1927	120	194	8	6	247	281	12	6

We are not discussing here the changes in the real volume of the trade and so need not be worried by correction for prices ; we are concerned only with a comparison of the two areas. Towards the end of the nineteenth century, the European, on the average, still bought rather more of British manufactures than a citizen of the Empire. In the present century, the positions are reversed and the difference in favour of the latter is growing. If we include the Russian area, the European market is somewhat larger than that of the Empire, while its purchases work out at 6s. per head or less. This is on the basis of individual buying. On the other hand, if we consider each market as a whole, it is clear from these figures that nominal exports to the Empire since the beginning of the century have increased approximately half as fast again as those to Europe ; and, as we are dealing with broadly similar goods, we are justified in assuming that the real volume of trade has changed in somewhat similar proportion. Whether we look at trade per head or markets as a whole, the conclusion is the same ; the Empire has steadily outstripped Europe as a consumer of British manufactures.

Now let us turn to some smaller units. There are certain resemblances in the economic condition of temperate South America and the Southern Dominions, of India and the Far East, of Canada and Scandinavia. We need not press the similarity too far, but a brief comparison is perhaps worth while. Let us consider in the first place the fifteen and a half million people of Argentina, Uruguay, Paraguay and Chile, side by side with the seven and a half million of Australia and New Zealand and put the results in the following short table, using as before the method of index numbers.

Exports of Manufactures from the United Kingdom.

Year.	To Australia and New Zealand.			To South American States.		
	£ Million.	Index No. of Exports.	Per Head of Population.	£ Million.	Index No. of Exports.	Per Head of Population.
1901	24·0	100	£ s. d. 5 5 6	9·7	100	£ s. d. 1 5 6
1913	40·9	170	7 9 10	26·1	269	2 2 1
1925	76·3	318	10 6 2	33·5	345	2 0 4
1927	74·2	309	10 0 6	30·3	312	1 16 6

Australia and New Zealand, throughout the period, have always been the larger market, but in the first ten years of the century South America was gaining rapidly in relative importance. Since 1913, however, it has fallen back relatively. If we estimate in terms of population, we find that in 1890 the average Australian and New Zealander bought of British manufactures over three times as much as the average South American; in 1901 over four times as much; while, in 1927, the amount has risen to over five times. On either basis of estimate, the Australian and New Zealand market has become relatively more valuable in recent years.

A similar table for India and the Far East is less precise owing to the difficulty of estimating the population of the latter area. In 1921, the Indian market consisted of about 323 million people, and the Far Eastern market, that is China and Japan, of perhaps 490 to 500 million. We may say that the latter is roughly half as large again as the former.

Exports of Manufactures from the United Kingdom.

Year.	To India and Ceylon.			To Far East.		
	£ Million.	Index No. of Exports.	Per Head of Population.	£ Million.	Index No. of Exports.	Per Head of Population.
1901	34·8	100	s. d. 2 4	17·0	100	s. d. —
1913	70·8	203	4 5	31·2	184	1 8
1925	85·4	245	5 3	34·0	200	1 5
1927	84·4	242	5 2	27·8	164	1 1

These figures, like those in the table above, represent the nominal value of the goods as consigned from Great Britain, not the amounts actually paid by the recipient; but our present view-point is that of British exports as recorded in British statistics, and this is the only convenient basis of comparison.

Over the whole of the period, the Far-Eastern trade, though from a much smaller beginning, increases at a slower rate than that with India and Ceylon. The heavy fall in 1927 hardly needs explanation and may perhaps be followed by a recovery. The relative importance of India is still more marked in the figures of trade per head. Whatever may be the possible errors in the last column, it is evident that the native of India buys far more of British manufactures than the

native of China and Japan. Though both markets are depressed at the moment, there seems to be no indication of any marked change in their relative position ; in fact, the figures point to a definite and sustained decline in purchases per head of the Far-Eastern population.

Let us now glance briefly at a part of the Empire where economic conditions are very different from those in the area, dealt with above.

Exports of Manufactures from the United Kingdom.

Year.	To Canada and Newfoundland.			To Scandinavia (Norway, Sweden and Denmark).		
	£ Million.	Index No. of Exports.	Per Head of Population.	£ Million.	Index No. of Exports.	Per Head of Population.
1901	7.3	100	£ s. d. 1 6 0	6.7	100	£ s. d. 0 13 7
1913	20.8	285	2 15 11	10.7	160	0 19 0
1925	23.7	325	2 8 2	19.0	284	1 10 10
1927	24.1	330	2 9 11	17.4	260	1 8 2

In the early part of this century, Canada gained rapidly on Scandinavia as a market, but later dropped back. Over the whole period, however, there is a distinct improvement in her relative position. We must not forget, in this comparison, that Scandinavia is nearer to Great Britain and has no United States on her boundaries with special advantages and opportunities for competition. Tested by purchases per head of population, Canada has lost ground recently, though she still ranks far above Scandinavia. The markets are fairly comparable in size, since, in 1927, Scandinavia contained about twelve million people, as against nine and a half million in Canada and Newfoundland. Collectively and individually the nine and a half buy considerably more of British manufactures than the twelve.

Can we really learn much that is useful from these figures of total values? It is true that they give a broad view of the relative importance of various markets from time to time ; but this is not enough. Trade deals in material things, and to approach nearer to reality we must consider goods of a definite kind. It is not possible, from the nature of the case, to draw a complete picture, but we can perhaps give a more precise meaning to part, at any rate, of the general figures of the tables above.

We may consider first the share of the Empire as a whole in our export of certain commodities, and then go on to ask to what parts of the Empire most of this share is credited? For purposes of comparison, we may perhaps ask similar questions as to certain foreign countries or groups of countries. The figures above show that some of the most marked changes in the distribution of the trade in this century have occurred since 1913, so we will content ourselves with asking what were conditions in 1927, the latest year for which complete figures are available, and how do these compare with the conditions of 1913, a year, it must be remembered, of prosperous trade.

First, let us turn to one of our most important basic industries—iron, steel, and engineering, including machinery and vehicles of all kinds, as well as structural and other materials. This great group accounts normally for about a quarter of the total value of manufactured exports from Great Britain, and the relative importance of its constituents is shown in the following table:—

Percentage of Total Exports of Manufactures from the United Kingdom.

	1913.	1925.	1927.
Iron and steel	13·5	11·2	12·5
Machinery	8·1	8·2	9·1
Vehicles, etc.	5·9	5·3	5·6
Total	27·5=£113 million	24·7=£136 million	27·2=£147 million

The real percentages are somewhat higher than those shown here, since the Board of Trade includes in the schedule of total exports of articles "wholly or mainly manufactured", various commodities which are not treated as "manufactures" in ordinary speech or thought. The percentage figures for 1927, compared with those for 1925, indicate a recovery almost to the level of 1913 in the relative position of the group as a whole, a recovery due to the increase under the heading "machinery".

The table above merely indicates the importance of the various items in the export business of Great Britain; and before analysing these in detail it is useful to have a general idea of their distribution by markets, more particularly in the Empire.

Per Cent. Exports to the Empire (by value).

	1913.		1925.		1927.	
	Per cent.	Total Exports all Destinations. £ Million.	Per cent.	Total Exports all Destinations. £ Million.	Per cent.	Total Exports all Destinations. £ Million.
Iron and steel ..	48.1	55.4	51.7	66.4	56.5	67.7
Machinery ..	32.5	33.6	45.0	48.2	47.0	49.0
Vehicles, etc. ..	38.2	24.5	55.7	31.5	55.2	30.3

Percentages are dangerous weapons in argument ; the share of the Empire in 1927 indicated above may be calculated on a larger, a smaller, or on the same total as in former years, and that total may be measured by nominal values as above or by actual quantity or volume. The growing share of the Empire in the three groups is evident, but it is essential, for a true picture, to know whether the figures of value represent a genuine increase in the volume of trade or merely a rise in price levels. Wherever possible, in the following analysis, quantity rather than value is used as the basis of comparison. Let us try to measure approximately the relative importance of markets in 1913 and 1927, omitting for the moment the group headed "vehicles" as being too specialized and miscellaneous to admit of broad quantitative comparisons.

*Volume and Distribution of Export Trade.
Iron and Steel.*

	Exports, 1913.	Index Numbers.		
	Million tons.	1913.	1925.	1927.
Total Exports	4.97	100	74	83
Foreign countries ..	2.69	100	68	67
Empire	2.28	100	77	102
Canada	0.19	100	55	49
Australia	0.57	100	76	110
New Zealand	0.15	100	99	94
South Africa	0.26	100	84	84
India	0.86	100	69	97

Machinery.

	Exports, 1913.	Index Numbers.		
	Million tons.	1913.	1925.	1927.
Total Exports	0·69	100	74	73
Foreign countries	0·46	100	60	58
Empire	0·23	100	101	103
Canada	0·02	100	70	95
Australia	0·04	100	93	100
New Zealand	0·01	100	163	146
South Africa	0·03	100	84	91
India	0·10	100	103	93

The figures above, though based on quantities, are only approximate guides to the facts, since a ton of steel or machinery is not necessarily constituted by various items in the same proportions in the two years. The broad conclusions, however, are not affected by this error. In spite of the higher nominal value, there is an actual fall in the total export of iron and steel in 1927 as compared with 1913, but the fall is confined to foreign countries, as the Empire shows a marked recovery in 1927 as compared with 1925. If we look at the constituent parts of the Empire we see that only in the relatively small Canadian trade is the fall greater than that to foreign countries generally. In all other groups, where a fall is recorded, it is less than the fall in the volume of the trade as a whole. In the case of machinery, the relative increase shown above in the percentage table is also a real increase, while progress in the Empire markets as a whole is rather greater than in iron and steel.

We will now attempt to analyse these general statistics in terms of definite groups of exports, that is to approach nearer to reality. In 1927, the total value of exports of iron and steel was nearly £68·0 million, divided approximately as in the following table :—

*Analysis of Exports of Iron and Steel from the United Kingdom
(Approximate Percentages by Value).*

	1913.	1925.	1927.
Pig iron	8·7	5·2	2·9
Structural iron and steel ..	11·2	7·9	8·8
Plates and sheets (uncoated)	5·6	7·5	8·9
Galvanized sheets	18·1	20·2	19·8
Tinned and terne plates ..	13·0	17·4	14·9
Tubes, pipes and fittings ..	8·4	9·3	10·5
Railway materials	12·1	8·3	12·1
Wire and wire goods	4·5	5·8	5·0
Miscellaneous	18·3	18·5	17·2
Total	100·0=£55·4 million	100·0=£66·4 million	100·0=£67·7 million

It is important, before discussing the share of the Empire in any particular group of exports, to estimate roughly the importance of that group in British exports as a whole ; for instance, a 10 per cent. gain in galvanized sheets is clearly of much greater significance than the same gain in wire. Thus, the purpose of the above figures is to give an idea of the relative importance of certain large groups as defined in our export statistics, that is to fill in the picture of iron and steel trade from the point of view of British industry. The last item, "miscellaneous", includes all items not specially scheduled above, and though incapable of further definition is a useful guide to general conditions in the export business of iron and steel. Let us now consider, with the aid of the diagram and the tables below, the position of the Empire in relation to the various parts of the trade in iron and steel. The figures represent the minimum necessary for our purpose.

Two broad facts are apparent in this picture ; in the first place, a comparison of the figures of total percentages in each group shows that in every section, except uncoated plates and sheets and railway material, the share of the Empire has increased to a marked degree ; in the second place, for structural iron and steel, galvanized sheets, tubes and pipes, railway material, wire and miscellaneous goods, the Empire, in 1927, was a larger market than all foreign countries together. This latter point is illustrated graphically in the diagram given in the Appendix. The remaining columns in the tables enable

Percentage of Exports of Iron and Steel from the United Kingdom to Empire Markets.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). Million Tons.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Total iron and steel	19.8	21.8	23.8	20.4	20.1	24.5	4.1	3.8	2.9	1.8	4.4	5.0	45.9	50.1	56.2	4.97	3.67	4.12
Pig iron	4.3	5.0	6.1	1.2	2.7	5.5	3.2	1.4	1.8	0.4	0.5	1.8	9.1	9.6	15.2	1.12	0.55	0.33
Structural	32.7	39.0	44.6	22.8	21.3	27.3	5.7	1.6	2.4	5.3	7.1	4.0	66.5	69.0	78.3	0.53	0.36	0.48
Plates (uncoated)	14.5	19.5	26.0	18.5	11.2	9.9	8.7	6.0	2.9	2.2	1.6	1.0	43.9	38.3	39.8	0.28	0.35	0.48
Galvanized sheets	21.9	23.5	26.7	33.1	40.3	42.6	4.6	1.7	1.4	3.4	4.6	6.8	63.0	70.1	77.5	0.76	0.70	0.76
Tinned plates ..	7.2	12.7	14.0	13.9	9.7	9.7	2.0	7.0	5.7	0.4	0.8	1.5	23.5	30.2	30.9	0.49	0.51	0.47
Tubes	20.1	28.8	35.1	17.0	19.4	19.7	4.4	1.7	2.8	7.8	15.6	7.7	49.3	65.5	65.3	0.40	0.28	0.37
Railway materials	32.0	15.6	8.5	21.3	21.3	26.9	0.1	1.0	0.8	21.6	30.8	20.2	75.0	68.7	56.4	0.77	0.42	0.72
Wire	41.4	50.4	47.6	7.4	8.1	10.6	7.0	5.5	8.0	1.8	3.5	4.9	57.6	67.5	71.1	0.12	0.12	0.11
Miscellaneous ..	19.3	20.1	21.5	25.8	27.0	30.2	3.5	2.3	2.7	6.4	11.0	10.4	55.0	60.4	64.8	0.50	0.39	0.40

us to give a more definite meaning to the diagram and the table of percentages. Let us analyse the position in 1927 as thus illustrated.

In the first place, it is clear that the total export of iron and steel to Empire markets in 1927 is to be credited mainly to two important groups, the Southern Dominions and the East Indies; the others are relatively insignificant. Though these large groups are of equal importance, approximately, in the trade as a whole, the factors in the totals differ. The Southern Dominions lead easily in structural material, plates uncoated and tinned, tubes and wire, while the East Indies offer a much larger market for galvanized sheets, railway material and miscellaneous iron and steel. British America appears as relatively important in pig iron, tinned plates and wire, although in no group is it so important as the two leading markets, while the rest of the Empire, largely Africa, takes considerable quantities of galvanized sheets, tubes and pipes, railway and miscellaneous material. Its share in railway material is especially marked.

This is the static view. If we compare with 1913, we see that there has been little change in the relative position of the Southern Dominions and the East Indies in the matter of total trade; in certain categories, however, such as plates uncoated or tinned, tubes and pipes, the East Indies have lost ground comparatively, while in others, such as railway material, they have gained. In Canada there is a decrease under most headings, as also in the total share of the trade, while in the rest of the Empire increases are not uncommon, though the total is small. We can conclude, broadly, from these tables not only how the total Empire share of each item is made up, but also in what directions the constituent factors are tending to change. We have thus some basis for an estimate as to where a trade is of importance at the moment, and where it is likely in the future to improve or otherwise.

The Empire, however, must not be treated in isolation; it is only part, though an important part, of the market for British manufacturers. What of the rest of the world? The position is summarized roughly in the following table, constructed on the same principle as the table above.

The unusually high figures for pig iron under the heading "other foreign countries" are accounted for by the United States, which took a large part of the exports. As the United States is only an occasional buyer of British iron and steel products it is not grouped separately. The foreign share of the market under this heading is exceptional, since the Empire is naturally not a buyer on a large scale of pig iron. If pig iron be omitted from the total, the share of the Empire in the iron and steel trade generally is thereby increased.

Percentage of Exports of Iron and Steel from the United Kingdom to certain Foreign Markets.

	Europe.			South America.			Far East (China, Japan, Hong-Kong).			Other Foreign Countries.			Total.			Total Exports (all Destinations). Million Tons.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Total iron and steel	26.5	20.7	14.8	11.5	11.3	11.4	6.5	5.7	5.7	9.6	12.2	11.9	54.1	49.9	43.8	4.97	3.67	4.12
Pig iron	66.7	58.4	63.4	1.8	1.6	1.5	8.6	1.4	2.8	13.8	29.0	17.1	90.9	90.4	84.8	1.12	0.55	0.33
Structural	10.3	12.4	6.6	8.3	6.0	4.4	7.6	3.0	3.9	7.3	9.6	6.8	33.5	31.0	21.7	0.53	0.36	0.48
Plates (uncoated)	29.0	16.2	3.6	5.1	12.7	21.7	16.6	29.2	28.1	5.4	3.6	6.8	56.1	61.7	60.2	0.28	0.35	0.48
Galvanized sheets	4.2	5.3	6.9	14.7	12.7	5.4	5.6	1.4	0.7	12.5	10.5	9.5	37.0	29.9	22.5	0.76	0.70	0.76
Tinned plates ..	45.9	41.6	44.6	6.8	10.1	9.0	10.1	9.0	5.7	13.7	9.1	9.8	76.5	69.8	69.1	0.49	0.51	0.47
Tubes, etc. .. .	9.6	4.8	7.4	31.8	14.8	12.3	2.7	2.7	2.2	6.6	12.2	12.8	50.7	34.5	34.7	0.40	0.28	0.37
Railway materials	6.2	0.9	2.0	9.9	19.4	19.3	—	—	—	8.9	11.0	22.3	25.0	31.3	43.6	0.77	0.42	0.72
Wire	14.2	13.3	10.5	10.5	8.2	7.8	—	—	—	17.7	11.0	10.6	42.4	32.5	28.9	0.12	0.12	0.11
Miscellaneous ..	8.0	5.8	5.0	16.4	11.0	9.0	4.2	4.6	4.4	16.4	18.2	16.8	45.0	39.6	35.2	0.50	0.39	0.40

Europe is mainly responsible for the decline in the foreign share of the exports; such decline might be anticipated in view of the post-war revival and reorganization of the iron industry in the western Continent, and the collapse of the market in the eastern areas. South America maintains its relative position, though both here and in the Far East there are interesting changes in the factors constituting the total, particularly in the closely related trades in uncoated, tinned and galvanized plates and sheets. The Far-Eastern market is tending to decline; if this tendency continues it will soon be outrivalled by the "Rest of the Empire" as a consumer of British iron and steel. It is not even to be measured on the same scale as the East Indies, while South America is falling still farther behind the Southern Dominions.

In the machinery section, as we have seen, the share of the Empire as a whole shows a remarkable advance in 1927 on 1913. The group labelled machinery, and valued in 1925 at about £49 million is constituted as follows:—

*Analysis of Exports of Machinery from the United Kingdom
(Approximate Percentages by Value).*

	1913.	1925.	1927.
Agricultural machinery ..	8.7	3.4	2.8
Boilers, etc... ..	5.3	5.8	5.7
Electrical machinery ..	6.7	11.9	13.6
Machine tools	3.0	3.4	3.3
Prime movers	15.5	11.1	9.8
Sewing machines	7.0	6.1	5.3
Textile machinery	24.6	25.0	24.0
Miscellaneous	29.0	33.3	35.9
Total	100.0=£33.6 million	100.0=£48.2 million	100.0=£49.0 million

If we look back to 1913, we find that agricultural machinery has fallen greatly in relative importance, while electrical has increased until it is second only to textile machinery in the special groups. Machinery other than that specially scheduled is now more than a third of the whole. The diagram and tables as before show the general distribution of these exports between foreign countries and the Empire and within the Empire in 1913 and 1927.

Percentage of Exports of Machinery to Empire Markets.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). Million Tons.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Total machinery..	11.5	14.9	15.9	16.7	24.5	23.8	3.2	3.5	4.3	2.6	3.5	3.6	34.0	46.4	47.6	689	509	504
Agricultural ..	7.0	34.7	32.4	3.8	5.5	5.6	—	—	—	1.9	13.8	5.5	12.7	54.0	43.5	073	021	018
Boilers	13.6	7.0	10.0	13.6	13.9	22.4	3.8	0.9	0.8	2.6	15.1	9.5	33.6	36.9	42.7	069	055	052
Electrical ..	21.4	38.5	44.5	14.9	21.0	17.7	7.5	3.5	4.2	2.6	6.5	4.7	46.4	69.5	71.1	027	039	041
Machine tools ..	16.0	23.5	22.1	8.6	26.8	26.9	—	—	—	5.1	8.4	9.6	29.7	58.7	58.6	016	014	014
Prime movers ..	14.1	13.7	13.8	16.9	33.5	30.7	2.0	5.1	9.3	2.7	2.3	2.5	35.7	54.6	56.3	095	056	049
Sewing machines	2.7	8.5	7.6	5.2	8.6	10.5	—	—	—	0.1	1.2	2.2	8.0	18.3	20.3	033	029	027
Textile	0.8	2.0	3.3	28.3	28.5	20.9	2.6	0.8	2.8	0.3	1.9	0.8	32.0	33.2	27.8	178	123	119
Miscellaneous ..	19.9	18.4	17.4	16.7	23.3	27.4	4.8	4.5	5.3	4.0	10.0	9.3	45.4	56.2	59.4	198	177	186

There is remarkable unanimity in the items. In all, with the exception of textile, the share of the Empire has increased in 1927; while, in agricultural and electrical machinery, machine tools, prime movers, and miscellaneous, constituting together nearly two-thirds of the total value of machinery exported, the Empire was a more important market than the rest of the world.

Let us examine more closely these two groups of figures, keeping in mind the relative importance of the various items in the British export trade. For instance, the figures for agricultural and electrical machinery in the column for the Southern Dominions must be interpreted in the light of the table above, showing the relative position of the two trades in 1913 and 1927. In the total export of machinery every part of the Empire shows a relative gain, though, as in the case of iron and steel, the chief markets are the East Indies and the Southern Dominions. The absence of certain items from the British American column is easy to understand. The change is most remarkable in agricultural machinery, but the apparent gain in the Empire must be discounted by the great fall in total exports mentioned above. The growth in Empire consumption of electrical machinery is a far different matter, since here the Empire is responsible for a larger share of a rapidly *increasing* trade.

The marked increase in the East Indian share of the whole trade is accounted for under the headings: boilers, electrical, machine tools, prime movers, and miscellaneous; there is naturally no large demand in that area for agricultural machinery. Moreover, in spite of the heavy fall in 1927, India still remains the chief individual market for textile machinery, though the small but growing share of the Southern Dominions—in this case, Australia—is worth notice. The table again illustrates the special conditions of the Canadian market and the growing importance in nearly all schedules of the "Rest of the Empire". Our final comparison, as before, is with groups of foreign countries.

Europe, again, is largely responsible for the decline in the relative importance of foreign countries in 1927; and it is significant that this decline is under all headings except that of textile machinery. The South American figures indicate a general decline in 1927, though agricultural machinery is steady. The unusual figure for textile machinery to this market in 1925, is perhaps worth notice, owing to its possible reaction on our export of textile goods. The Far East was never of great importance and is a falling market apart from

Percentage of Exports of Machinery to Foreign Markets.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). Million Tons.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Total machinery..	37.7	26.1	27.2	10.5	10.2	8.1	6.5	5.9	5.8	11.3	11.4	11.3	66.0	53.6	52.4	.689	.509	.504
Agricultural ..	65.0	31.5	41.2	13.2	13.2	13.6	—	—	—	9.1	1.3	1.7	87.3	46.0	56.5	.073	.021	.018
Boilers	30.5	21.9	25.1	9.2	5.9	6.9	5.1	12.2	9.6	21.6	23.1	15.7	66.4	63.1	57.3	.069	.055	.052
Electrical ..	13.4	14.3	11.0	17.9	7.8	8.1	11.9	5.7	6.4	10.4	2.7	3.4	53.6	30.5	28.9	.027	.033	.041
Machine tools ..	37.7	29.0	24.8	11.7	3.3	6.2	13.6	3.5	2.8	7.3	5.5	7.6	70.3	41.3	41.4	.016	.014	.014
Prime movers ..	33.9	11.4	20.6	11.6	7.4	7.9	6.3	3.5	2.4	12.5	23.1	12.8	64.3	45.4	43.7	.095	.056	.049
Sewing machines	80.4	69.8	61.2	2.7	0.6	0.4	1.2	5.5	8.1	7.7	5.8	10.0	92.0	81.7	79.7	.033	.029	.027
Textile	43.1	43.8	52.2	7.2	13.4	6.6	13.0	3.7	9.1	4.7	5.9	4.3	68.0	66.8	72.2	.178	.123	.119
Miscellaneous ..	20.8	13.0	12.5	12.4	9.4	9.2	3.7	4.3	2.9	17.7	17.1	16.0	54.6	43.8	40.6	.198	.177	.186

the small business in sewing machines. As the statistics throughout are on the same basis, that is percentages of our total exports in each case, it is easy to make a direct comparison between any foreign and any Empire group, both for general trade and for any particular item on the schedules. Such comparisons illustrate in detail the growing importance of the Empire as a market for British exports of machinery, and give a fuller meaning to the diagram and the tables of total percentages.

To complete our review of a quarter of British manufactured exports, we will turn to the group labelled "vehicles", and valued in 1927 at about £30 million.

*Analysis of Exports of Vehicles from the United Kingdom
(Approximate Percentages by Value).*

	1913.	1925.	1927.
Ships	45.2	20.1	14.9
Locomotives and parts.	11.4	10.1	9.5
Railway carriages and parts.	13.8	17.2	20.9
Tractors.. ..	2.6	1.5	1.2
Motor cars	9.9	14.4	13.3
Motor chassis ..	1.9	7.4	12.6
Motor cycles	3.0	5.7	7.0
Cycles	2.5	3.7	3.3
Parts of motors and cycles.	9.4	16.3	13.8
Aeroplanes and parts.	0.2	3.7	3.6
	100.0=£24.5 million	100.0=£31.5 million	100.0=£30.3 million

A comparison between 1927 and 1913 is here of vital significance. The motor vehicle, in some form, has ousted the ship from its leading position in the group and has left even the products of the railway industry far behind. Within the motor section, the motor cycle has gained on the car, while the most rapid progress of all is made by motor chassis. The table will indicate the extent to which the various parts of the Empire are concerned in these revolutionary changes.

Percentage of Exports of Vehicles to Empire Markets.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Ships and boats ..	9.1	9.1	8.8	2.1	4.9	14.9	3.3	12.6	10.1	1.5	8.7	4.0	16.0	35.3	32.8	10.98	6.28	4.50
Locomotives ..	18.1	20.0	9.6	37.1	42.9	32.1	—	—	—	5.0	9.1	11.3	60.2	72.0	53.0	2.78	2.65	2.27
Railway carriages	8.1	7.6	6.2	41.8	39.1	33.5	—	—	—	6.8	8.7	10.8	56.7	55.4	50.5	3.35	5.38	6.28
Tractors	16.1	25.4	15.2	15.4	21.3	33.4	3.1	0.9	0.9	3.8	4.5	6.2	38.4	52.1	55.7	0.63	0.48	0.35
Motor cars ..	37.5	46.3	25.5	23.6	24.4	39.6	2.2	0.3	0.5	3.2	10.2	13.5	68.5	81.2	79.1	2.40	4.50	4.00
Motor chassis ..	57.4	81.5	80.2	8.7	6.9	4.6	5.2	0.4	0.6	0.5	3.0	3.9	71.8	91.8	89.3	0.47	2.32	3.78
Motor cycles ..	51.3	39.3	35.6	7.0	5.6	6.4	—	—	—	8.8	9.2	7.1	67.1	54.1	49.1	0.73	1.80	2.11
Cycles	9.3	7.1	6.3	28.3	36.2	48.5	7.4	2.1	4.4	11.1	22.1	16.4	56.1	67.5	75.6	0.61	1.15	0.99
Parts of motors ..	24.5	20.4	23.1	8.7	13.3	15.0	1.5	0.9	2.6	3.7	4.6	9.3	38.4	39.2	50.0	2.29	5.10	4.17

Of the trades represented in the above table, some have declined while others have increased in volume. In most, the share of the Empire is larger, but railway vehicles seem to offer a serious exception. The Empire has always drawn largely on Great Britain for the equipment of its railways, but the trade tends to fluctuate widely from year to year and from country to country in response to railway policy ; hence it is difficult to draw conclusions from the comparison of two selected years. This point is well illustrated by the locomotive figures for 1925 and 1927. For railway vehicles, the East Indies still remain the chief market, though the development of transport in Africa is making an impression under the heading " Rest of Empire ". The blank in the British-American column needs no comment.

We have noted the fall in the export of ships. The Empire has never been a large market, yet its share of the total is now nearly a third. It has improved its position only because the trade is heavily reduced and through the exceptional demand from Canada and the East Indies. The export of ships, like that of railway material, is naturally subject to rapid changes over short periods, and it is difficult to estimate general tendencies.

In the motor and motor-cycle business, as in railway material, British America is naturally an insignificant market since Canada herself exports, but the Southern Dominions and East Indies compensate, particularly the former. There is a marked increase also in the " Rest of the Empire ", and the Empire as a whole accounts not only for most of the market but also for most of the increase in the period. The distribution of the export of cars in relation to chassis in the various groups is noteworthy, while that of bicycles has peculiarities well illustrated in the figures. The whole group can be understood only in relation to the table below dealing with foreign countries.

In ships, Europe was formerly our chief customer and there is no alternative market of like size. Here, therefore, is the main source of the depression. Japan now builds for herself, while the figures for " other foreign countries " measure both a relative and an absolute increase in miscellaneous markets. For railway vehicles and equipment, South America is the only large market outside the Empire ; the decline here may perhaps be temporary, as may be the rise in the figures for miscellaneous foreign markets. Europe also accounts largely for the decline in our foreign exports of tractors, motor cars and chassis, and cycles, though for the last the Far East is also responsible. The small South American trade, really in " luxury "

Percentage of Exports of Vehicles to Foreign Markets.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Ships	63.5	47.3	37.9	5.5	8.1	12.5	10.3	—	—	4.7	9.3	16.8	84.0	64.7	67.2	10.98	6.28	4.50
Locomotives ..	3.9	5.2	1.1	32.2	20.9	22.8	—	—	6.7	3.7	1.9	16.4	39.8	28.0	47.0	2.78	2.65	2.27
Railway carriages	1.8	4.8	6.5	35.2	26.3	22.9	—	—	—	6.3	13.5	20.1	43.3	44.6	49.5	3.35	5.38	6.28
Tractors	43.9	8.3	6.1	1.8	0.7	10.2	0.8	3.9	1.7	15.1	35.0	26.3	61.6	47.9	44.3	0.63	0.48	0.35
Motor cars ..	20.8	8.0	7.8	5.3	0.9	2.5	—	—	—	7.4	9.9	10.6	33.5	18.8	20.9	2.40	4.50	4.00
Motor chassis ..	22.5	2.2	2.8	0.8	1.5	4.2	0.8	1.7	0.4	4.1	2.8	3.3	28.2	8.2	10.7	0.47	2.32	3.78
Motor cycles ..	28.2	34.1	40.0	—	—	—	—	—	—	4.7	11.8	10.9	32.9	45.9	50.9	0.73	1.80	2.11
Cycles	17.4	6.4	5.8	3.5	1.5	1.6	11.1	5.6	2.5	11.9	19.0	14.5	43.9	32.5	24.4	0.61	1.15	0.99
Parts of motors, etc.	42.0	33.7	27.2	1.8	1.8	2.9	5.2	7.3	5.5	12.6	18.0	14.4	61.6	60.8	50.0	2.29	5.10	4.17

cars, is reduced, while that in chassis increases. Except for motor cycles, where the European market has expanded, the foreign business is now of secondary importance, in spite of a general growth in miscellaneous foreign markets. Any large increase seems likely to depend on the further development of Empire markets with the building of vehicles to suit their special conditions.

Up to this point, we have been dealing in percentages to illustrate, generally and in detail, the relative rates of progress of Empire and foreign markets. The details in the tables are based for the most part on quantities, though in some cases totals are given in values. In effect this mixing of two standards matters little, since the general percentages calculated on quantity are not so far removed from those calculated on value as to affect the substantial accuracy of the picture. The totals are added to give a rough idea of the size or importance of the trade to which the percentage figures refer.

We will now try to summarize broadly the meaning of the percentages in the groups dealt with above, in the light of certain facts which are not directly shown in the figures as set out. We have noted above, incidentally, that the exports analysed are sometimes growing, sometimes declining, and that increases in the share of the Empire must be qualified accordingly. Let us consider, in this sense, the three main groups discussed above, and in the first place, iron and steel.

In this group, in 1927 compared with 1913, if we regard the total volume of the various constituent trades, uncoated plates, alone, show a marked increase, while galvanized sheets are steady; in all other items on the list, total exports from Great Britain register an actual decrease, ranging from 4 to 8 per cent., except under pig iron, where the fall is as much as 70 per cent., and under "miscellaneous", where the decrease is 20 per cent. We must not forget, however, in this connection, that trade in the year 1913 was unusually prosperous, so that the decline from the average pre-war level is probably less than the figures suggest. As we see from the tables above, there was a slight fall in the *share* of the Empire in uncoated plates, and a greater fall in railway material. The significance of the figures in the latter case has been already discussed. In all other items the share of the Empire increases to a marked degree, while in the general total it rises from 46 to 56 per cent. This is from the point of view of relative progress; but how far is this progress actual? What is the real movement of Empire trade considered by itself?

The figures of totals, here, are merely the net result of counting plus and minus factors, and in these factors lies the real significance of the changes. In the actual volume of Empire trade, there was a slight fall—less than 5 per cent.—in the period, under “miscellaneous”, and a fairly heavy fall in the exports of pig iron and railway material, although in the case of the former, exports to the Empire were never of substantial proportions; in all other groups the volume of British exports to Empire markets increased. The rate of increase varied from 8 to 57 per cent., but in only one schedule was it less than 18 per cent. The result of these gains and losses was a very slight gain in the grand total; and we may say broadly, that the iron and steel trade with the Empire, though depressed in certain directions, has reached generally the level of a most prosperous pre-war year. The decline of 17 per cent. in the total of British exports in the group is seen to be due entirely to foreign markets.

In machinery, though the general movement is similar, the factors entering into it are more varied and the result on balance more difficult to estimate. In this group there is a decline in total exports under every heading except “electrical machinery”, which records a 50 per cent. gain. The decline ranges from 6 per cent. for “miscellaneous” to 75 per cent. for agricultural machinery, but decreases lie for the most part between 20 and 50 per cent. This is on the total export. How does the Empire stand in regard to these trades? Except for a slight loss in textile machinery, the share of the Empire increases considerably in every section of the trade, and rises in the total from 34 to 48 per cent.

As trade has declined under nearly all headings, percentages are clearly not sufficient; we must consider also the actual trade with the Empire. In this, the most serious fall is one of 40 per cent. in textile machinery, followed by agricultural machinery and prime movers, with about 17 and 18 per cent. respectively and a slight decline in boilers and boiler-house plant. Other schedules register increases ranging from 20 per cent. for “miscellaneous” to 130 per cent. for “electrical”. The net result is again a slight rise in the figures for the total volume of Empire trade, leaving, as in the case of iron and steel, the fall of 27 per cent. in total exports of machinery to the account of the foreign market. In the sections of the trade where there is a decline in the total, in some instances exports to the Empire show an actual increase, in others a decrease, but nearly always such

decrease is less proportionately in Empire than in foreign markets. Hence the rise in the relative importance of the Empire as a market for British manufactured exports of iron, steel, and machinery.

Under the general heading "vehicles", the export of ships and locomotives falls heavily, the fall in ships being over 60 per cent. For ships and tractors, the fall to the Empire is less than that in the whole trade, and the share of the Empire, therefore, increases. On the other hand, exports of motor cars and parts and of motor cycles and cycles all show a heavy increase. Only in motor cycles does the Empire show a relative decline, though the actual exports to the Empire are more than doubled. In all other parts of the motor and cycle business, without exception, not only has the percentage exported to the Empire risen greatly, but actual exports have increased by 120 to 140 per cent. under the various headings. The gains in the newer trades compensate for losses in the older; for these gains the Empire is mainly responsible, while the losses are generally, though not invariably, greater in foreign markets.

The group below may be labelled generally "textile", though certain items under apparel, such as boots, belong to another category. The relative importance of the different sections and the share of the whole group in our manufactured exports are shown in the table following:—

Percentage of Total Exports of Manufactures from the United Kingdom.

	1913.	1925.	1927.
Cotton yarns and piece-goods, etc.	30·8	33·6	27·2
Wool tops, yarns and manufactures	8·7	9·8	10·3
Miscellaneous textiles	4·4	4·9	5·3
Apparel	5·1	4·0	4·0
Total	49·0=£201 million	52·9=£309 million	46·8=£253 million

We may regard these trades as normally responsible for about half our exports of manufactures; the depression in the cotton business accounts for the lowering of this proportion in 1927, while wool and miscellaneous are growing steadily in relative importance. To estimate

their significance from the point of view of Empire trade we must consider the groups separately. Let us analyse the group of cotton goods. The total exports are made up in the following proportions :—

*Analysis of Exports of Cotton Goods from the United Kingdom.
(Approximate Percentages by Value).*

	1913.	1925.	1927.
Piece-goods	77·3	75·4	73·9
Yarns	11·8	15·4	16·0
Flags and shawls	1·0	1·2	1·1
Lace and net	3·2	1·1	1·0
Thread	2·7	3·8	4·3
Miscellaneous	2·6	2·5	3·2
Manufactured waste	1·2	0·3	0·2
Total	100·0=£127 million	100·0=£198 million	100·0=£147 million

From the point of view of Great Britain, piece-goods and yarns are the main basis of the trade; the distribution of these, together with the smaller items, among Empire and foreign markets is sufficiently indicated in the diagram and tables. If we add together the *value* of all piece-goods, we find that the share of the Empire has decreased very slightly and stands approximately at a half. Our tables, based on quantities, show a similar fall. The Empire share in yarns has also decreased, but in all the minor items of the list it has increased moderately.

In 1913, the East Indies constituted the chief Empire market for the cotton trade except in the comparatively unimportant lace and miscellaneous sections. The decline in this great market accounts largely for the 40 per cent. loss in total export of piece-goods and for the fact that the share of the Empire is almost stationary. The Southern Dominions and "Rest of Empire" improve their relative positions under every schedule, but their trade in piece-goods and yarns is so small, relatively, that its growth has little effect on the general position. The piece-goods trade is such a large part of the whole cotton business that its progress merits further analysis.

Percentage of Total Exports of Cotton Manufactures from the United Kingdom to the Empire.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Piece-goods ..	3.9	5.9	6.9	45.6	31.7	40.0	2.2	1.7	1.8	2.7	5.3	5.6	54.4	44.6	54.3	97.80	149.60	108.90
Yarns	0.7	1.4	2.7	18.6	8.5	10.9	1.7	0.6	0.8	0.9	1.8	1.7	21.9	12.3	16.1	15.00	30.50	23.60
Flags and shawls.	3.5	9.5	11.3	10.1	5.9	7.0	2.2	5.9	9.2	7.3	9.0	11.9	23.1	30.3	39.4	1.22	2.36	1.63
Lace and net ..	9.2	20.7	21.6	2.0	7.2	5.9	7.0	10.4	9.9	1.8	4.2	4.7	20.0	42.5	42.1	4.11	2.19	1.62
Cotton thread..	7.2	9.9	11.9	10.1	11.7	11.3	3.6	2.9	2.4	2.4	3.1	4.0	23.3	27.6	29.6	3.46	7.54	6.35
Miscellaneous..	32.9	46.5	47.2	13.2	8.1	6.6	15.0	7.7	9.5	5.7	7.5	9.7	66.8	69.8	73.0	3.34	5.01	4.66

Volume and Distribution of Export Trade in Cotton Piece-Goods.

	Exports, 1913.	Index Nos.		
	Million Yards.	1913.	1925.	1927.
Total exports ..	7,075	100	65·2	58·8
Foreign countries ..	3,225	100	79·2	59·0
Empire	3,850	100	53·5	58·6
South Africa ..	68	100	100·1	103·2
Australia ..	168	100	97·3	106·2
New Zealand ..	43	100	94·4	90·9
India	3,057	100	43·7	50·7
Canada	110	100	42·5	42·7
West Africa ..	154	100	117·8	108·7

The decline in the total trade is due more to the Empire than to foreign countries, since the share of the former was larger in 1913 and it shows a slightly greater percentage fall. For this fall, the explanation must be sought mainly in India, since the Canadian trade is relatively insignificant. The position in the Southern Dominions and West Africa is far more favourable.

As foreign countries account for nearly half of this important trade, a comparison here is clearly necessary.

In the piece-goods trade the notable increase in the share of Europe may perhaps be temporary; for yarns, it has been always, and still remains, the chief market. South America has improved its position only slightly, while both the Southern Dominions and the Rest of the Empire now buy more British piece-goods than the whole of the Far East. In spite of the improvement in the Southern Dominions and the Rest of the Empire, it is clear that the future of Empire trade in cotton goods as a whole is bound up with the conditions of the great market of India.

We may expect to find some marked differences when we turn to wool, though here again certain items stand out as defining the main part of the industry.

Percentage of Total Exports of Cotton Manufactures from the United Kingdom to Foreign Countries.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Piece-goods ..	7.4	15.6	13.7	6.8	10.4	8.9	11.0	4.4	3.1	20.4	25.0	20.0	45.6	55.4	45.7	97.80	149.60	108.90
Yarns	63.8	81.0	76.7	3.6	2.7	3.0	1.2	0.5	0.8	9.5	3.5	3.4	78.1	87.7	83.9	15.00	30.50	23.60
Flags and shawls.	29.0	13.8	11.0	17.0	19.4	20.0	5.4	3.1	3.3	25.5	33.4	26.3	76.9	69.7	60.6	1.22	2.36	1.63
Lace and net ..	27.5	13.2	14.1	9.5	7.8	9.1	—	—	—	43.0	36.5	34.7	80.0	57.5	57.9	4.11	2.19	1.62
Cotton thread ..	31.0	19.2	17.7	21.5	23.3	18.5	3.2	4.7	6.2	21.0	25.2	28.0	76.7	72.4	70.4	3.46	7.54	6.35
Miscellaneous ..	7.0	6.3	6.7	10.0	8.2	4.3	2.1	1.0	0.8	14.1	14.7	15.2	33.2	30.2	27.0	3.34	5.01	4.66

*Analysis of Exports of Woollen Manufactures from the United Kingdom
(Approximate Percentages by Value).*

	1913.	1925.	1927.
Tops	10.2	9.1	10.2
Yarns	22.5	20.4	20.6
Woollen tissues	40.6	44.0	45.0
Worsted tissues	17.3	15.4	13.1
Carpets, etc.	4.3	5.1	5.1
Miscellaneous	5.3	5.9	5.9
Total	100.0=£35.7 million	100.0=£58.0 million	100.0=£55.4 million

The relative position of yarns and tissues has not changed greatly since 1913, but within the group of tissues, woollens have been gaining in comparison with worsteds. The Empire takes a rather larger proportion of yarns and carpets, but less of worsteds and woollens, particularly the latter, though there is some improvement in woollens in 1927. The following table shows the distribution of the trade within the Empire.

The decrease in the proportion of woollens to the Empire is seen to be due almost entirely to the East Indies; in the case of worsteds, the Southern Dominions and the East Indies alike decline in importance, but there is compensation in the demand of Canada. In the small carpet trade, the Southern Dominions, owing to the decline in British America, have become the only important Empire market, and it is due to them that the Empire as a whole now accounts for nearly three-quarters of the total exports. In contrast with British America and the Southern Dominions, the East Indies show a falling off in all sections of the trade, except in yarn where the figures are insignificant. These figures must be interpreted in the light of the fact that, in 1927 as compared with 1913, the total export of British worsteds, measured by quantity, was down by nearly 50 per cent., that of woollens only by 10 per cent. For the whole trade, with the exception of carpets, foreign countries still constitute the major part of the market.

Europe is still the chief market for yarns, and loses only moderately in this as in other sections, while South America balances losses and gains in woollens and worsteds. The most remarkable change, however,

Percentage of Exports of Woollen Manufactures to Empire Markets.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations), £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Yarns ..	2.4	4.8	3.1	0.3	0.8	0.7	5.4	4.7	5.3	0.1	0.5	0.2	8.2	10.8	9.3	8.04	11.61	11.38
Woolens ..	13.1	12.9	13.5	11.1	4.5	5.7	14.7	10.5	14.6	0.4	1.5	1.3	39.3	29.4	35.1	14.47	25.49	24.93
Worstedes ..	14.8	8.9	10.4	8.7	3.7	3.4	15.2	26.4	23.3	1.5	0.9	0.8	40.2	39.9	37.9	6.19	8.93	7.25
Carpets ..	30.1	54.3	59.7	4.8	3.4	3.0	29.9	6.6	7.3	1.5	4.3	4.1	66.3	68.6	74.1	1.54	2.98	2.85

Percentage of Exports of Woollen Manufactures to Foreign Markets.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations), £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Yarns ..	87.1	73.3	77.0	1.2	1.5	1.4	1.0	9.3	9.4	2.5	5.1	2.9	81.8	89.2	90.7	8.04	11.61	11.38
Woolens ..	26.0	22.2	18.8	14.2	12.7	12.0	19.4	22.6	20.0	7.1	13.1	14.1	60.7	70.6	64.9	14.47	25.49	24.93
Worstedes ..	11.8	7.3	8.4	12.7	17.0	17.7	13.1	18.7	14.8	22.2	17.2	21.2	59.8	60.1	62.1	6.19	8.93	7.25
Carpets ..	10.2	7.5	8.4	10.8	6.5	4.8	2.0	7.8	1.0	10.7	9.6	11.7	33.7	31.4	25.9	1.54	2.98	2.85

is in the position of the Far East, which improves its position, particularly in yarns and woollen tissues. It is now more important than the Southern Dominions or British America as a market for woollens and second only to British America for worsteds ; while of yarn it takes as much as the whole of the British Empire.

The group labelled "miscellaneous textiles" is interesting, though small ; it consists of silk piece-goods, artificial silk, linen and jute in various forms. Some of these may be termed "luxury" goods and imply a market with considerable purchasing power. Briefly, we may say that for silks, artificial silks (except yarn), linens of all kinds, jute piece-goods and sacks, the Empire as a whole takes an increasing share of the trade ; while jute yarn shows little change. The following table involves certain statistical difficulties, but with the diagram gives a sufficiently accurate view of the facts.

In this group of trades the East Indies are of distinctly minor importance, and the increase in the relative importance of the trade in silks and linens is due to the other parts of the Empire. In the various items Canada registers both losses and gains, while the Southern Dominions in most cases improve their position. For certain goods, as silks, linens, and jute sacks, the Rest of the Empire is a growing market.

The commodities dealt with in the tables above must not all be regarded in the same light as iron and steel and other necessary articles of general consumption. Silks and linens tend to come under the category of luxuries ; they imply a fairly high standard of living and the market within the Empire is necessarily somewhat specialized and limited. Moreover, in the case of silks, India and the Far East are themselves producers. In the second table, the unusually high proportion of linens exported to "other foreign countries" is due to the United States, by far the richest single market. In these groups, from their very nature, the foreign market is likely to remain for a long time more important than that of the Empire. Jute yarn, on the other hand, is a raw material for industry, and its export is necessarily restricted to countries where the industry is established. Hence the large share of Europe and South America. Jute piece-goods and sacks are largely intended for use in the transport of certain kinds of produce and their sale is limited to certain regions, more without than within the Empire. The blanks in the East Indian column hardly need comment, but it must not be forgotten that India herself is increasing her export of finished jute goods partly at the expense of Great Britain, both in the Empire and in foreign markets.

Percentage of Exports of Miscellaneous Textiles from the United Kingdom to Empire Markets.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Silk piece-goods ..	7.5	25.0	23.7	5.8	2.1	7.4	11.6	10.7	7.1	12.7	8.7	13.9	37.6	46.6	52.1	1.17	1.08	1.52
Linen thread ..	18.9	21.8	17.5	2.9	2.5	3.8	8.2	9.3	12.7	2.7	1.8	1.8	32.7	35.4	35.8	0.35	0.84	0.61
Linen piece-goods	9.1	16.2	16.2	4.8	2.8	4.2	6.7	7.5	8.0	1.1	0.6	0.7	21.2	27.1	29.1	5.97	6.78	5.13
Miscellaneous linen	8.7	10.1	9.7	2.5	2.8	2.2	19.2	16.3	19.6	2.8	5.6	4.2	33.2	34.8	35.7	1.93	3.39	3.84
Jute yarn ..	1.1	1.6	2.0	—	—	—	8.1	6.0	7.0	1.8	1.0	1.7	11.0	8.6	10.7	0.78	1.39	1.23
Jute piece-goods ..	4.4	4.8	5.4	1.2	0.3	0.4	13.3	12.0	15.0	0.7	1.3	1.1	19.6	18.5	21.9	3.07	4.09	3.30
Jute sacks ..	7.1	16.3	14.3	—	—	—	4.6	0.5	0.8	4.2	7.9	8.7	15.9	24.7	23.8	1.22	1.10	0.71
Miscellaneous jute	22.1	22.2	7.8	—	—	—	3.0	0.6	0.7	11.2	6.4	4.4	36.3	29.2	12.9	0.27	0.63	0.41

Percentage of Exports of Miscellaneous Textiles from the United Kingdom to Foreign Markets.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Silk piece-goods ..	24.3	21.2	28.6	5.1	3.7	2.7	—	—	—	33.0	28.5	16.6	62.4	53.4	47.9	1.17	1.08	1.52
Linen thread ..	35.6	26.2	28.3	8.1	13.0	10.0	—	—	—	23.6	25.4	25.9	67.3	64.6	64.2	0.35	0.84	0.61
Linen piece-goods	3.5	4.8	5.7	6.8	7.2	5.5	1.5	1.9	3.4	67.0	59.0	58.3	78.8	72.9	70.9	5.97	6.78	5.13
Miscellaneous linen	10.8	3.0	2.2	8.3	4.6	4.2	—	—	0.5	47.7	57.6	57.4	66.8	65.2	64.3	1.93	3.39	3.84
Jute yarn ..	35.4	40.5	40.5	43.5	35.3	36.3	—	—	—	10.1	15.6	12.5	89.0	91.4	89.3	0.78	1.39	1.23
Jute piece-goods	9.6	15.1	8.7	13.8	6.0	12.7	—	—	—	57.5	60.3	56.7	80.4	81.2	78.1	3.07	4.09	3.30
Jute sacks ..	34.3	27.1	26.5	28.6	25.1	31.9	—	—	—	21.2	23.1	17.8	64.1	75.3	76.2	1.22	1.10	0.71
Miscellaneous jute	13.1	44.0	52.6	13.9	6.1	9.0	—	—	—	36.7	20.7	25.5	63.7	70.8	87.1	0.27	0.63	0.41

Percentage of Exports of Artificial Silk from the United Kingdom to the Empire.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). £ Million.		
	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.
Yarns, etc. ..	11·7	16·6	20·6	9·8	11·4	25·9	34·9	15·3	0·5	1·0	4·0	2·0	57·4	47·3	49·0	0·82	2·29	1·81
Piece-goods, etc...	11·0	24·7	22·3	29·7	10·2	16·0	4·8	11·6	14·9	5·9	14·2	10·4	51·4	60·7	63·6	2·18	3·07	5·77

Percentage of Exports of Artificial Silk from the United Kingdom to Foreign Countries.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). £ Million.		
	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.	1920.	1925.	1927.
Yarns, etc. ..	5·5	20·4	20·3	3·2	10·0	11·0	8·4	9·6	10·3	25·5	12·7	9·4	42·6	52·7	51·0	0·82	2·29	1·81
Piece-goods, etc...	7·8	2·6	2·9	12·4	6·9	11·2	1·8	4·8	3·0	26·6	25·0	19·3	48·6	39·3	36·4	2·18	3·07	5·77

There remains artificial silk ; but this trade is so recent that comparative figures are difficult to interpret, as they cover only a very short period.

This is a rapidly expanding trade, in which the Empire increases its share in piece-goods but loses on Canadian yarn business. The only other loss of importance is in the East Indian share in piece-goods. Foreign countries have increased their proportion of yarns, but the United States, which took half the total export in 1920, is now negligible as a market. The decline in the foreign market for piece goods is due to the United States and Europe, particularly the former. It is difficult to draw conclusions as to a new and rapidly changing trade, but the Empire seems to offer on the whole a more favourable market.

To complete our review of this important section of the export trade, there remains apparel, now, owing to the new trade in artificial silk, of less importance than the miscellaneous textile group.

Owing to statistical difficulties, the tables below are based on values instead of quantities, and give, therefore, no basis for comparison of one year with another ; but so far as can be judged from available figures of quantities, and from a consideration of prices, nearly all these trades are less in volume in 1927 than in 1913. The one notable exception is stockings, which show a 45 per cent. increase, due to the new industry in artificial silk. In the reduced trades, the Empire for the most part maintains or improves its position, as the Southern Dominions compensate largely for serious losses in the Canadian market, while the " Rest of the Empire " gains under every schedule. The result is seen in the diagram as well as in the last column of percentage figures. The fall in the Empire *share* in the export of stockings is not due to a smaller consumption, since the Southern Dominions and Canada alike show increases in the quantities imported and offset the decline in India ; it is due to the exceptionally rapid growth of exports to certain foreign markets illustrated in the table below.

This is one of the few groups in which the column headed " Other Foreign Countries " is of unusual importance, as these countries with Europe cover most of the foreign market. Europe shows a relative decline in all but the last two items, and this movement is reflected in the total column. The fall here would have been more marked but for the higher figures for other foreign countries. In overcoats,

Percentage of Exports of Apparel from the United Kingdom to the Empire.

	Southern Dominions.			East Indies.			British America.			Rest of Empire.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Overcoats (proofed)	12·3	28·6	23·7	2·6	5·0	5·4	27·6	5·2	8·0	2·5	4·7	4·3	45·0	43·5	41·4	1·02	1·25	1·05
Other outer and under garments.	58·0	59·3	55·5	4·9	4·1	4·4	10·4	5·3	6·8	4·3	8·9	8·9	77·6	77·6	75·6	8·65	7·64	6·30
Haberdashery ..	32·0	39·2	41·1	14·7	10·4	16·5	15·8	8·9	4·3	6·7	13·8	19·1	69·2	72·3	81·0	1·25	0·35	0·23
Boots and shoes ..	39·9	51·2	46·3	11·7	5·5	7·1	8·3	11·4	11·9	6·2	8·5	10·0	63·1	76·6	75·3	4·31	3·20	3·27
Hats	28·2	35·7	40·6	3·9	7·1	6·5	21·8	11·7	15·6	5·6	10·1	9·3	59·5	64·6	72·0	2·31	2·32	2·69
Stockings ..	55·2	38·5	37·2	5·9	2·6	2·8	17·6	10·3	11·6	2·3	7·1	3·9	81·0	58·5	55·5	1·16	4·69	4·07
Woven underwear, etc.	32·1	38·0	32·1	5·5	7·2	6·4	28·6	8·8	10·8	6·1	11·3	9·9	70·3	63·3	59·2	1·48	2·18	2·07

Percentage of Exports of Apparel from the United Kingdom to Foreign Markets.

	Europe.			South America.			Far East.			Other Foreign Countries.			Total.			Total Exports (all Destinations). £ Million.		
	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.	1913.	1925.	1927.
Overcoats (proofed)	41.3	37.4	34.8	—	—	1.3	—	—	—	13.7	19.1	22.5	55.0	56.5	58.6	1.02	1.25	1.06
Other outer and undergarments.	9.7	6.7	7.4	4.9	1.8	1.5	0.5	0.5	0.7	7.3	13.4	14.8	22.4	22.4	24.4	8.65	7.64	6.30
Haberdashery ..	13.6	4.3	6.1	3.2	2.9	1.7	5.0	0.9	0.9	9.0	19.6	10.3	30.8	27.7	19.0	1.25	0.35	0.23
Boots and shoes..	24.8	10.2	8.6	5.2	0.7	0.5	—	—	—	6.9	12.5	15.6	36.9	23.4	24.7	4.31	3.20	3.27
Hats	24.2	12.9	10.2	5.8	1.8	1.1	2.2	3.8	4.1	8.3	16.9	12.6	40.5	35.4	28.0	2.31	2.32	2.69
Stockings ..	14.3	19.2	27.9	0.9	1.6	1.2	0.9	0.5	0.5	2.9	20.2	14.9	19.0	41.5	44.5	1.16	4.69	4.07
Woven underwear, etc.	9.4	9.1	13.5	4.9	6.3	5.2	4.8	3.1	3.0	10.6	18.2	19.1	29.7	36.7	40.8	1.48	2.18	2.07

other outer and under garments, boots and shoes, hats, stockings, and woven underwear, the United States takes a greatly increased proportion of the trade, and helps to maintain the total in spite of the falling off in Europe. Except in the last two items in the table, the future proportion of foreign to Empire exports in these miscellaneous trades seems to depend largely on the continued demand of this one country. Such a basis is somewhat insecure, and that provided by the Empire is to be preferred.

The "textile" group, discussed above, is extremely varied in character; it is difficult, therefore, to fit the pieces into a single picture. Normally, the group in the aggregate accounts for about half the total of British manufactured exports and is divided roughly between cotton, wool, and "all other" in the proportion of three, one, and one. In the main items under cotton and wool, trade was much smaller in volume in 1927 than in 1913, and the Empire contributed to the general decline. The decrease in the total export of cotton yarn was slight and that in woollen tissues only about 10 per cent., while that in cotton piece-goods was about 40 per cent. and that in worsteds no less than 50 per cent.

In cotton yarn, owing to the reduced demand in India, the share of the Empire is less, while in piece-goods it is about the same by quantity but larger by value; but in all the minor forms of cotton it is greater in 1927 than in 1913. In spite of the depression, the Empire is more important relatively as a market. In the wool trades, though the share of the Empire in woollen tissues shows a decrease on 1913 as measured by quantity, measured by values it shows a slight increase. This suggests that the Empire may be buying goods of rather better quality. The worsted trade on the other hand, has declined in nearly all markets, within or without the Empire, and shows no sign of recovery in 1927. It is not to be compared with that in woollens.

Owing to the lack of measures of quantity, it is not possible to estimate general progress in exports of textiles and apparel, but the relative position of the Empire can be indicated roughly. If we add together the values of those items in which the share of the Empire, measured by values, has increased, these amount to about £160 million out of the total of £250 million for the group; while, on the £25 million assigned to woollen tissues, the Empire percentage by value remains steady. The figures merely tell us that the Empire is improving its relative position over a certain range of

trades ; but this is not enough, we must attempt to relate the percentages to the actual trade. By another method of addition we find that on about £130 million out of the £160 million, made up of cotton piece-goods and miscellaneous textiles and apparel, not only is the share of the Empire increasing somewhat, but it stands at over 50 per cent. in 1927. In other words, over more than half this composite group the Empire buys more to-day than all foreign countries together. These general figures, interpreted in the light of the details in the tables, may assist in giving some idea of the relative importance of Empire markets in this half of British export business, though taken by themselves they are liable to misinterpretation.

The figures and diagrams to this point have provided a rough analysis of nearly three-quarters of the exports of "manufactures" from Great Britain as defined above, that is excluding coke. There remains a vast mass of miscellaneous items, difficult to classify or to discuss in detail, but of great importance to the prosperity of British industry: Let us try to put together a few of the more important groups:—

Exports of Manufactures from the United Kingdom.

	1925.		1927.	
	Per cent. of Total Exports.	Per cent. to Empire.	Per cent. of Total Exports.	Per cent. to Empire.
Electrical goods and apparatus	1.90	53.4	1.44	46.5
Paper, etc.	1.52	72.8	1.55	73.0
Books	0.67	63.0	0.76	64.4
Rubber tyres, etc.	0.63	50.7	0.65	54.4
China and earthenware	1.03	47.9	1.11	51.2
Glass	0.38	59.2	0.39	66.5
Arms and ammunition	0.72	45.3	0.70	58.5
Soap	0.55	62.3	0.65	62.8
Cordage	0.28	47.9	0.31	44.6
Printers' colours	0.61	54.2	0.68	58.7
Manufactures of leather	0.27	50.7	0.28	53.9
Machine belting (not leather)	0.21	48.1	0.21	54.7
Cement	0.24	69.5	0.31	72.5
Total	9.01 = £53 million		9.04 = £49 million	

Here we have another 9 per cent. of our exports, selected from industries of every kind, in which the share of the Empire ranges from rather less than a half to rather more than two-thirds. The remainder, somewhat less than 20 per cent., is composed of copper, tin, leather, copper and brass goods, miscellaneous tools and cutlery, stationery, rubber goods, jewellery, manufactures of wood, chemicals and fertilizers, and miscellaneous textile products not analysed in the above tables. In these, though the share of the Empire is not on the whole small, it is for most items of importance below 50 per cent.

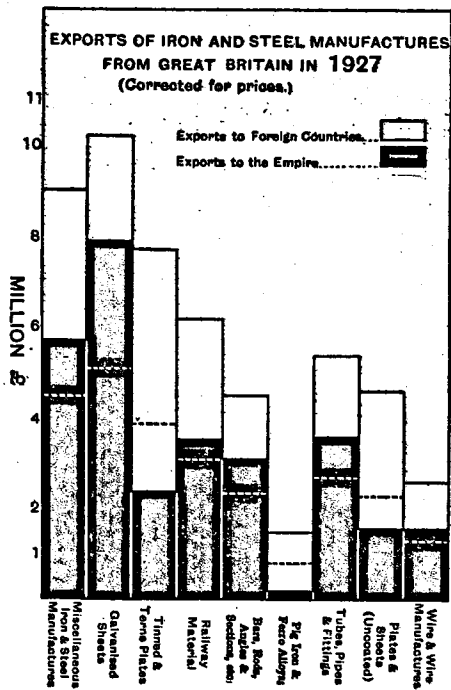
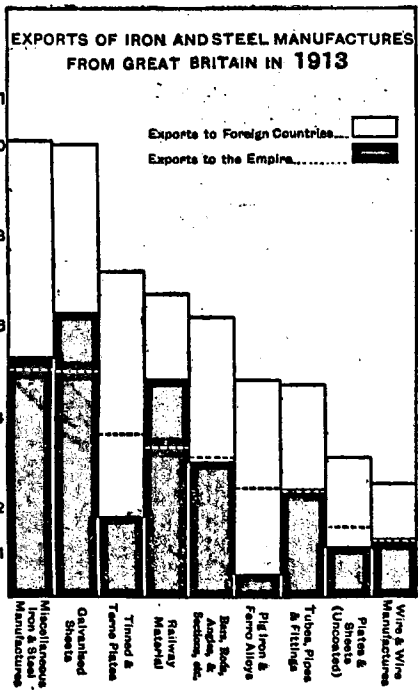
We have thus filled in, with a fair amount of detail, about 85 per cent. of the outline picture of the markets for British manufactures, though the last 10 per cent. is not elaborated as the first 75. This picture, like any other, is made up of various colours and shades and contrasts. It is composite but real. It is convenient, for some purposes, to do as we did in the first section, to discuss the distribution of trade in general in the form of statistical values; this method may lead us into fallacies, but can it tell us anything real? Statements based on combined values are for the most part statements as to figures not as to material things. There is little in common, industrially or economically, in steel girders, rubber tyres, sulphuric acid, and cotton lace; yet we combine these to arrive at a general figure of exports, and combine them in any proportion whatever, so that the same total value may be made up in an infinite number of ways. On the basis of such figures, arguments are propounded and comparative estimates worked out; yet what useful result can be expected from a total figure made up from steel girders and lace in the proportion of 99 to 1, or 1 to 99, or anything whatever between? In the previous pages an attempt had been made to build up a picture in large blocks, with some division into essential parts. Such a picture is incomplete, since each of these parts in itself can be sub-divided into many smaller units. A complete schedule of ultimate units would be strictly accurate as to facts but incomprehensible; a wide statistical generalization has no real content. The above figures represent a compromise between the two methods, an attempt to deal with definite material things, without entirely sacrificing the advantages of statistical symmetry.

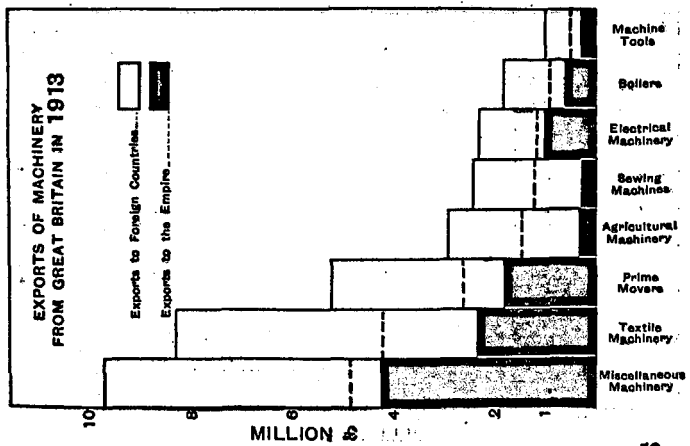
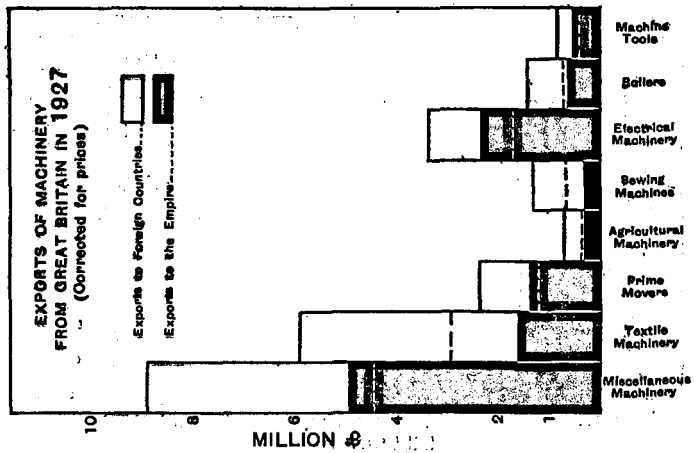
The markets for British manufactured exports analysed above may be classified broadly into two types. Some countries are capable of producing on a large and varied scale goods similar to those produced in Great Britain. Such countries, protected by tariffs, tend to provide

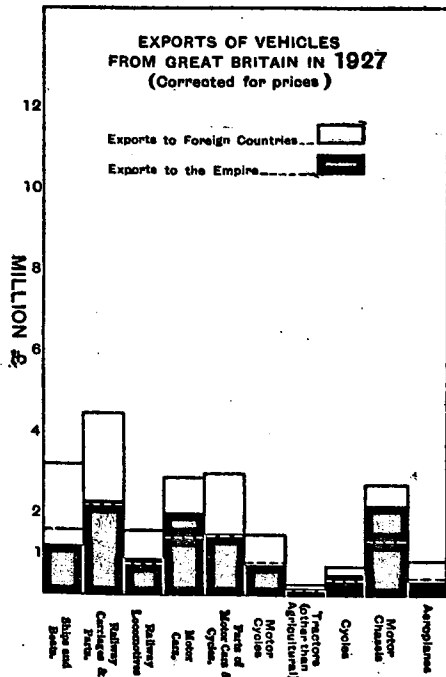
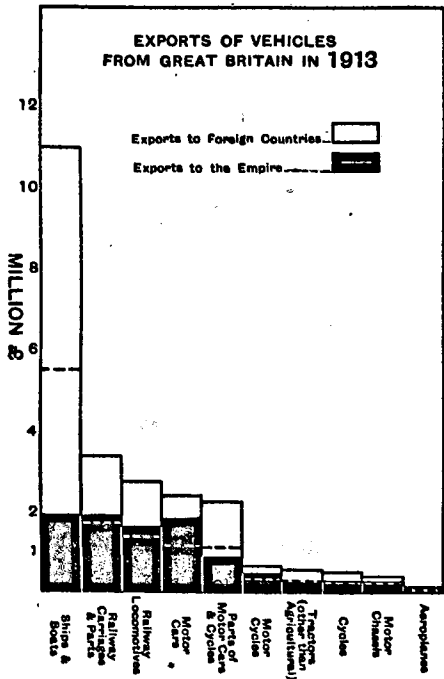
markets only for goods of a special kind, in accord with the real or fancied needs of their native industries. Other countries, even if capable of large industrial production, are in a stage of development in which they offer natural markets for most of the manufactured exports of Great Britain. The British Empire, generally, belongs to this class, but it differs from foreign countries in the same class in that, as a result of history or policy, it offers to British trade in many regions special advantages not shared by foreign countries. The present stage of economic development, however, is not necessarily permanent. In view of the population and physical character of the main areas in the Empire, changes in some directions are likely to be slow; but there must be a certain growth in manufacturing industry. We need not deduce from this that the Empire market for British goods will decline; rather it should expand, with the increase in number and wealth of the population. It will, however, change, and the continued holding of this most valuable outlet for our manufactures is likely to depend on continual anticipation and conscious adjustment of the form of British industry to correspond to the internal economic changes and needs of the various important sections of the Empire.

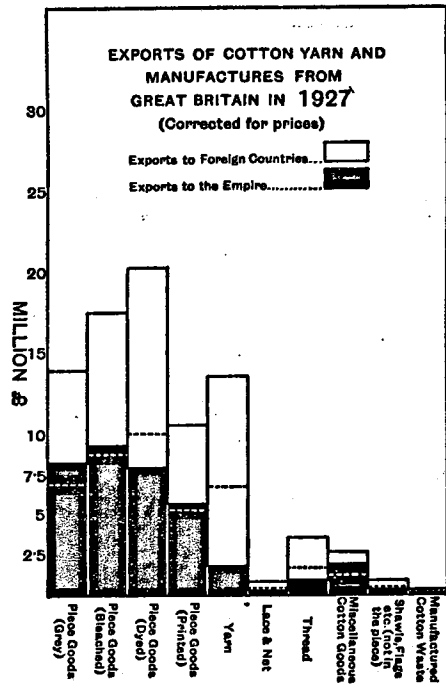
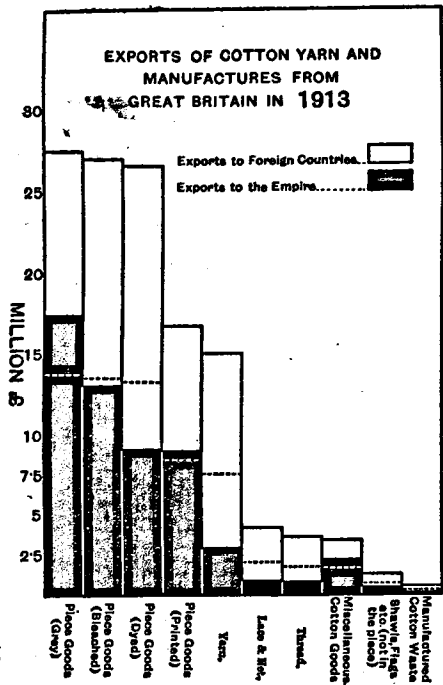
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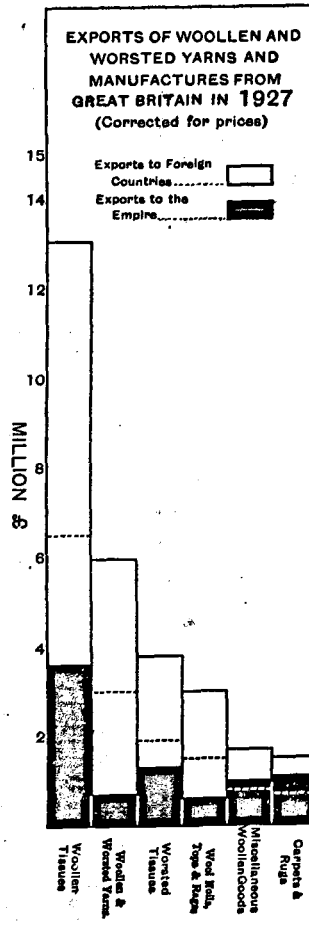
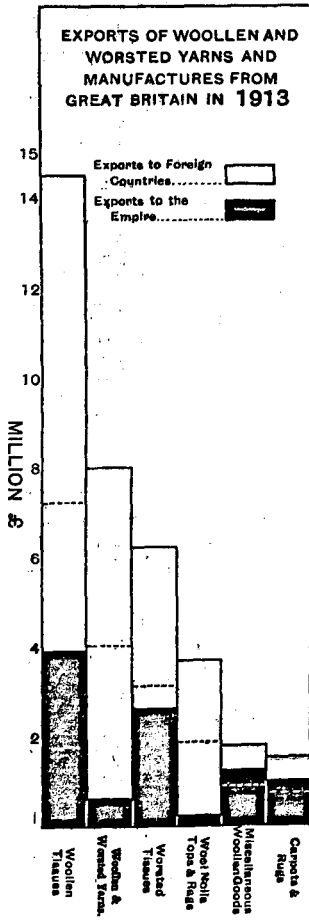
Certain figures for 1928 are now available and may modify some of the conclusions based on 1927. In Iron and Steel and Machinery there are moderate gains in the trade generally, but in the Empire the Australian market is depressed. The same is true in vehicles and textiles. Though India registers some gains in Machinery and Vehicles, her demand for piece-goods is again dropping. Among foreign countries, the Chinese market for cotton piece-goods shows a remarkable recovery, and there is some improvement in South America. It is not possible, however, with the figures available at the moment, to estimate the relative position of the Empire or Empire groups generally or in detail, though correction may be applied to particular items.

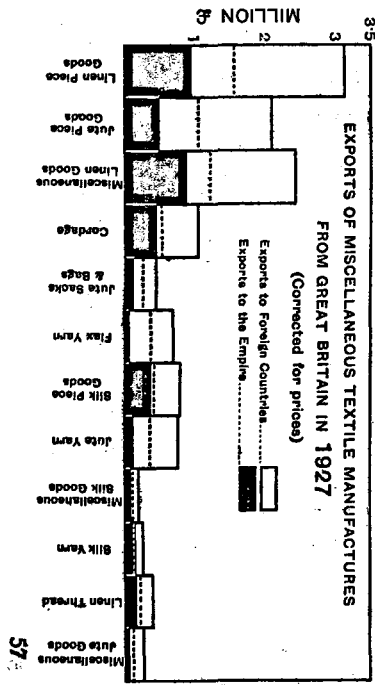
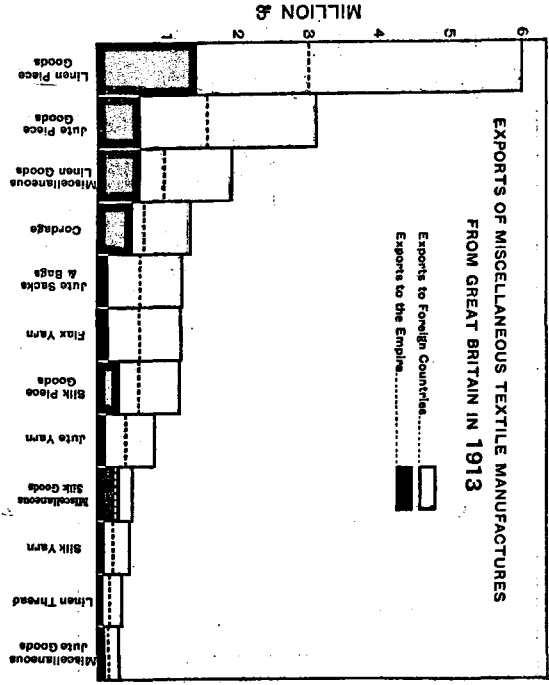


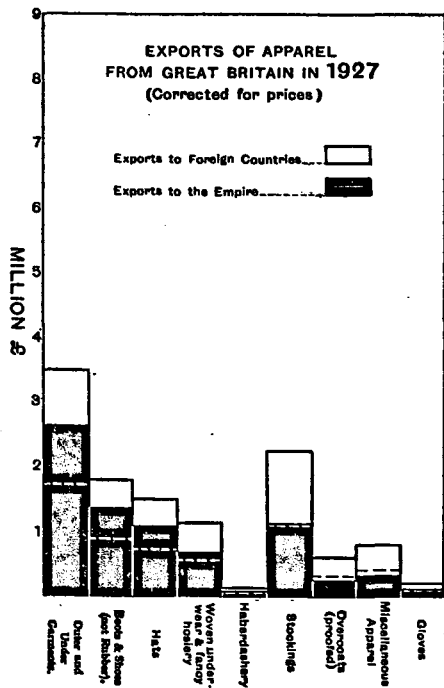
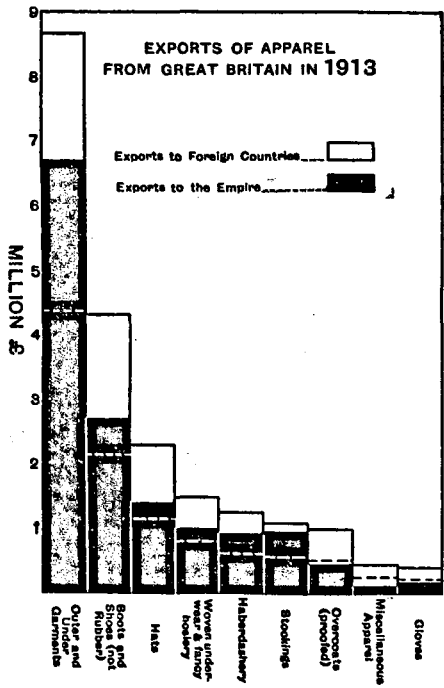












E.M.B.27

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COCOA

WORLD PRODUCTION & TRADE

MEMORANDUM PREPARED IN THE
STATISTICS AND INTELLIGENCE BRANCH
OF THE EMPIRE MARKETING BOARD



MAY, 1930

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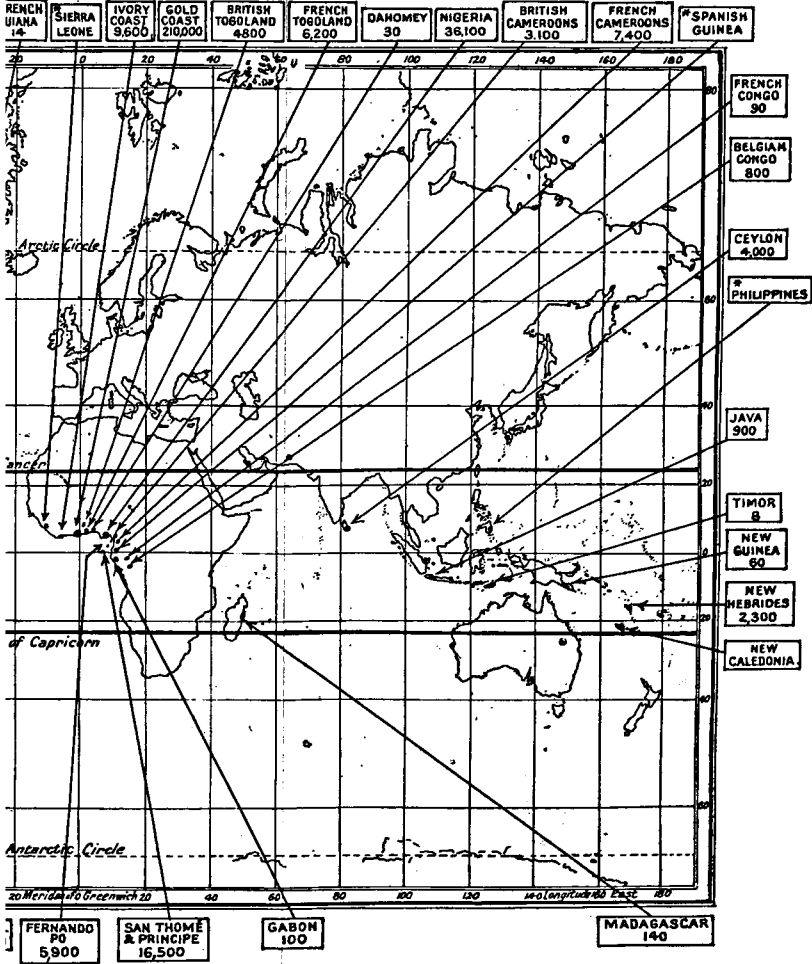
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TABLE OF CONTENTS.

	<i>Page</i>		<i>Page</i>
Foreword	5	Import—	
Introduction	7	United Kingdom	46
Production and Export—		Canada	52
Gold Coast	9	Australia	53
British Togoland	11	New Zealand	55
Sierra Leone	12	Union of South Africa	56
Nigeria	12	Irish Free State	57
British Cameroons	15	United States	58
Trinidad and Tobago	16	Germany	61
Grenada	19	Netherlands	63
Jamaica	21	France	67
St. Lucia	22	Spain	69
St. Vincent	23	Italy	70
Ceylon	24	Czechoslovakia	71
Western Samoa	26	Switzerland	72
Ecuador	27	Belgium	73
Brazil	29	Sweden	75
Venezuela	32	Norway	76
Costa Rica	34	Denmark	77
Haiti	35	Poland	78
Panama	36	Austria	78
Dominican Republic	36	Rumania	79
San Thomé and Principe	38	Portugal	79
French Colonies and Mandated		Jugo-Slavia	80
Territories—	39	Russia	80
Ivory Coast	40	Argentina	81
Togoland	41	Philippines	82
Cameroon	41		
Dahomey	42	Conclusion and Summary	83
Martinique	42		
Fernando Po	42		
Surinam	43		
New Hebrides	44		
Other countries	45		

COUNTRIES OF THE WORLD. EXPORTS IN TONS.)



trade in raw cocoa.

Malby & Sons, Lith.

FOREWORD.

THE prices which cocoa producers throughout the world have received for their product have shown a marked decline during the past few years, and fears have been expressed in some quarters lest production may be developing at too rapid a pace. The problem is not new; indeed it occurs in the case of almost every product in regard to which production is expanding, and especially where the period between planting and the first financial return to the planter is to be measured in years. But cocoa is perhaps of peculiar importance owing to the abnormal rate of expansion of the industry during the past two decades, and to the overwhelming share of the British Empire in world production.

A number of British Colonies have approached the Empire Marketing Board for information and for advice as to the future of the industry and the Board's Agricultural Economics Committee accordingly suggested that the Statistics and Intelligence Branch of the Board should undertake a statistical survey of world production and consumption of cocoa, for the information of producers, and others interested in the product.

The memorandum here presented follows much the same lines as the earlier survey of this nature issued by the Board, dealing with Oranges.* It is essentially a statistical record of the trade in raw cocoa in recent years, with some indication of the general trend of consumption of cocoa preparations. No attempt has been made, except to a very limited extent, to deal with the relative price of the different qualities of raw cocoa, the costs of production, preparation and marketing, transport costs, or the general mechanism of marketing. Such questions naturally have an important bearing upon the volume of raw cocoa entering world trade, and upon prospects for the future, but they would entail a much more detailed and intensive study than could easily be included in the scope of this memorandum. Moreover, questions of marketing will come within the scope of the enquiry into the marketing of tea, coffee and cocoa which the Imperial Economic Committee is at present conducting.

Precise agreement between the different tables is not to be expected, owing to the variation in methods of classification of exports and imports. Thus the cocoa trade between two countries often shows

* Oranges : World Production and Trade (E.M.B. 15) 1s. net.

considerable discrepancies when the import returns of the one country and the export returns of the other are compared; this is a difficulty which, of course, is of constant occurrence in analysing figures of trade distribution, and it is one for which, unfortunately, there is no remedy.

Finally it should be explained that the terms "fine" and "ordinary" relate not to two kinds or qualities of cocoa, but to an infinity of qualities between the very finest product and the most inferior which enters the world market. The range within each of the two groups is very wide; the difference between cocoas on the borderline of the two groups is very narrow. The classification into "fine" and "ordinary" is intended only to give a broad indication of the relative changes in the world supply of cocoas which might perhaps be more accurately, if less concisely, termed "fine to medium or good" and "medium or good to common."

Statistics and Intelligence Branch,
Empire Marketing Board.

April, 1930.

COCOA.

WORLD PRODUCTION AND TRADE.

INTRODUCTION.

1. Although there is some divergence of opinion as to the original home of the cocoa tree, it is generally believed to have originated in the region of the basins of the Orinoco and the Amazon. Cocoa appears to have been cultivated by the Indians for centuries before the discovery of America by the Old World, and it is probable that these nomads, in their wanderings, helped to spread the cocoa plant throughout tropical South America.

2. Cocoa was first discovered by Cortes in Mexico at the beginning of the 16th century, but it was not appreciated as a beverage in Europe until early in the 17th century. Owing to its costliness, the consumption of cocoa was confined to a relatively small class, and did not become popular until the latter part of last century. Among the greatest factors in popularising the consumption of cocoa were the invention in 1828 of a method of preparing cocoa powder, by C. G. van Houten, by which means a great part of the cocoa butter was removed, making a lighter and more digestible beverage; and the progressive reduction in the import duty on cocoa in this country in the first half of last century.

3. The cocoa growing countries of South and Central America, together with the West Indies, are the "old" cocoa producing countries, as cocoa is known to have been cultivated there since the 15th century. Brazil is an exception as, although cocoa grows there in a wild state, and cultivation has been carried on to a small extent in the State of Para since the middle of the 18th century, it is only within the past 50 years that cocoa has become important in the State of Bahia. The cocoa growing countries in Africa and Asia are mostly of comparatively recent development, the newest comers in the field being the British and French territories in West Africa.

4. Cocoa is entirely a tropical crop, and will not grow in the sub-tropics. It will not flourish in a climate where the temperature falls below 60°, nor generally at an altitude of more than 1,800 feet above sea level. Sufficient humidity is also of the utmost importance.

5. The area suitable for the cultivation of cocoa is consequently restricted—a great deal more so, for example, than that adapted for coffee. Fortunately, there lie within the Empire large areas of land in West Africa and elsewhere suitable for the cultivation of cocoa, and the enormous expansion in world production during the present century is largely attributable to British colonies there, which now supply the bulk of the “ordinary” cocoa consumed by the world. But it is not only in the production of “ordinary” cocoa that the Empire predominates. In the supply of high grade cocoa also, the Empire holds an important position as to both quantity and quality. The products of the West Indies, Ceylon and Western Samoa are universally recognised as standards of quality.

6. In the five years from 1923 to 1927, the British Empire supplied from 280,000 to 300,000 tons of raw cocoa annually towards the world's requirements. Some part of this quantity was shipped to other parts of the Empire, and, moreover, Empire countries import considerable quantities of cocoa from countries lying without the Empire. But taking the Empire as a unit, there was in these same years a net export varying from 200,000 to 250,000 tons annually, with an average of 228,000 tons. At a moderate estimate, the average value of the Empire's net cocoa exports may be set down as over £10,000,000 per annum.

7. In the following pages it is proposed to deal first with the various producing countries, showing the development of production and exports over a period of years, the destination of exports and the general tendency towards increase or decrease in production. In the second part figures are given for the leading importing countries. The final section gives summarised figures.

PRODUCTION AND EXPORT.

Gold Coast.

8. The first exports of cocoa from the Gold Coast were recorded in 1891 with a shipment of 80 lb. Progress has since been rapid, and now this country produces about 45 per cent. of the world's total supply, with a cocoa area estimated at about 900,000 acres, carrying some 180 million trees. The crop is grown entirely by the natives, who, under the stimulus of high prices at the end of the war, rapidly increased the cocoa acreage. The following table shows the volume of cocoa exports in certain pre-war years and annually since 1920 :—

TABLE I.—*Exports of Raw Cocoa from the Gold Coast.*

<i>Year.</i>						<i>Tons.</i>
1900	..	..	..	..	..	540
1909	..	..	..	..	..	20,210
1910	..	..	..	..	..	22,630
1911	..	..	..	..	..	39,730
1912	..	..	..	..	..	38,650
1913	..	..	..	..	..	50,550
1920	..	..	..	..	..	124,770
1921	..	..	..	..	..	133,190
1922	..	..	..	..	..	159,300
1923	..	..	..	..	..	197,660
1924	..	..	..	..	..	223,330
1925	..	..	..	..	..	218,150
1926	..	..	..	..	..	230,840
1927	..	..	..	..	..	209,910
1928	..	..	..	..	..	225,080
1929	..	..	..	..	..	238,490

9. Although the high prices realised by the 1920 crop encouraged production in the following years, prices fell before the new crops matured, and consequently a great deal of cocoa never reached the market from places where transport was difficult. The increased production from 1922 to 1924 is considered to have been largely due to improved transport facilities, as new roads and railways have greatly extended the area in which the production of cocoa is economically possible, and also released labour formerly needed for head transport. It is believed that when new railway lines now in course of survey are constructed considerable new areas of cocoa will be opened up.

10. Since 1924 there has been a significant check to the increase in exports. To some extent fluctuations from year to year are due to the fact that the figures relate to calendar years, whereas the main crop is harvested from October to January or later ; hence a late season or (more often) the holding back of supplies by the natives or shippers for any reason, may reduce the exports in one year and magnify those of the next. The exports in 1913 and from 1924 to 1928 were as follows :—

TABLE II.—*Distribution of Exports of Raw Cocoa from the Gold Coast.*

Exported to	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	26,650	39,620	53,920	46,700	48,290	51,210
Canada	—	50	840	1,550	1,200	680
Germany	15,460	41,620	44,840	51,920	44,040	54,330
France	8,440	15,280	18,650	14,950	7,290	9,090
Holland	—	66,980	36,550	38,710	38,950	43,040
U.S.A.	—	50,210	54,290	65,200	60,530	52,740
Belgium	—	890	480	480	280	1,110
Norway	—	1,100	390	1,180	970	1,040
Italy	—	1,960	2,430	4,220	1,660	4,250
French Togoland	—	4,600	4,900	4,910	4,840	5,260
Other countries	—	1,020	860	1,020	1,860	2,330
Total	50,550	223,330	218,150	230,840	209,910	225,080

11. As the Gold Coast furnishes more than one-half of the world's supply of "ordinary" cocoa, exports are naturally distributed largely among those countries which have important cocoa manufacturing trades. The United Kingdom has in the past few years taken between 20 and 25 per cent. of total exports, the United States being the leading purchaser, and Germany and the Netherlands challenging the United Kingdom for second place. The Gold Coast holds so important a place in the world's cocoa trade that it is worth while devoting some space to the possibilities of increased production or the prospect, if it exists, of a decline. The ability of the Gold Coast to increase its production of cocoa appears to depend mainly on :—

- (a) Sufficient labour.
- (b) An increased area for cultivation.
- (c) Controlling disease and deforestation.
- (d) Increasing yields and soil fertility.

12. There appears to be sufficient labour available for a substantially larger production, and no check to the increase in exports would be likely from that cause alone for many years to come. As regards the area of cocoa land, there are fairly large areas still untapped, and considerable increases in planting are possible, especially as transport facilities improve.

13. At the same time as new areas are being opened up, however, the older farms are becoming exhausted. The fertility of the soil is decreasing through constant cropping without cultivation and manuring; the control of pests is a troublesome problem owing to the difficulty of persuading the native farmer to undertake preventive measures—so much so that the Government entomologist has declared that in most areas where cocoa is now growing it is almost impossible, on account of pests, to establish new cocoa; finally, many farms have fallen out of production owing to the lack of shade and humidity on account of deforestation.

14. There is at present, however, little probability of decreased production, as new cocoa areas can still be opened up, and labour tends to migrate from the outworn farms in sufficient quantity to reinforce the local population to the point of maintaining the output. Indeed, any improvement in prices to make it worth while to harvest and export the crop would doubtless result in a further increase in exports. If problems of infestation, deforestation and soil exhaustion, all tending to operate with increasing power throughout the period of expansion of the industry, can be solved with some success within a reasonable period, it is certain that the Gold Coast can produce even larger quantities of cocoa in the future than in the past. But such increase is naturally dependent upon a remunerative market for the product being maintained.

15. In this connection the Department of Agriculture of the Gold Coast, alive to the importance of improving the rather low standard of quality of Gold Coast cocoa, has for some time past impressed upon the native producer (who is responsible for practically the whole output) the importance of complete fermentation and proper drying, and Gold Coast (and Nigerian) cocoas are now much nearer a parity with the finer sorts than they were a few years ago.

British Togoland.

16. The area under cocoa in British Togoland is increasing, and many new plantations have been established in recent years. In

Table III are shown the exports to French Togoland, whither the bulk of the consignments are sent. The figures are exclusive of any quantities sent to the Gold Coast, with which country trade is likely to expand owing to the vastly improved communications.

TABLE III.—*Exports of Raw Cocoa from British Togoland (to French Togoland).*

<i>Year.</i>							<i>Tons.</i>
1925 ..	..	..	..	..	..	..	4,941
1926 ..	..	..	..	..	..	..	4,890
1927 ..	..	..	..	..	..	..	4,842
1928 ..	..	..	..	..	..	..	5,255

17. The figure for 1927 would have been higher but for the fact that the 1927–28 crop was late, and hence the proportion exported before the close of the calendar year 1927 was smaller than usual. Moreover, considerable quantities of cocoa which would normally have passed into French Togoland were despatched to the Gold Coast owing to the closing of the frontier for two months on account of an outbreak of fever in the French zone.

Sierra Leone.

18. On account of climate and soil conditions the area suitable for cocoa growing in Sierra Leone is restricted to a narrow belt in the extreme south along the Liberian frontier. A good many trees have been planted in this district in recent years. The export trade is at present very small, amounting to only 84 tons in 1928, and although it is expected to develop in the near future, there seems to be little prospect of Sierra Leone taking any but a minor place in the supply of cocoa to the world.

Nigeria.

19. Nigeria is the third largest producer of cocoa in the world, only the Gold Coast and Brazil exporting larger quantities. As in the Gold Coast, the crop is practically entirely native grown, and is cultivated under very much the same conditions. That Nigerian cocoa production is so much smaller than that of the Gold Coast is to some extent due to the competition of other crops. For whereas cocoa accounts for over 80 per cent. of the Gold Coast's domestic exports, it forms only about 13 per cent. of Nigeria's exports. There is, however, a considerable degree of similarity in the development of the crop in the two countries, with an interval of some 15 years or so between them. The Gold Coast in 1901 exported 1,000 tons,

which had risen in the five years before the war to about 35,000 tons. Exports from Nigeria in the five years before the war averaged about 3,500 tons; in the last few years they have averaged over 45,000 tons.

20. The quality of Nigerian cocoa is similar to that produced in the Gold Coast, and the considerable improvement which has been made recently may be largely attributed to the work of the government fermentaries. These are worked on a co-operative basis by the Department of Agriculture, and have been most valuable in demonstrating to the farmer the proper method of fermenting cocoa, and in convincing him that a better price is obtained by adequate fermenting and grading. The Government has also instituted a system of inspection of cocoa intended for export.

21. Transport difficulties have hitherto militated against a more rapid expansion of the cocoa industry, but the new programme of the Nigerian Government for road and railway construction should gradually improve the situation in this respect.

22. In Table IV below are shown exports of cocoa from Nigeria in 1900, from 1909 to 1913 and since 1920 :—

TABLE IV.—*Exports of Raw Cocoa from Nigeria.*

<i>Year.</i>						<i>Exports.</i>
						<i>Tons.</i>
1900	..	..	..	..	..	202
1909	..	..	..	..	..	2,241
1910	..	..	..	..	..	2,932
1911	..	..	..	..	..	4,401
1912	..	..	..	..	..	3,390
1913	..	..	..	..	..	3,621
1920	..	..	..	..	..	17,155
1921	..	..	..	..	..	17,944
1922	..	..	..	..	..	31,256
1923	..	..	..	..	..	32,821
1924	..	..	..	..	..	37,205
1925	..	..	..	..	..	44,705 (a)
1926	..	..	..	..	..	39,099 (a)
1927	..	..	..	..	..	39,210 (a)
1928	..	..	..	..	..	49,164 (a)
1929	..	..	..	..	..	55,248 (a)

(a) Including exports from Cameroons, amounting to 3,639 tons in 1925, 3,104 tons in 1926, 3,121 tons in 1927, 3,573 tons in 1928 and 2,967 tons in 1929.

23. Up to 1914 the cocoa exported was divided between the United Kingdom and Germany with the rather larger proportion going to the former. During the war other countries replaced Germany, and in post-war years the United States has been taking a steadily increasing proportion of the total exports, until, in 1927, it assumed first place with over 35 per cent. of the whole quantity exported. The distribution of exports in 1913 and in the six years 1923 to 1928 is shown in Table V:—

TABLE V.—*Distribution of Exports of Raw Cocoa from Nigeria.*

Destination.	1913.	1923.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United States	—	8,680	9,480	13,310	9,340	14,090	15,180
United Kingdom	1,990	14,270	13,140	15,970	13,100	8,770	12,620
Germany	1,630	5,140	6,810	9,070	6,630	8,050	8,800
Netherlands	—	2,360	6,540	3,750	7,400	7,110	11,490
France	—	1,880	1,060	1,690	1,940	520	370
Italy	—	330	30	80	—	50	—
Other countries	—	160	140	830	690	620	700
Total	3,620	32,820	37,200	44,700	39,100	39,210	49,160

24. Exports to unspecified countries go almost entirely to the French Cameroon, with occasional small quantities to Belgium and other Continental destinations not shown above.

25. As in the case of the Gold Coast, the main cocoa crop is harvested from October onwards, and figures of exports by calendar years are not an entirely reliable guide to annual production. Actually, exports continue throughout the year, but the peak is usually reached from December to February.

26. As regards prospects of future development of the cocoa industry, it has already been pointed out that Nigeria has now arrived at the level of export volume that the Gold Coast had reached just before the war. Since that time the Gold Coast's exports have increased by over 400 per cent.; there seems to be nothing to prevent Nigeria progressing rapidly during the next 20 years, given an adequate development of transport facilities, and sufficient inducement to extend production. The cocoa area is limited climatically to a coastal

belt roughly 150 miles broad, but there is adequate land available within this region for an immense increase in the cocoa area. The population of Nigeria is eight times as large as that of the Gold Coast, and the development of the palm oil industry in the Dutch East Indies and British Malaya may have an important bearing upon the cocoa position in Nigeria, since any depression in the price of palm nuts and oil, the staple exports of Nigeria, would doubtless tend to direct labour towards cocoa cultivation and away from the collection of palm nuts and the extraction of the oil.

British Cameroons.

27. The Germans had made considerable progress in cocoa growing in the Cameroons before the war, and exports in the three years before the war averaged about 3,800 tons per annum. When the cocoa plantations in the British Cameroons were put up to auction in London a few years ago, they were very largely purchased by their former German proprietors.

28. Production in the Cameroons differs from that of the Gold Coast in that a substantial part of the cocoa is grown on large plantations, the largest being some 40,000 acres in extent. In these European plantations great care is taken in the cultivation, handling and picking of the crop. The average yield is estimated at 500 lb. of cured cocoa per acre.

29. There is a projected scheme among the European planters to market their crop co-operatively under the name of "Cameroon Cocoa" as they claim that at present their product realises little more than good Accra cocoa, in spite of the scientific care taken in drying and fermentation.

30. A movement is also reported to have been started by the European planters to purchase native cocoa, ferment it under scientific supervision and place it on the market as "native cocoa, plantation fermented."

31. In Table VI below are shown exports from the ports of Victoria and Tiko during the seven years 1923 to 1929. These indicate only approximately the development of exports from the British Cameroons; cocoa produced in that territory is not shipped solely through Victoria and Tiko nor do such shipments consist exclusively of Cameroon cocoa.

TABLE VI.—*Exports of Raw Cocoa from the Ports of Victoria and Tiko (British Cameroons).*

<i>Year.</i>						<i>Cocoa.</i>
						<i>Tons.</i>
1923	..	..	..	..	..	1,640
1924	..	..	..	..	..	3,170
1925	..	..	..	..	..	3,640
1926	..	..	..	..	..	3,100
1927	..	..	..	..	..	3,120
1928	..	..	..	..	..	3,570
1929	..	..	..	..	..	2,970

From 1925 onwards these figures have been included in exports from Nigeria (see Tables IV and V).

32. Extensive plantings have been made by natives during recent years, and German planters have manured their plantations and generally improved cultivation, which had been neglected. Hence a considerable increase in exports is to be expected within the next few years.

Trinidad and Tobago.

33. These two islands produce a superior quality of cocoa, which, owing to its fine flavour, is used very largely for blending with West African cocoa. There are three recognised types, Criollo, Forastero and Calabacillo, and owing, doubtless, to hybridization, a mixed assemblage of all grades of purity is found on almost all estates. The predominant type is Forastero, with relatively more of the hardier and poorer Calabacillo on poor lands, in drier situations, or where less care has been taken in seed selection. The crop is cultivated both in estates and by peasant proprietors, and a great deal of attention and care have been taken to preserve the reputation of the crop for its uniform good quality.

34. The recorded area under cocoa has shown a continuous decline, but there is some reason to doubt the accuracy of acreage returns, especially in earlier years. In 1928 the area had fallen to less than 190,000 acres. The oil industry has depleted certain fields owing to the clearing of cocoa lands for erecting derricks, roads, buildings, etc., while in the proximity of some of the sugar factories whole plantations of cocoa have been put under sugar. Nevertheless, production has been fairly well maintained, and the average total export for the years 1925-1929 was above that of the quinquennium preceding the war.

35. Among producers of the finer types of cocoa, Trinidad easily maintains second place, and owing to the rapid decline in production in Ecuador in recent years is now challenging that country for the leadership.

36. In the following table are shown annual exports during the pre-war quinquennium, and from 1920 to 1929. The main crop is harvested from December to May or later (with a secondary crop in September–October), and exports by calendar years are consequently not entirely satisfactory as an indication of varying production, as a late or early harvest may affect the year's figures considerably. However, there is no doubt that production in recent years has tended to decline, although a recovery seems to be now in evidence, owing to the reduction in area from the causes enumerated above, and because, at prices now ruling, there is little inducement to develop new plantations in substitution for those taken out or falling out of cultivation.

TABLE VII.—*Exports of Raw Cocoa from Trinidad.*

Year.	Trinidad Produce.	Re-exported Produce
	Tons.	Tons.
1909	23,020	3,580
1910	25,830	3,620
1911	22,230	4,960
1912	18,580	4,720
1913	21,480	4,300
1920	28,010	—
1921	33,590	3,710
1922	22,610	2,740
1923	30,220	2,860
1924	25,180	1,770
1925	22,090	3,250
1926	22,350	3,030
1927	23,190	2,900
1928	25,900	4,130
1929	27,540	4,730

37. There is a considerable import trade in raw cocoa into Trinidad, mainly from Venezuela, with smaller quantities from other British West Indian Islands. Almost the whole of the imported cocoa is re-exported.

38. The United States is by far the most important purchaser of Trinidad cocoa, taking between 40 and 60 per cent. of all exports. Distribution of Trinidad's domestic exports in 1913 and in recent years is given below :—

TABLE VIII.—*Distribution of Exports of Trinidad Cocoa.*

Destination.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United States	10,570	13,170	11,500	14,010	9,480	12,000
France	6,980	3,440	3,190	2,480	4,620	3,910
Netherlands	830	1,960	930	1,770	2,630	1,830
United Kingdom ..	1,750	2,130	2,720	1,530	1,900	1,360
Germany	470	2,220	1,390	800	1,390	2,210
Canada	310	690	560	450	1,020	1,980
Australia	(a)	900	860	610	880	1,030
Italy	330	100	220	150	430	430
Belgium	(a)	190	230	210	230	390
Spain	30	20	100	70	210	200
Argentina	(a)	(a)	190	170	190	180
Other countries ..	210	360	200	100	210	380
Total	21,480	25,180	22,090	22,350	23,190	25,900

(a) Included in other countries.

39. Venezuelan and other cocoa imported is also shipped mainly to the United States, which takes nearly 70 per cent. of the re-exports of cocoa, with the United Kingdom, Canada and France, the leading other purchasers.

40. The downward tendency in cocoa production in Trinidad is serious, especially taken in conjunction with the even more pronounced decline in Ecuador and Venezuela. Costs of production are high in comparison with those in West Africa and other countries producing "ordinary" cocoa. By reason of its quality, Trinidad cocoa has always enjoyed a substantial premium over the common types of cocoa, and it is only by virtue of this premium that it is able to compete in the world's markets. The fall in the price of cocoa during the past year or two has accentuated the difficulties of the producers, and the improving quality of West African cocoa is enabling manufacturers to dispense with the finer flavouring cocoas to an increasing extent. Hence, in spite of the decrease in production, the premium

paid for fine cocoas tends to narrow, and it seems likely that production in Trinidad will continue to decline, unless and until the consuming public shows a much more marked preference for the "finer" cocoas—a contingency which appears to be somewhat remote in view of the improvement in quality of the ordinary cocoas and the manufacturers' success in dealing with them.

41. Some reference should be made to the Cocoa Planters' Association of Trinidad, which is a co-operative society of planters for marketing their produce. The association was formed by twenty-six planters in 1905 with the idea of securing a better premium for their superior grade of cocoa, as it was realised that manufacturers will not pay the premium merited by a better grade of product unless they can be assured of continuity of supply. This association now markets about one-seventh of the colony's total output.

Grenada.

42. This island produces a fine grade of plantation cocoa which, as in the case of Trinidad, is used widely in blending with West African and Brazilian cocoas. It takes first place as regards volume of production of fine cocoa among the minor producing countries, being exceeded only by the three major producers, Trinidad, Ecuador and Venezuela.

43. Up to about 1920 there was a gradual increase in production, the average output rising from about 4,400 tons per annum in the six years 1897-1902 to 5,600 tons annually in the years 1915-20. During the earlier part of this period the increase was no doubt due to extension of cultivation and increase in the yield of young trees as they came into full bearing. There has been little or no extension in cocoa cultivation for many years, and the maximum crops of the island were reached during the period 1915-20. Following that period there was a fall in production, and the average output from 1921-26 was under 4,000 tons per annum, or less than 24 years earlier. The main cause of the decline after 1920 was a severe hurricane which struck the island in 1921, causing much damage. There was subsequently a slow improvement as the plantations recovered from the effects of the hurricane, but the interplanting of nutmeg-trees with the cocoa and the cutting out of unprofitable plantations, have militated against a rapid recovery in production. The cocoa trees had barely recovered from the effects of the hurricane when a rather severe drought was experienced at the beginning of 1927, resulting in certain areas receiving a further set-back and generally retarding

the crop, so that exports which had increased from 3,600 tons in 1922 to over 5,000 tons in 1927, again declined in 1928 to 4,600 tons. Exports of cocoa in pre-war and post-war years are shown below :—

TABLE IX.—*Exports of Raw Cocoa from Grenada.*

<i>Year.</i>						<i>Exports.</i>
						<i>Tons.</i>
1909	..	..	..	..	..	5,410
1910	..	..	..	..	..	5,930
1911	..	..	..	..	..	5,020
1912	..	..	..	..	..	5,050
1913	..	..	..	..	..	5,260
1918	..	..	..	..	..	6,780
1919	..	..	..	..	..	4,970
1920	..	..	..	..	..	4,090
1921	..	..	..	..	..	4,370
1922	..	..	..	..	..	3,640
1923	..	..	..	..	..	3,890
1924	..	..	..	..	..	4,270
1925	..	..	..	..	..	3,660
1926	..	..	..	..	..	4,170
1927	..	..	..	..	..	5,020
1928	..	..	..	..	..	4,570
1929	..	..	..	..	..	4,550

44. The United Kingdom and the United States together take the greater part of Grenada's cocoa exports, and Canada is the only other important purchaser. Distribution of exports in 1913 and from 1924 to 1928 is shown below :—

TABLE X.—*Distribution of Exports of Raw Cocoa from Grenada.*

Destination.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	2,980	2,390	1,550	1,720	1,940	2,100
United States	1,490	1,420	1,850	2,130	2,430	1,800
Canada	—	170	110	100	500	620
France	790	150	120	170	130	40
Other countries	—	140	30	50	20	10
Total	5,260	4,270	3,660	4,170	5,020	4,570

45. Cocoa production in Grenada is intensive on the whole, although the peasant owner is an important element, and in spite of the reduction in the area under the crop, the output is not likely to decline seriously. On the other hand, there is little prospect of any increase in the cocoa area. Cocoa accounts for about three-fifths of the value of exports annually, and the recent reduction in cocoa prices is a serious blow to the producers, but in view of the concentration of production in the most suitable plantations, the volume of production should be maintained at about its present level, unless climatic causes again intervene to reduce the crop, or a further fall in prices leads to a further reduction in area.

Jamaica.

46. Jamaica produces cocoa similar to that of Trinidad, although slightly inferior in quality, but the cultivation of this crop has been somewhat neglected owing to the increased attention given to bananas and sugar. The cocoa area, which in pre-war years amounted to 11,700 acres, had fallen by 1924 to 9,000 acres, and by 1928 to 4,700 acres.

47. Exports in recent years have fallen far below the heavy figures for 1922, and the average for the five years ended 1929 was only slightly above the pre-war level. Exports of cocoa in pre-war and post-war years are shown below:—

TABLE XI.—*Exports of Raw Cocoa from Jamaica.*

<i>Year.</i>						<i>Tons.</i>
1909	..	..	..	..	..	2,974
1910	..	..	..	..	..	1,750
1911	..	..	..	..	..	2,681
1912	..	..	..	..	..	3,284
1913	..	..	..	..	..	2,318
1920	..	..	..	..	..	2,522
1921	..	..	..	..	..	3,248
1922	..	..	..	..	..	3,842
1923	..	..	..	..	..	2,156
1924	..	..	..	..	..	2,960
1925	..	..	..	..	..	2,617
1926	..	..	..	..	..	3,008
1927	..	..	..	..	..	2,863
1928	..	..	..	..	..	2,252
1929	..	..	..	..	..	3,032

48. The United Kingdom and the United States are the largest consumers of Jamaican cocoa, Canada and France being the only other important purchasers. The distribution of exports pre-war and in recent years is shown in the following table :—

TABLE XII.—*Distribution of Exports of Raw Cocoa from Jamaica.*

Destination.	Average 1910-14.	1923.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom ..	1,220	1,492	799	1,813	102	678	201
British Empire ..	156	264	242	48	320	560	450
U.S.A.	497	220	966	243	1,886	1,135	1,114
Other countries ..	857	180	953	513	700	490	487
Total	2,730	2,156	2,960	2,617	3,008	2,863	2,252

St. Lucia.

49. Cocoa has been successfully cultivated in St. Lucia for fifty years. Most of the plantations are situated in the moist and cooler areas of the island, mainly at the heads of sugar growing valleys and lining the minor valleys throughout the island. The present area under cocoa is estimated at 6,000 acres. There is a considerable area now under native forest suitable for cocoa cultivation.

50. During the years 1927 and 1928 growers gave increased attention to their estates owing to the more favourable prices ruling, and the quality of the beans has shown a marked improvement. There has been a marked falling off of the quantity consigned overseas in 1928 and 1929 in comparison with the recovery of the previous year.

51. In the following table are shown the exports from St. Lucia from 1911 to 1913 in comparison with post-war years; it will be noted that there has been a substantial fall in the quantity exported :—

TABLE XIII.—*Exports of Raw Cocoa from St. Lucia.*

<i>Year.</i>	<i>Tons.</i>
1911	926
1912	855
1913	729
1922	729
1923	641
1924	608
1925	522
1926	502
1927	609
1928	550
1929	445

52. Shipments are mainly to the United Kingdom, Trinidad and the United States. The quantity sent to the Netherlands has fallen off in the past two years. In the following table are shown the quantities exported to the main countries of consignment in 1913 and in recent years:—

TABLE XIV.—*Distribution of Exports of Raw Cocoa from St. Lucia.*

Consigned to.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	300	294	292	201	264	292
Trinidad	—	33	72	126	230	161
U.S.A.	46	230	64	49	113	71
Netherlands	37	14	73	118	—	8
Other countries	346	37	21	8	2	18
Total	729	608	522	502	609	550

St. Vincent.

53. The cultivation of cocoa is not of great importance in this island, as conditions are not considered to be very favourable to its cultivation. The quantity exported is now much less than in pre-war days, as is shown by the following table of the total exports in the years 1911 to 1913 and 1922 to 1929:—

TABLE XV.—Exports of Raw Cocoa from St. Vincent.

Year.							Tons.
1911	..	..	..	..	..	..	128
1912	..	..	..	..	..	..	100
1913	..	..	..	..	..	..	95
1922	..	..	..	..	..	..	62
1923	..	..	..	..	..	..	54
1924	..	..	..	..	..	..	58
1925	..	..	..	..	..	..	69
1926	..	..	..	..	..	..	78
1927	..	..	..	..	..	..	61
1928	..	..	..	..	..	..	80
1929	..	..	..	..	..	..	70

54. The principal countries of destination of St. Vincent exports of cocoa are the United Kingdom, Barbados and the United States. Below are given the quantities consigned to various destinations in a series of recent years as compared with 1913 :—

TABLE XVI.—Distribution of Exports of Raw Cocoa from St. Vincent.

Consigned to.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	40	12	38	28	18	36
Barbados	(a)	31	17	29	23	30
U.S.A.	17	—	5	20	13	10
Other countries	38	15	9	1	7	4
Total	95	58	69	78	61	80

(a) Included in other countries.

Ceylon.

55. Cocoa cultivation received its first impulse on this island between 1870 and 1880 when a leaf disease was destroying the coffee plantations. The "Forastero" plant, which is hardy and highly yielding, is gradually replacing the less prolific Venezuela "Criollo," generally known as the "Old Ceylon Red," the original cocoa plant of the island. The change is due to the greater resistance to disease of the Forastero plant and to the long periods of drought which occur in the cocoa growing districts. Nevertheless, diseases are still rife and seriously curtail output. While the Criollo produces a finer grade of cocoa

which commands a higher price, the heavier yields from the Forastero compensate for the lower market value of the product.

56. The amount of land suitable for cocoa cultivation in Ceylon is limited, as the plant cannot be cultivated below 500 feet or above 2,000 feet elevation. It is estimated that there are at present about 35,000 acres under cocoa.

57. There have been considerable yearly fluctuations in exports owing chiefly to the main harvest lasting into January, with the result that an early or late harvest may considerably alter the yearly figures. The main or autumn crop is gathered in November, December and January, and the small spring crop in May, June and July. Averaged over quinquennial periods, which eliminate to a considerable extent the fluctuations caused by early or late seasons, there has been relatively little variation in exports, although post-war years showed a slight falling off. Average exports in the five years from 1909 to 1913 amounted to 3,537 tons; in the following quinquennium they rose to 3,576 tons. From 1919 to 1923 the average was only 3,216 tons, but there was a recovery in the years 1924 to 1928 to an average of 3,573 tons.

58. Annual exports during the five years from 1909 to 1913 and from 1919 onwards are shown below :—

TABLE XVII.—*Exports of Raw Cocoa from Ceylon.*

<i>Year.</i>						<i>Exports.</i>
						<i>Tons.</i>
1909 .. .. .	..	..	..	..	..	4,036
1910 .. .. .	..	..	..	..	..	3,564
1911 .. .. .	..	..	..	..	..	3,071
1912 .. .. .	..	..	..	..	..	3,588
1913 .. .. .	..	..	..	..	..	3,426
1919 .. .. .	..	..	..	..	..	2,944
1920 .. .. .	..	..	..	..	..	2,820
1921 .. .. .	..	..	..	..	..	3,112
1922 .. .. .	..	..	..	..	..	4,161
1923 .. .. .	..	..	..	..	..	3,045
1924 .. .. .	..	..	..	..	..	3,468
1925 .. .. .	..	..	..	..	..	3,439
1926 .. .. .	..	..	..	..	..	3,238
1927 .. .. .	..	..	..	..	..	4,040
1928 .. .. .	..	..	..	..	..	3,681
1929 .. .. .	..	..	..	..	..	4,134

59. The Philippine Islands, the United Kingdom and the United States are the leading markets for Ceylon cocoa, but a number of other countries take considerable quantities. The quantity of cocoa purchased by the United Kingdom from Ceylon has declined from 2,200 tons in 1913 to 550 tons in 1928, but the deficiency has been more than counter-balanced by the increased buyings by other countries, more especially the Philippine Islands.

60. The details of the countries to which Ceylon cocoa was consigned in the years 1913 and from 1925 to 1928 are given below :—

TABLE XVIII.—*Exports of Raw Cocoa from Ceylon.*

Exported to	1913.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	2,196	1,180	590	823	546
Belgium	20	45	50	69	28
Germany	212	44	90	237	92
Holland	42	20	14	134	13
Australia	13	150	330	244	120
Hong Kong	—	5	—	54	18
New Zealand	71	1	21	27	18
Straits Settlements	66	—	20	32	27
U.S.A.	182	357	383	566	432
South Africa	5	3	8	17	18
Canada and Newfoundland ..	57	202	184	279	333
Philippine Is.	407	1,264	1,306	1,258	1,514
Argentina	(a)	—	24	42	38
Denmark	(a)	5	13	24	11
Italy	(a)	—	14	91	32
Mexico	(a)	156	12	33	413
Sweden	(a)	7	7	18	14
Other countries	155	—	172	92	14
Total	3,426	3,439	3,238	4,040	3,681

(a) Included in "Other countries."

Western Samoa.

61. A very choice variety of cocoa is cultivated in Western Samoa. About 4,000 acres are entirely devoted to cocoa, and a further 500 acres of rubber are interplanted with cocoa trees. Production is

increasing, although shortage of labour seriously handicaps the industry, and the yield has grown from 678 tons in 1925 to 757 tons in 1927.

62. There is very little native production, but efforts are being made to encourage native plantation, and education in cocoa cultivation is being given by inspectors.

63. The increase in production is reflected in the expansion of exports, which in recent years have been as follows :—

TABLE XIX.—*Exports of Raw Cocoa from Western Samoa.*

<i>Years.</i>							<i>Tons.</i>
1925	..	..	..	..	..	..	664
1926	..	..	..	..	..	..	356
1927	..	..	..	..	..	..	792
1928	..	..	..	..	..	..	959

The decrease in exports in 1926 was due to unfavourable weather conditions early in the year.

Ecuador.

64. Prior to 1910 Ecuador ranked first among cocoa growing countries, but has since been surpassed by the Gold Coast, Nigeria, Brazil and the Dominican Republic. Yet, although Ecuador has had to cede place as regards quantity, its cocoa still ranks very high as regards quality.

65. Cocoa is grown in five provinces in Ecuador, each one producing a distinctive quality. Los Rios produces the product known commercially as "Arriba", and the other provinces cocoas which are much less well known than "Arriba", which is the finest in quality. It is produced all through the year, but the main crop is from March to June; it is then at its best, and the cocoa is known as "Summer Arriba."

66. The cocoa is cultivated mostly on estates situated along the river banks near the littoral; the estates are in general very large, and are said to be mostly owned by foreign capital, chiefly British and German.

67. The industry made great progress from 1890 onwards owing to the introduction of Forastero trees from Trinidad, but, unfortunately, the introduction of these trees affected the quality of the

product. Exports from 1919 onwards are shown in Table XX, in comparison with the averages for 1909-13 and 1914-18 :—

TABLE XX.—*Exports of Raw Cocoa from Ecuador.*

<i>Year.</i>					<i>Exports. Tons.</i>
1909-13 (average)	..	..	..	..	36,760
1914-18 (average)	..	..	..	..	41,420
1919	..	..	..	..	43,960
1920	..	..	..	..	46,030
1921	..	..	..	..	42,170
1922	..	..	..	..	43,550
1923	..	..	..	..	30,390
1924	..	..	..	..	32,720
1925	..	..	..	..	32,380
1926	..	..	..	..	21,430
1927	..	..	..	..	23,200
1928	..	..	..	..	22,600

68. During the twelve years from 1911 to 1922 exports were remarkably uniform, varying only from a minimum of 36,400 tons in 1915 to a maximum of 46,000 tons in 1920. However, a fungus disease (" Monilia ") made its appearance in 1917 and soon spread rapidly, while in 1927 the dread " witch-broom " was noted, and has since caused immense havoc on the plantations. The methods of cultivation used have facilitated the spread, and have rendered difficult the control, of fungoid diseases.

69. The effect is apparent from the above figures, annual exports from 1926 to 1928 being about half the average from 1914 to 1922. The Department of Agriculture of Ecuador has even stated, in a bulletin published in November, 1926, that the diseases have become so widespread that cocoa production in the country may have to cease. Many plantations have already been abandoned, and others have been planted with bananas, coffee and other crops. The climate and situation of Ecuador appear to favour the spread of fungus disease, and control methods have so far proved prohibitively expensive. In one group of plantations in the Balao district production, which averaged about 3,300 tons per annum from 1918 to 1922, fell to 1,700 tons in 1923, to 800 tons in 1924, and to only 90 tons in 1925.

70. As in the case of most South American producing countries, the bulk of the crop is shipped to the United States, with France, Germany and Holland the principal other purchasers. Distribution of exports in recent years is shown below :—

TABLE XXI.—*Distribution of Exports of Cocoa from Ecuador.*

Destination.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.
United States	13,060	15,200	10,410	8,400	8,820
Germany	6,840	5,100	2,340	3,960	4,370
France	1,840	2,810	2,810	3,940	2,790
Netherlands	5,810	3,650	2,250	3,160	2,290
Spain	920	1,250	990	1,390	1,240
United Kingdom	1,480	1,510	930	380	520
Italy	740	690	650	570	550
Sweden	550	580	280	290	410
Belgium	400	550	230	290	470
Denmark	430	480	160	280	250
Argentina	10	130	130	200	150
Australia	190	210	110	160	130
Other countries	450	220	140	180	610
Total	32,720	32,380	21,430	23,200	22,600

71. Ecuador cocoa, owing to its quality, has in the past enjoyed a very wide distribution for flavouring purposes, but as in the case of the other fine cocoas, demand purely for flavouring is now rather less keen than formerly. As indicated above, exports have declined with striking rapidity, and although even so late as 1927 the country was still the largest exporter in the world of fine cocoa, there seems to be considerable prospect of production continuing to decline, and of demand being eventually compelled to turn to other sources for supplies of the finest types of cocoa.

Brazil.

72. Brazil takes second place to the Gold Coast in volume of production of cocoa. In 1926 the total number of cocoa trees in Brazil was estimated at about 130 million (compared with 180 million in the Gold Coast), of which 110 million were in the state of Bahia.

73. Cocoa is grown in the States of Para, Maranhao, and Bahia, but the last named supplies over 90 per cent. of the total cocoa exports of the country, and the product is commercially known as "Bahia." The best quality is usually regarded as slightly superior to Gold Coast cocoa, and its price is usually a shade higher. Cocoa has been cultivated for a considerable time in the state of Para, and the product is superior to that of Bahia, but the output is relatively small.

74. Brazil has to import every year about 50 per cent. of her home requirements from Venezuela, as her own product does not find much favour unless blended with a superior quality of cocoa.

75. The State Department of Agriculture and the Cocoa Growers' Association are making strenuous efforts to encourage the cultivation of Venezuelan Criollo in the state of Bahia on account of the higher price realised for this product. It is said that some 20,000 trees of this variety already exist in the State, but planters are not enthusiastic over it owing to the lighter yield.

76. Table XXII below shows exports in 1880, and in certain pre-war and post-war years. Development has been fairly continuous since 1910, and in 1927 exports reached their maximum with a total of over 74,000 tons, or more than double the quantity exported from any other country except the Gold Coast.

TABLE XXII.—*Exports of Raw Cocoa from Brazil.*

Year.	Tons.	Year.	Tons.
1880	1,510	1922	44,560
1910	28,670	1923	64,300
1911	34,430	1924	67,780
1912	30,010	1925	63,510
1913	29,280	1926	62,310
1914	40,120	1927	74,350
1920	53,540	1928	71,230
1921	42,200		

77. The great expansion in cocoa production from 1890 onwards is said to be due to bands of nomadic workers resulting from the emancipation of the slaves of the sugar plantations of the north. Living in huts under most primitive conditions, they clear the forest and plant

cocoa. Planters with capital frequently obtain established plantations by buying up a number of connecting holdings from these nomads, who then move on to fresh fields and repeat the process.

78. The United States has for long been the principal purchaser of Brazilian cocoa, but in 1913 took only about one-third of total exports, while the United Kingdom took over one-quarter of the exports in that year. The United Kingdom's purchases have, however, declined to small proportions, and in recent years the United States has taken from 50 to 60 per cent. annually of total exports, while Germany, Holland, France and other continental countries take the greater part of the remainder.

79. Table XXIII shows the distribution of Brazil's cocoa exports in 1913, and from 1922 to 1926.

TABLE XXIII.—*Distribution of Exports of Cocoa from Brazil.*

Exported to	1913.	1922.	1923.	1924.	1925.	1926.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Germany	3,620	8,310	5,850	12,450	6,540	5,680
Argentina	1,000	2,400	2,940	2,720	2,780	2,560
Belgium	50	1,660	2,320	1,890	1,130	880
Colombia	—	—	—	—	530	1,030
Denmark	210	880	850	920	970	960
U.S.A.	9,890	18,310	38,740	33,030	32,580	39,780
France	4,710	5,120	4,840	6,570	5,850	3,000
United Kingdom ..	7,830	970	390	600	1,340	750
Holland	950	4,020	4,210	5,230	6,160	3,760
Italy	140	200	830	1,760	2,380	1,710
Norway	10	870	660	290	470	340
Sweden	—	1,420	2,070	1,920	2,080	1,070
Uruguay	80	330	420	130	310	240
Other countries ..	790	70	180	270	390	550
Total	29,280	44,560	64,300	67,780	63,510	62,310

80. There seems no reason to suppose that cocoa production in Brazil, which has made so marked an advance in the past fifteen years, will not continue to increase. The industry labours under a number of handicaps, such as high export and municipal taxes, heavy transport charges, and the scarcity and costliness of labour. As the

permanent workers on the plantations are not sufficient to harvest the crop, planters have to rely on casual labour at harvest time. These labourers have to be paid in cash, which is generally secured in the form of an advance against contracts to deliver cocoa. This naturally tends to depress the price the grower receives for his product.

81. There has been considerable agitation among the planters for some sort of Government protection against fluctuations in prices, such as already exists in the coffee trade. But it is generally recognised that the obstacles in the way of such a scheme are insurmountable, among these being the fact that cocoa cannot be stored for any length of time in a hot, damp climate. Moreover, of course, Brazil does not occupy the same position among the world's cocoa growing countries as among coffee producing countries.

82. It is claimed that Brazil is ideally situated for the production of cocoa, and land recently opened up is said to be better suited for cocoa cultivation than any to be found in Bahia. In spite, therefore, of the adverse factors militating against the development of the industry, it seems likely that production will continue to increase.

Venezuela.

83. Venezuela is one of the group of countries producing choice cocoa, and as regards quality its product holds first place on the market. Two varieties of cocoa are cultivated in Venezuela—"Criollo" and "Trinitario." The Venezuelan "Criollo" variety, which is cultivated in the centre and west of the country, was at one time classed as an ideal cocoa, as it was said to contain all the elements necessary for perfect cocoa, but the importance of preserving the purity of the strain was not sufficiently realised, and cross fertilisation with "Trinitario" has produced a number of varieties all more or less inferior to the original "Criollo."* "Trinitario" is cultivated mostly in the east of the country.

84. It is estimated that there are about 148,000 acres under cocoa, and that there is still a fairly large area available for development. However, production has fallen off considerably in recent years, and there does not appear to be any immediate prospect of a recovery, owing to shortage of labour, lack of capital and the competing interest of coffee planting. Annual exports of cocoa are shown in Table XXIV.

* Pitter "Las Plantas Usuales de Venezuela."

TABLE XXIV.—*Exports of Raw Cocoa from Venezuela.*

<i>Year.</i>						<i>Exports. Tons.</i>
1909-13 (average)	..	..	..	..	..	15,800
1920	..	..	..	..	..	17,310
1921	..	..	..	..	..	21,340
1922	..	..	..	..	..	20,560
1923	..	..	..	..	..	22,070
1924	..	..	..	..	..	17,050
1925	..	..	..	..	..	22,580
1926	..	..	..	..	..	14,810
1927	..	..	..	..	..	15,160

85. Exports reached their maximum in the quinquennium beginning 1921, during which shipments fell below 20,000 tons in only one year. In 1926 and 1927 exports were below the average of the five years before the war. The United States is now the chief purchaser, although before the war more than one-half the exports went to France, and that country is still a fairly close second, and has recently been increasing her share. Table XXV shows the distribution of exports in 1913, and from 1924 to 1927.

TABLE XXV.—*Distribution of Exports of Cocoa from Venezuela.*

<i>Country.</i>	1912-13.	1924.	1925.	1926.	1927.
	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>
United States	1,990	6,320	8,890	5,670	5,690
France	8,100	4,070	3,020	3,850	4,030
Germany	610	1,710	1,840	520	1,260
Spain	1,600	1,030	1,090	1,020	1,350
Holland	90	1,210	1,240	570	870
United Kingdom	60	500	700	560	760
Trinidad	1,980	1,060	980	870	200
Belgium	10	290	390	140	210
Italy	60	190	140	170	140
Other countries	70	670	4,290	1,440	650
Total	14,570	17,050	22,580	14,810	15,160

86. Considerable quantities of cocoa are exported to Trinidad from Venezuela, but the bulk of this cocoa is subsequently re-exported to the United States, United Kingdom, Canada, France and elsewhere.

Costa Rica.

87. The development of cocoa production in Costa Rica has been very rapid since pre-war days. In the quinquennium ending 1913, exports averaged only 284 tons, while by 1922 shipments had increased to over 2,000 tons; four years later they had grown to over 5,200 tons, and in 1928, when there was a record crop, to 5,700 tons.

88. The rapid expansion of cocoa cultivation in recent years is mainly in the province of Limon, where land thrown out of banana cultivation owing to the ravages of Panama disease is now devoted to cocoa. Further increase in the production in this area is to be expected. There was a rapid extension in the cocoa area between 1919 and 1922, and the extension is reflected in the increase in exports during the past few years.

89. Exports of cocoa during pre-war years and from 1922 onwards are shown below :—

TABLE XXVI.—*Exports of Raw Cocoa from Costa Rica.*

<i>Year.</i>				<i>Exports.</i> <i>Tons.</i>
1909–13 (average)	..	..	..	280
1922	..	..	..	2,060
1923	..	..	..	4,190
1924	..	..	..	3,620
1925	..	..	..	4,080
1926	..	..	..	5,230
1927	..	..	..	3,370
1928	..	..	..	5,680

90. The United States is the chief purchaser of the Costa Rica product, as is shown in the following table of the exports giving details of countries for the years 1913 and 1924 to 1927.

TABLE XXVII.—*Distribution of Exports of Cocoa from Costa Rica.*

Exported to	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
U.S.A.	40	990	910	1,900	1,110	—
Colombia	(a)	930	870	1,330	750	—
Panama	(a)	240	490	1,110	640	—
Germany	(a)	180	290	80	270	—
Chile	(a)	130	140	130	240	—
United Kingdom	240	20	90	60	80	—
San Salvador	(a)	110	80	110	80	—
Peru	(a)	140	340	250	80	—
France	(a)	740	680	210	80	—
Guatemala	(a)	70	100	40	30	—
Other countries	100	70	90	10	10	—
Total	380	3,620	4,080	5,230	3,370	5,680

(a) Included in "Other countries."

91. The area suitable for cocoa growing on the Atlantic side is estimated at about 370,000 acres, or about five times the present area under cocoa. Cultivation would also be possible on the Pacific side if irrigation were provided. A very high grade of cocoa is produced.

Haiti.

92. Except for a small plantation at Bayeux where about 15 acres are cultivated, the whole of the cocoa produced in Haiti grows wild. It is picked by the natives when the price is sufficiently attractive for it to assume a greater interest than work in the coffee plantations or upon other crops, and exports are consequently very variable, depending almost entirely upon the market price. In any case the output is comparatively small, and shows little signs of increase.

93. Owing to lack of care in fermenting, the quality is inferior to the product from other West Indian Islands. The bulk of the crop is absorbed by the United States, but Germany has in recent years increased its purchases, and from 85 per cent. of total exports in 1923 the share of the United States had declined to about 71 per cent. in 1928. However, of the small exports of 1,340 tons in 1929, the United States again took over 80 per cent. (1,090 tons), while Germany and France took 140 and 110 tons respectively.

94. Exports of cocoa for the fiscal years ending 30th September showing quantities and countries of destination are given below :—

TABLE XXVIII.—*Distribution of Exports of Cocoa from Haiti.*

Exported to	1923.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United States of America	1,700	1,060	1,080	1,110	690	1,660
France	260	540	320	810	600	310
Germany	10	—	110	220	250	360
Other countries	20	20	—	20	60	20
Total	1,990	1,620	1,510	2,160	1,600	2,350

Panama.

95. While a high grade of cocoa is produced in parts of Panama, in certain areas in Darien it grows wild. Exports have very considerably expanded since before the war. The annual average for the five years 1909 to 1913 was only 29 tons, whereas in both of the years 1926 and 1927 the quantity exported was over 2,000 tons, and in 1928 over 3,000 tons, the details being given in Table XXIX below. The bulk is consigned to the United States :—

TABLE XXIX.—*Exports of Raw Cocoa from Panama.*

Year.	Tons.
1909–13 (average)	29
1925	2,000
1926	2,490
1927	2,290
1928	3,090

Dominican Republic.

96. This country produces an "ordinary" cocoa of the kind known commercially as San Domingo. The crop comes in through the whole year, but the main crop is picked from March to June, with a second crop picked from October to December. Plantings in recent years have been on a small scale only.

97. Exports have shown an increasing tendency since the year 1922, and although in comparison with the larger producers of common cocoa, the Dominican Republic is not of great importance, the

country ranks fourth, on 1927 figures, among all exporting countries, having superseded Ecuador in that year, although an appreciable falling off occurred in the following year. Exports in pre-war and post-war years are shown below :—

TABLE XXX.—*Exports of Raw Cocoa from Dominican Republic.*

<i>Year.</i>						<i>Exports.</i>
						<i>Tons.</i>
1911	..	..	..	..	..	19,510
1912	..	..	..	..	..	20,500
1913	..	..	..	..	..	19,160
1921	..	..	..	..	..	26,150
1922	..	..	..	..	..	18,690
1923	..	..	..	..	..	19,520
1924	..	..	..	..	..	22,780
1925	..	..	..	..	..	23,110
1926	..	..	..	..	..	19,770
1927	..	..	..	..	..	26,090
1928	..	..	..	..	..	19,000
1929	..	..	..	..	..	21,150

98. Almost the whole of the Dominican cocoa crop is taken by the United States, and other countries are represented by very small quantities. The details for 1923 to 1928 are given in the following table :—

TABLE XXXI.—*Distribution of Cocoa Exports from the Dominican Republic.*

<i>Destination.</i>	1923.	1924.	1925.	1926.	1927.	1928.
	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>	<i>Tons.</i>
U.S.A.	19,320	22,290	22,220	19,400	25,600	18,460
France	60	110	260	20	60	50
Germany	110	170	210	—	30	—
Netherlands	—	90	300	140	90	140
Mexico	—	—	20	110	250	280
Other countries	30	120	100	100	60	70
Total	19,520	22,780	23,110	19,770	26,090	19,000

San Thomé and Príncipe.

99. These Islands produce a medium type of "ordinary" cocoa, which usually ranks somewhat above that of Bahia as to quality. A great deal of care is taken in cultivation and the preparation of the beans for market. The exports for the years 1925 to 1927 are compared with the averages of those of earlier periods in Table XXXII below:—

TABLE XXXII.—*Exports of Raw Cocoa from San Thomé and Príncipe.*

<i>Period.</i>				<i>Exports. Tons.</i>
1895-99 (average)	..	..	..	9,250
1900-04 (average)	..	..	..	17,920
1905-09 (average)	..	..	..	26,430
1910-13 (average)	..	..	..	34,080
1920-24 (average)	..	..	..	19,370
1925	..	..	..	20,530
1926	..	..	..	12,270
1927	..	..	..	16,500

100. Cocoa has been cultivated since 1828 and reached its peak of production shortly before the war, at which time the islands were the second largest exporters of cocoa in the world, taking second place only to Ecuador. Since the pre-war period exports have shown a steady decrease, largely due to the ravages of "thrips" and to deforestation. Strong measures have been taken to combat "thrips," but there is no present indication of any recovery in cocoa production. As in British West Africa the main crop ripens in October and November, with a secondary crop in March and April.

101. The whole of the crop is exported to Lisbon, whence the greater part is re-exported to other markets. As will be seen from Table XXXIII below, showing re-exports of San Thomé cocoa from Portugal in 1923, 1924 and 1927 (figures for intervening years are not available), Germany and Holland are the most important buyers of the produce of San Thomé, with other Continental countries, especially France and Italy, also of appreciable importance:—

TABLE XXXIII.—*Re-exports of San Thomé Cocoa from Portugal.*

Destination.	1923.	1924.	1927.
	Tons.	Tons.	Tons.
Germany	5,400	9,840	4,920
Belgium	800	460	290
United States	1,580	470	420
France	370	360	1,050
Holland.. .. .	6,010	5,280	3,800
United Kingdom	440	1,290	590
Italy	3,120	3,160	1,730
Other countries	210	230	240
Total	17,930	21,090	13,040

French Colonies and Mandated Territories.

102. Exports of raw cocoa from French dependencies are not yet of very great importance, combined exports from the colonies and mandated territories in Africa and elsewhere falling considerably short of the exports from Nigeria and amounting to barely one-tenth of Gold Coast exports. Up to the outbreak of the war the two main French producing colonies were Martinique and Guadeloupe, which together accounted for over 90 per cent. of French colonial production in the quinquennium 1900-04, and over 80 per cent. from 1910 to 1914. During the war period the export trade of French West and Equatorial Africa made substantial progress, and in the past few years, while Guadeloupe and Martinique have been exporting on the average rather less cocoa than earlier in the century, the Ivory Coast has developed to the point of exporting, in 1923, between 14,000 and 15,000 tons of raw cocoa. In addition, the French mandated territories of the Cameroon and Togo are being assisted to develop their cocoa production. In Table XXXIV below are shown exports of raw cocoa from the various French colonies and mandated territories in 1913, and from 1924 to 1927 :—

TABLE XXXIV.—*Exports of Raw Cocoa from French Colonies and Mandated Territories.*

Exported from	1913.	1924.	1925.	1926.	1927.
	Tons.	Tons.	Tons.	Tons.	Tons.
Ivory Coast	45	4,230	6,180	6,730	9,600
Madagascar	35	130	155	120	145
Guadeloupe	895	690	640	600	710
Martinique	515	530	440	430	390
Guiana	15	20	5	15	15
Gabon	155	180	90	130	100
Dahomey	5	50	20	30	30
Togo	—	6,330	4,530	5,140	6,210
Cameroon	—	4,420	4,840	5,260	7,450
New Caledonia	5	1,270	790	800	430
Congo	—	—	50	35	90
Total	1,670	17,850	17,740	19,290	25,170

103. Cocoa produced in the French possessions enjoys a substantial preference over other cocoas in the French market, and practically all the exports from French colonies and mandated territories are exported to France. Notes on the principal producing areas among French dependencies are given in the following paragraphs.

IVORY COAST.

104. Cocoa was first introduced into the Ivory Coast about 1870, but made slow progress, and as recently as 1908 only a few scattered plantations existed, while the amount annually exported was negligible. The industry appears to be developing very much along the same lines as in the Gold Coast in the early stages, and there are prospects of future development continuing the parallel.

105. The coastal region is well adapted for the cultivation of the crop, although the natives are apparently less enterprising than their neighbours in the Gold Coast, and are reported to have resisted most strongly the earlier attempts to introduce the new crop. However, in 1912, owing to the crisis in rubber, the natives took up the cultivation more actively. In the early stages of the industry the French authorities had to take energetic measures to ensure that the natives did not abandon their plantations.

106. Demonstration farms have been established by the Government in several centres, and there is also a service of travelling inspectors who give advice, demonstrations, etc., to the natives. Unlike the Gold Coast and Nigeria, there are a number of European plantations in the Ivory Coast.

107. In considering the possibilities of the Ivory Coast, the relative scantiness of the population must be taken into account, for although the area suitable for the cultivation of cocoa is vast, it is sparsely populated, with 5.5 inhabitants per square kilometre against 10.2 in the Gold Coast and 20.7 in Nigeria. Although exports in 1928 amounted to less than 15,000 tons, a writer in the "Revue des Deux Mondes" in September, 1929, stated that in two years' time the Ivory Coast will supply the whole of the cocoa required annually for French consumption.

108. Well prepared Ivory Coast cocoa is equal in quality to good Gold Coast, San Thomé or Bahia cocoa. In 1924 a system of control for all cocoa marketed was inaugurated, and no cocoa is allowed to be sold or exported unless it conforms to various requirements as to condition, fermentation and taste.

109. A preference of the full tariff is given on cocoa entering from this colony into France.

FRENCH TOGOLAND.

110. The French authorities are actively encouraging the cultivation of cocoa in this country, and the result of their efforts can be judged by the increase in exports during recent years.

111. This increase in production is principally due to the free distribution of cocoa plants from the Government nurseries which have been established at various centres. There can be little doubt that the continuation of this policy will lead to a further considerable increase in the cocoa exports within the next few years. The quality of the cocoa exported is controlled by the local Chamber of Commerce.

112. Exports of cocoa in 1928 amounted to 6,220 tons, almost all of which was destined for France.

FRENCH CAMEROON.

113. The active co-operation of the French authorities with the native cocoa planters has been most successful in this country. As the following export figures show, there has been a substantial increase in production since 1920, and especially since 1923.

TABLE XXXV.—*Exports of Raw Cocoa from French Cameroon.*

Year.			Tons.	Year.			Tons.
1920	..	..	2,540	1925	..	..	4,840
1921	..	..	3,420	1926	..	..	5,260
1922	..	..	3,400	1927	..	..	7,450
1923	..	..	3,410	1928	..	..	7,200
1924	..	..	4,420				

Government fermentaries have been established, and the quality of the cocoa is good.

DAHOMEY.

114. Exports from Dahomey hitherto have been small, later figures than those given in Table XXXIV showing only 20 tons in 1928 and 30 tons in 1929, but there should be a substantial increase in the future, as a result of the policy of free distribution of plants and seeds which is being adopted by the French authorities here and elsewhere. Exports go entirely to France.

MARTINIQUE.

115. Although official attempts have been made to interest planters in cocoa production in Martinique, little success has been achieved, owing to the attention paid to the sugar cane, and little expansion is to be looked for in the near future. The total area devoted to cocoa is estimated at under 4,000 acres. Exports are consigned exclusively to France.

Fernando Po.

116. Cocoa has long been grown in Fernando Po, and it is generally agreed that the first cocoa introduced into the Gold Coast came thence. A native of the Gold Coast, who was returning home from Fernando Po in 1879, carried with him a few cocoa seeds, from which has developed the tremendous cocoa industry of British West Africa.

117. Most of the cocoa plantations are very old, and many planters are reported to be turning their attention to coffee owing to the difficulty of obtaining satisfactory yields of cocoa from these old plantations and the impossibility of starting a good growth of young cocoa.*

* Leonard I. Schwarz, U.S.A. Dept. of Agriculture in "Cocoa in West Africa."

118. Export figures of cocoa from Fernando Po are not available, but the imports thence into Spain, which comprise practically the total exports of the colony, will suffice to give an idea of the trend of production.

TABLE XXXVI.—*Imports of Raw Cocoa from Fernando Po into Spain.*

<i>Year.</i>					<i>Tons.</i>
1909-13 (average)	..	..	..	..	3,590
1922	..	..	..	..	5,920
1923	..	..	..	..	7,090
1924	..	..	..	..	9,480
1925	..	..	..	..	5,870
1926	..	..	..	..	5,670
1927	..	..	..	..	5,870
1928	..	..	..	..	8,420

119. Exports are on a substantially larger scale than before the war, but a tendency to decline is in evidence, so far as the figures given in the above table may be taken as a guide; but fluctuations from year to year, as in other producing countries, may well be caused by variation in the date of the harvest, or by the planters' practice of holding up supplies when price movements appear to justify it.

120. Almost the whole of the exports go to the Spanish market for which the cocoa is specially prepared. A very substantial rebate in the export duty is granted on all cocoa shipped from Fernando Po to Spanish ports.

Surinam (Dutch Guiana).

121. Cocoa has been exported from this country since 1725. The exports in 1895 reached 4,310 tons. At that time "witch broom" disease was noticed, and year after year the damage from this disease became more extensive until in 1904 not more than 830 tons were exported. However, means were found to control the disease, and production recovered until 1910, when over 2,000 tons were exported. Droughts in 1911 again caused a decline. Since the war, production has showed a steady falling off as the following table of exports will show:—

TABLE XXXVII.—*Exports of Raw Cocoa from Surinam.*

<i>Year</i>						<i>Exports. Tons.</i>
1909–13 (average)	..	..	..	..	..	1,580
1921	..	..	..	..	..	1,610
1922	..	..	..	..	..	1,540
1923	..	..	..	..	..	1,390
1924	..	..	..	..	..	730
1925	..	..	..	..	..	800
1926	..	..	..	..	..	130
1927	..	..	..	..	..	210
1928	..	..	..	..	..	250

122. Cultivation is difficult and costly owing to the plantations being situated along rivers subject to the tidal movement of the sea, which raises their level above that of the plantations at high tide. This necessitates the upkeep of strong dykes, and an elaborate system of drainage canals and sluices.

123. Almost the whole of the crop is exported to the Netherlands, but as the above figures show, the quantity exported is negligible in comparison with world supplies. Nor does there appear any likelihood of a recovery in production in Surinam in view of the difficulties with which production is faced, and the fact that many trees have been replaced by Liberian coffee.

New Hebrides.

124. Cocoa plantations in the New Hebrides are practically all in the hands of the French, who continue to plant up new areas. Exports expanded from 1,060 tons in 1923 to 2,340 tons in 1927; there was a set back in 1928 to 1,420 tons, but this was caused by two severe storms, and was not due to any decrease in cultivation. Exports for the years 1923 to 1928 (nearly all going to Australia) are given in following table :—

TABLE XXXVIII.—*Exports of Raw Cocoa from New Hebrides.*

<i>Year.</i>						<i>Tons.</i>
1923 ..	..	..	..	..	..	1,062
1924 ..	..	..	..	..	..	1,517
1925 ..	..	..	..	..	..	1,495
1926 ..	..	..	..	..	..	1,950
1927 ..	..	..	..	..	..	2,344
1928 ..	..	..	..	..	..	1,422

Other Producing Countries.

125. There are a number of other countries which produce cocoa in larger or smaller quantities. Among these may be mentioned :—

Dominica, which exported 305 tons of cocoa in 1927 and 166 tons in 1928, as compared with an average of 540 tons in the five years before the war.

British Honduras, where the cocoa tree grows wild. Cocoa has been cultivated in several places, but the output has declined steadily in recent years owing to neglect, which has been attributed to lack of knowledge and shortage of labour.

British Guiana, in which cocoa production, never very extensive, has shown a steady decline, with 1,200 acres under cultivation in 1928.

Belgian Congo, which exports between 800 and 900 tons of cocoa annually and where new plantations in combination with coffee and oil palm are being developed.

Dutch East Indies.—Java produces a small quantity of very choice cocoa, and exports roughly 1,000 tons per annum to the Netherlands. In the other Dutch possessions of Sumatra, Celebes, Borneo and Timor the cultivation of cocoa is in its initial stages.

126. In addition to the above, there are many countries which produce fairly considerable quantities of raw cocoa, but even so do not grow enough for their own requirements, and need to import from other larger producing countries. These include Mexico, with an annual production of about 1,400 tons; the Philippines, with an annual output of about 1,000 tons; Bolivia, producing about 2,000 tons annually; Colombia, which produces about 5,000 tons per annum. There are also a number of other minor producers, some of which are exporters on a small scale, such as Guatemala, Nicaragua, Spanish Guinea, New Guinea and others which have not been dealt with in the preceding paragraphs. None of these is important in world trade.

127. Experiments in cocoa cultivation have been made in Fiji Islands, North Australia, Indo-China and the Portuguese Colonies in India, Timor and Kambing. Other countries which have been suggested as possibly suitable for the cultivation of cocoa are India, Straits Settlements, Malay States, Andaman and Nicobar Islands, Cayman, Turks and Caicos Islands, the Virgin Islands, Montserrat, Siam and Formosa.

IMPORTS.

United Kingdom.

128. The United Kingdom is the third largest importer of cocoa in the world, ranking next in importance to the United States and Germany. Retained imports have increased enormously since before the war, and are now about double the 1913 figure; in the four years ended 1928 the quantity retained for home consumption was practically uniform at slightly over 55,000 tons, whereas in 1913 it was only 27,000 tons. The imports of raw cocoa entered for home consumption for the years 1920 to 1929 in comparison with 1913 are shown in Table XXXIX below:—

TABLE XXXIX.—*Imports of Raw Cocoa entered for Home Consumption in the United Kingdom.*

Year.	Foreign.	Prop. of Total.	Empire.	Prop. of Total.	Total.
	Tons.	Per cent.	Tons.	Per cent.	Tons.
1913	(a)	(a)	(a)	(a)	27,090
1920	6,955	14	43,695	86	50,650
1921	4,745	10	41,105	90	45,850
1922	3,215	6	47,315	94	50,530
1923	3,550	7	46,250	93	49,800
1924	4,260	8	47,580	92	51,840
1925	4,745	8	51,560	92	56,305
1926	4,465	8	51,945	92	56,410
1927	3,200	6	52,640	94	55,840
1928	3,370	6	52,180	94	55,550
1929	(a)	(a)	(a)	(a)	57,500

(a) Not available.

129. The above figures show retained imports at full and preferential rate of duty, and may be taken as an indication of Empire and foreign retained imports. No allowance has been made for exports or imports of cocoa preparations, and the figures, therefore, do not show domestic consumption of cocoa and its products.

130. The table reveals that the retained imports of Empire-produced raw cocoa have considerably increased since 1920, having risen from 43,700 tons, or 86 per cent. of the total quantity imported,

to 52,200 tons, or 94 per cent. in 1928. Meanwhile, the produce obtained from foreign sources of supply has declined from 7,000 to 3,400 tons.

131. No figures are available of the actual retained imports of Empire cocoa prior to 1920, but the import statistics show that 53 per cent. of the imports during 1913 were of Empire origin. This remarkable change in the proportion of the raw product obtained from the Empire, that is, from one-half of the total to nearly the whole, is due largely to two factors—the establishment of a preferential tariff and the increased output from the Gold Coast.

132. Of the imports of cocoa in 1928, British West Africa supplied 87 per cent. of the total, while British West Indies was the second most important source of supply with a share of 6 per cent., the only other Empire countries with a contribution of any significance being Ceylon, and Nauru and Western Samoa.

133. Imports from British West Africa show no signs of decreasing. In 1928 over 55,000 tons were received from this source, which was the highest figure reached since 1921, while in 1929 imports reached the striking total of 69,000 tons. In 1913 only 9,000 tons were received from this area.

134. Imports from the West Indies have shown a considerable falling off since 1919. The average imports from these islands during the quinquennium 1920–1924 amounted to 7,800 tons, while the 1929 imports amounted to only 4,000 tons.

135. Imports from foreign countries were small in comparison with those from the two main Empire sources of supply. Venezuela was the principal foreign shipper in 1928, followed by Ecuador and Brazil. In fact, these three countries are the only important suppliers outside the British Empire, and imports from them have diminished. The average imports from these three countries for the period 1919–24 amounted to 6,400 tons, compared with 2,800 tons in 1928. Brazil, which in 1913 was one of the most important suppliers with a contribution of 5,800 tons, or one-sixth of the total imports, sent only 800 tons in 1928. Imports from Portugal (San Thomé cocoa), which in 1913 amounted to 1,100 tons, have now dwindled to 140 tons.

136. In the following table are shown the imports of cocoa into the United Kingdom from 1924 to 1929 in comparison with 1913, and also the quantities received from each of the principal countries of consignment.

TABLE XL.—Imports of Raw Cocoa into the United Kingdom.

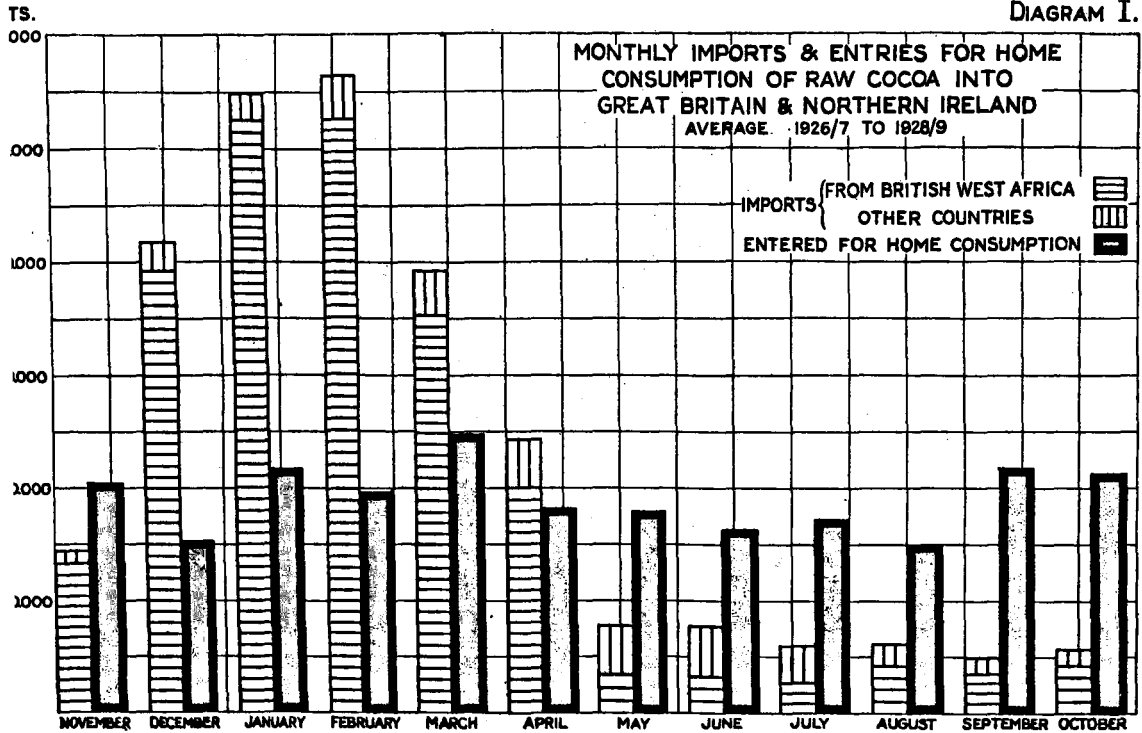
Imported from	1913.	1924.	1925.	1926.	1927.	1928.	1929.
	(a)						
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
British West Africa ..	9,070	46,750	53,780	50,540	54,400	55,050	68,750
British West Indies ..	7,160	4,980	5,980	4,410	4,510	3,880	4,050
Ceylon	2,250	1,270	1,150	570	770	510	730
Nauru and Western Samoa	—	640	430	90	150	190	} 410
Other Empire countries	60	70	120	20	40	50	
Ecuador	3,980	1,490	2,490	1,160	1,590	840	890
Venezuela	320	950	1,400	800	1,170	1,160	980
Brazil	5,760	310	1,170	940	530	810	} 1,600
Portugal	1,140	640	140	230	270	140	
Portuguese West Africa	190	400	30	160	110	40	
Netherlands	270	160	150	200	90	200	
Panama	30	90	110	80	80	120	
Costa Rica	240	40	90	70	80	120	
German Possessions in the Pacific.	170	—	—	—	—	—	
German West Africa ..	710	—	—	—	—	—	
Other foreign countries	3,630(b)	530	260	190	270	220	
Total Empire countries	18,540	53,710	61,460	55,630	59,870	59,680		73,940
Total foreign countries	16,440	4,610	5,840	3,830	4,190	3,650	3,470
Total	34,980	58,320	67,300	59,460	64,060	63,330	77,410

(a) Imports include those into the Irish Free State.

(b) "Other foreign countries" in 1913 included Germany, 1,560 tons; Belgium, 870 tons; France, 440 tons; and San Domingo, 330 tons.

137. The season of maximum imports of West African raw cocoa into the United Kingdom extends from November to April, with the peak of the season about January. From May to October imports from British West Africa are very small. Imports from the British West Indies are at their highest from about February to May or June, while May and June see the peak of the imports from Ecuador and Venezuela. In Table XLI below are shown

DIAGRAM I.



2000 1000 500 0 500 1000

Maly & Sons

imports from the main countries of consignment in each month from November, 1926, to October, 1929, and, in the last column the total quantities of raw cocoa entered for home consumption each month. The average figures for the past three years are shown graphically in Diagram 1.

TABLE XLI.—Imports of Raw Cocoa into the United Kingdom from November, 1926, to October, 1929.

Month.	Venezuela.	Ecuador.	British West Africa.	Ceylon.	British West Indies.	Other Countries.	Total.	Entered for Home Consumption.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
1926-27.								
November ..	.5	—	47.1	.3	—	0.9	48.8	128.5
December ..	1.3	—	198.3	1.1	3.4	2.7	206.8	90.8
January ..	.2	1.7	239.3	1.0	4.8	5.1	252.1	112.0
February ..	.6	3.1	188.2	1.6	12.6	1.1	207.2	122.7
March ..	2.3	0.9	145.8	2.4	10.0	4.8	166.2	139.7
April ..	2.7	1.2	103.5	3.8	18.5	3.1	132.8	70.1
May ..	4.8	5.6	8.6	1.6	13.8	1.2	35.6	76.1
June ..	2.8	10.7	4.4	0.5	6.9	2.6	27.9	67.9
July ..	1.0	6.1	13.5	1.6	7.1	1.5	30.8	70.6
August ..	2.1	1.8	36.4	1.3	5.7	1.5	48.8	93.4
September ..	1.7	0.8	27.9	0.5	0.5	2.0	33.4	102.4
October ..	2.3	0.3	42.6	0.5	4.3	3.5	53.5	93.1
1927-28.								
November ..	.9	—	74.0	.4	3.2	3.8	82.3	90.3
December ..	1.0	0.4	215.4	1.1	4.8	3.8	226.5	79.3
January ..	.6	.5	226.6	2.1	4.1	3.5	237.4	108.8
February ..	1.4	.5	208.9	1.2	11.2	3.5	226.7	83.3
March ..	0.7	1.0	203.6	1.0	7.2	4.9	218.4	122.7
April ..	1.5	1.8	104.9	0.7	9.5	1.1	119.5	96.5
May ..	.8	2.0	13.1	0.4	11.1	2.2	29.6	87.9
June ..	2.5	7.7	21.8	—	13.0	4.0	49.0	84.6
July ..	4.3	1.8	24.3	0.9	5.9	1.3	38.5	97.9
August ..	2.4	1.0	17.9	0.7	3.0	1.3	26.3	74.8
September ..	3.7	0.1	20.4	0.5	1.5	2.7	28.9	103.3
October ..	2.3	—	6.8	0.4	3.1	2.5	15.1	116.2
1928-29.								
November ..	1.1	1.3	75.9	.5	.9	4.6	84.3	86.0
December ..	2.9	0.3	174.7	2.1	4.0	7.3	191.3	59.8
January ..	.8	0.1	318.5	2.7	5.0	7.3	334.4	105.2
February ..	.9	1.4	390.1	2.7	11.1	6.2	412.4	83.7
March ..	1.9	0.5	176.1	2.4	19.9	3.6	204.4	110.0
April ..	2.3	0.3	91.4	1.5	12.1	5.8	113.4	104.7
May ..	1.5	8.0	28.9	1.2	5.8	3.6	49.0	105.5
June ..	2.3	4.6	19.9	0.5	6.4	2.1	35.8	92.3
July ..	3.1	2.1	0.4	0.6	6.9	5.3	18.4	95.7
August ..	2.4	0.5	8.0	1.0	3.6	1.7	17.2	57.2
September ..	0.8	0.3	4.8	0.3	2.6	4.2	13.0	111.4
October ..	1.8	0.3	12.4	0.2	1.6	1.3	17.6	106.4

138. Consumption of raw cocoa, as shown in the last column of the above table, is fairly uniform over the year, although tending to rise during the winter and spring, and fall during the summer months. The seasonal nature of imports thus involves an accumulation of stocks of raw cocoa in bonded warehouses in this country. During the past three years the average bonded stocks on the 30th April have amounted to 41,000 tons, while seven months later, on 30th November, the average stocks have fallen to 14,000 tons.

139. Almost the whole of the increase in the imports of raw cocoa into the United Kingdom has been accounted for by increased domestic consumption of cocoa products. Re-exports of raw cocoa have been very little, if at all, heavier in recent years than in the years before the war, and the export trade in British manufactured cocoa products, although greater than in pre-war years, has only increased to a very moderate extent. Total exports of cocoa preparations, manufactured in the United Kingdom, amounted in 1913 to 165,000 cwts., and in 1912 to 158,000 cwts., these figures including cocoa butter as well as cocoa powder and chocolate sweetened and unsweetened. Total exports of cocoa preparations (including cocoa butter) in the past three years have amounted to 190,000 cwts. in 1926, 169,000 cwts. in 1927, and 157,000 cwts. in 1928, exports to the Irish Free State being excluded from these figures.

140. Unfortunately, pre-war export figures did not distinguish between the various kinds of cocoa preparations. Present day exports consist very largely of "preparations without sugar" and of chocolate confectionery. Exports of the principal cocoa products from the United Kingdom in recent years are given in the following table:—

TABLE XLII.—*Exports of Cocoa Preparations from the United Kingdom.*

Description.	1924.	1925.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Without sugar	72·5	99·4	101·4	90·7	92·9
Bars and blocks (containing sugar)	24·4	17·4	19·2	22·3	24·4
Confectionery (containing sugar) ..	57·9	56·8	69·2	64·0	51·1
Other cocoa preparations (with sugar)	3·6	2·8	3·2	4·0	3·0
Cocoa butter.. .. .	28·4	15·6	27·4	16·5	15·5

The above figures show that the export trade in cocoa preparations has recently been about maintained, but there are no signs of material increase. Exports of cocoa preparations without sugar in 1929 totalled 100,900 cwts. and with sugar 84,800 cwts., thus showing a very slight recovery from the fall of 1928.

141. About 60 per cent. of the exports of cocoa preparations are shipped to the Empire, with the Irish Free State, and the Union of South Africa as leading purchasers, followed by India, New Zealand, Australia, Channel Islands and Canada. In 1913 nearly 90 per cent. of the cocoa preparations exported were shipped to Empire countries, a post-war decrease in exports to these countries being counter-balanced by increased consignments to the Continent. But exports to foreign countries are mainly of cocoa preparations without sugar, and appear to consist chiefly of the cocoa powder obtained as a by-product from the extraction of cocoa butter. Of the 92,900 cwts. of "cocoa preparations not containing sugar" exported in 1928, about 65,500 cwts. were consigned to foreign countries, with an average declared value of about 19s. 6d. per cwt., and of this total the Netherlands took 55,800 cwts. valued at only 12s. 8d. per cwt. The remaining 27,400 cwts., consigned to Empire countries, were valued at £7 2s. per cwt. Apart from exports of low priced cocoa preparations without sugar, the Empire was still, in 1928, taking 85 per cent. of the United Kingdom's exports of cocoa preparations.

142. It may be here noted that in contrast to its export trade in manufactured cocoa preparations, the United Kingdom is also a large importer. In fact, imports of cocoa preparations are rather in excess of exports, figures for recent years being shown in Table XLIII below :—

TABLE XLIII.—*Net Imports of Cocoa Preparations into the United Kingdom.*

Description.	1913.	1924.	1925.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Without sugar	246·5	20·9	22·2	17·4	22·2	10·6
Bars and blocks (containing sugar).		107·4	152·9	81·5	91·6	88·9
Confectionery (containing sugar).		21·3	12·0	79·1	73·1	70·7
Other cocoa preparations (containing sugar).		9·5	13·2	25·1	34·1	33·9
Total cocoa preparations	246·5	159·1	200·3	203·1	221·0	204·1
Cocoa butter	18·2	32·9	27·8	26·6	46·1	60·2

143. Cocoa butter imports are obtained almost entirely from the Netherlands, which also supplies the bulk of the "cocoa preparations without sugar" (of the average value in 1928 of £3 8s. per cwt. as compared with United Kingdom exports to the Netherlands in this classification of less than 13s. per cwt.). Switzerland furnishes the bulk of the chocolate in bars and blocks, and Belgium the other sorts containing sugar, while these two countries share with the Netherlands the trade in chocolate confectionery.

Canada.

144. The consumption of cocoa in Canada has shown a fairly steadily increasing tendency during recent years, and there has been a marked increase compared with the pre-war figures. The imports for the years 1924 to 1928 and the average for 1909-1913 were as follows:—

TABLE XLIV.—*Imports of Raw Cocoa into Canada.*

	Tons.		Tons.	
Average 1909-13 ..	1,890		Calendar year 1926 ..	6,840
Calendar year 1924 ..	5,340		" " 1927 ..	6,740
" " 1925 ..	6,340		" " 1928 ..	7,490

145. The following table shows the imports into Canada according to countries whence consigned. It will be noticed that a considerable proportion of the supplies are imported via the United Kingdom and the United States, and in the circumstances it is difficult to arrive at any estimates of the proportions of the different classes of cocoa in the total supply. Imports of cocoa from the British West Indies are rapidly increasing since the trade agreement between the two countries in 1926, under which British West Indian cocoa is imported into Canada duty free.

TABLE XLV.—*Imports of Raw Cocoa into Canada (years ended 31st March).*

Imported from	1923.	1924.	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom ..	1,110	1,270	1,500	2,240	1,750	1,790	700
United States ..	2,100	2,330	1,230	1,720	1,610	1,370	1,410
British West Africa ..	1,070	1,720	350	2,030	1,440	1,720	1,050
British West Indies ..	2,120	2,220	1,270	1,170	990	2,790	3,630
Ceylon ..	230	230	160	140	260	250	250
Venezuela ..	—	40	10	10	10	10	} 10
Other countries ..	550	—	20	100	90	10	
Total ..	7,180	7,810	4,540	7,410	6,150	7,940	7,050

146. Imports of cocoa preparations are shown below. The export returns of the Canadian Government do not distinguish any kind of cocoa preparations :—

TABLE XLVI.—*Imports of Cocoa Preparations into Canada.*

Description.	1924-25.	1925-26.	1926-27.	1927-28.	1928-29.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Cocoa paste (in blocks or cakes)	1·2	1·6	1·5	1·6	1·9
Cocoa or chocolate powder ..	11·3	15·7	11·5	10·9	15·0
Other cocoa preparations ..	0·5	0·8	1·2	0·9	1·7
Chocolate confectionery ..	3·4	7·0	18·4	10·0	5·9
Cocoa butter	46·1	46·0	46·4	48·3	45·3

147. Of these imports Holland supplies the bulk of the cocoa butter, followed by the United States and the United Kingdom ; the same three countries are the chief sources of cocoa powder, and the United Kingdom, the United States, Holland and Switzerland furnish most of the chocolate confectionery.

Australia.

148. Imports of cocoa into Australia in 1928 were eight times the average pre-war imports. The quantities imported in the years 1924 to 1928 and the average for 1909 to 1913 are given in the following table. The exports of raw cocoa (mainly to New Zealand), which in some years are considerable, fell in 1927-28 to very small dimensions. These figures are also shown below :—

TABLE XLVII.—*Imports of Raw Cocoa into Australia.*

Year.	Imports.	Re-exports.
	Tons.	Tons.
1909-13 (Average)	550	21
1923-24	4,240	109
1924-25	4,280	302
1925-26	4,700	99
1926-27	3,760	228
1927-28	4,510	20

149. British West Africa is the principal supplier, although a large proportion comes from the British West Indies, and altogether a large number of countries figure in the import returns. The imports giving details of the quantities from the various consigning countries for the years 1926 to 1928 are shown below :—

TABLE XLVIII.—*Imports of Raw Cocoa Beans and Shells into Australia (year ended 30th June).*

Imported from	1925-26.	1926-27.	1927-28.
	Tons.	Tons.	Tons.
British West Africa	1,700	1,080	1,760
West Indies	1,040	830	1,340
Ecuador	430	160	210
Pacific Islands (New Hebrides) ..	380	660	340
Brazil	260	250	220
Ceylon	220	300	190
Venezuela	190	50	70
San Thomé	140	170	150
New Guinea	70	60	60
U.S.A.	65	35	70
Costa Rica	50	20	—
French West Africa	40	—	—
Netherland East Indies	30	60	10
South Africa	30	60	—
Panama	25	15	10
Portuguese West Africa	20	—	—
Other countries	10	10	80
Total	4,700	3,760	4,510

150. Australia has established a considerable manufacturing industry in cocoa products, and in addition to raw cocoa, imports over 1,000 tons of cocoa butter annually. Exports in 1927-1928 exceeded by a considerable margin the import trade in these commodities, but, unfortunately, the export trade in confectionery does not distinguish between chocolate and other sorts. Until a few years ago, exports of prepared cocoa for potable use also exceeded imports, but the export trade has declined very substantially. New Zealand takes the bulk of these exports. Imports and exports in recent years are shown below :—

TABLE XLIX.—*Australian Imports and Exports of Cocoa Preparations.*

Description.	1925-26.		1926-27.		1927-28.	
	Imports.	Exports.	Imports.	Exports.	Imports.	Exports.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Confectionery—						
Chocolate ..	167	636	146	673	137	983
Other ..	451		499		525	
Cocoa mass or slab	128	—	169	—	85	—
Cocoa or chocolate for potable use.	152	23	149	31	124	21
Cocoa butter ..	1,144	—	1,277	—	1,271	1

New Zealand.

151. Although New Zealand is a comparatively small importer of cocoa, its imports are substantially larger than in 1913. Its supplies are drawn from many different sources, and the following table of imports in 1913 and from 1925 to 1928 shows that the market does not appear to be dominated by any particular country. There was a considerable drop in the quantity imported during 1927, which was, however, followed by a complete recovery in 1928.

TABLE L.—*Imports of Raw Cocoa into New Zealand.*

Imported from	1913.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.
Western Samoa	—	135	60	100	120
British West Indies	30	85	110	100	230
Ceylon	80	—	20	30	10
British West Africa	—	—	20	—	30
Other British countries	70 ^(a)	5	10	—	—
New Hebrides	—	170	280	40	110
Ecuador	—	50	30	40	90
Brazil	—	70	60	30	100
U.S.A.	10	80	70	20	20
Venezuela	—	20	20	10	20
Other foreign countries	35	5	10	10	10
Total	225	620	690	380	740

(a) Chiefly United Kingdom.

152. New Zealand imports fair quantities of cocoa products and cocoa butter, and is apparently developing a manufacturing industry to meet her own needs for prepared chocolate. Exports of cocoa preparations are negligible.

TABLE LI.—*Imports of Cocoa Preparations into New Zealand.*

Description.	1913.	1925.	1926.	1927.	1928.
	000 cwt.	000 cwt.	000 cwt.	000 cwt.	000 cwt.
Cocoa and chocolate	5.5	6.2	5.7	6.1	6.5
Chocolate,—					
Confectionery in plain packages.	2.2	8.2	8.4	7.9	12.3
In fancy packages	(a)	(a)	(a)	(a)	
Cocoa butter	5.8	14.5	14.8	14.7	20.1

(a) Imports by value only—£83,000 in 1913; £131,000 in 1925; £117,000 in 1926; £113,000 in 1927.

153. Of the above imports the Netherlands supply most of the cocoa butter, the United Kingdom and Australia share the bulk of the confectionery trade, followed by Canada and Switzerland, and the United Kingdom is the chief source of cocoa and chocolate.

Union of South Africa.

154. Imports of cocoa beans into the Union of South Africa are mainly from the British West Indies and Portuguese West Africa, but the quantities imported have been irregular in recent years. Table LII gives the imports from 1924 to 1928 from the principal consigning countries :—

TABLE LII.—*Imports of Raw Cocoa into the Union of South Africa.*

Imported from	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.
British West Indies	88	12	9	97	68
Portugal	—	—	—	49	—
Portuguese West Africa ..	89	7	127	28	29
Guatemala	—	1	—	28	—
Ecuador	14	5	12	15	12
Ceylon	—	2	8	13	14
Brazil	—	1	2	5	10
British West Africa	11	12	8	1	24
Other countries	60	1	9	18	42
Total	262	41	175	254	199

155. Fair quantities of cocoa products are annually received by the Union of South Africa, mainly from the United Kingdom and the Netherlands. The imports for the years 1924 to 1928 are shown in the following table :—

TABLE LIII.—*Imports of Cocoa Preparations into the Union of South Africa.*

Description.	1924.	1925.	1926.	1927.	1928.
	000 cwt.	000 cwt.	000 cwt.	000 cwt.	000 cwt.
Block chocolate, mass, paste and slab unsweetened.	0·7	1·1	1·4	2·1	2·5
Other unsweetened cocoa ..	5·8	6·1	5·7	5·8	5·7
Sweetened cocoa for confectionery industry.	—	0·8	1·3	2·4	1·8
Chocolate confectionery ..	5·8	11·4	17·1	18·7	17·6
Cocoa butter	2·6	2·2	2·6	3·1	3·6

Irish Free State.

156. Imports of raw cocoa into the Irish Free State have shown a marked increase in each of the past five years, and the quantity obtained in 1928 was more than two and a half times as heavy as in 1924. Practically the whole of these supplies are represented by re-exports from the United Kingdom, which supplied 240 out of the 244 tons imported in 1927, and the whole of the imports in 1928. Imports in each of the five years 1924 to 1928 are shown in Table LIV below :—

TABLE LIV.—*Imports of Raw Cocoa into the Irish Free State.*

Year.	From all Countries.	From the United Kingdom.
	Tons.	Tons.
1924	109	99
1925	179	172
1926	187	176
1927	244	240
1928	283	283

157. Although the Irish Free State is only a very moderate importer of raw cocoa, it is a substantial customer for cocoa preparations, which are also nearly all obtained from the United Kingdom,

and comparatively small quantities from the Netherlands. There has, however, been a considerable decline in the quantities imported since 1924, although there was a slight recovery in 1928. Details of imports are given in Table LV, but the Irish Free State trade returns do not show separately the various kinds of cocoa preparations included in the totals.

TABLE LV.—*Imports of Cocoa Preparations into the Irish Free State.*

Year.	From All Countries.	From the United Kingdom.	From the Netherlands.
	Tons.	Tons.	Tons.
1924.. .. .	2,641	2,485	143
1925.. .. .	2,122	1,939	163
1926.. .. .	1,772	1,611	136
1927.. .. .	1,672	1,529	135
1928.. .. .	1,740	1,598	137

United States.

158. By far the largest consumer of cocoa in the world is the United States, which imported 170,000 tons in 1928, or more than the combined imports of its two nearest rivals, Germany, which received 75,000 tons, and the United Kingdom, which purchased 65,000 tons in the same year. The consumption of cocoa in the United States has more than trebled since before the war. Whereas in 1913 about 60,000 tons were imported, the average imports for the quinquennium 1925-1929 amounted to nearly 190,000 tons. "Prohibition" and the high standard of living enjoyed by the people during and after the war are major contributing factors to the increased consumption.

159. The United States usually draws approximately one-third of its supplies of cocoa from British West Africa, but in 1929 obtained over 40 per cent. from that source (as compared with the United Kingdom, which takes almost 90 per cent. of its supplies from the same countries). Brazil is the next important source of supply; over 46,000 tons were received from this country in 1927, and 41,000 tons in 1929. These were record years, as generally imports from Brazil do not exceed 35,000 tons, or approximately one-fifth of the total imports of cocoa.

160. Owing to the close economic relations between the two countries, the United States takes practically the total output of San Domingo. Nearly 21,000 tons were imported from there during 1929, or about the average imports of the preceding five years.

161. Imports from the British West Indies amounted to over 20,000 tons in 1929 compared with 17,000 tons in the previous year. These islands are the main source of supply for the finer grades of cocoa. Other important supplies of fine cocoa came from Venezuela and Ecuador, the combined imports from these two countries amounting to 16,500 tons. At the same time it is noticeable that of the total United States imports almost 17 per cent. came from the British West Indies, Ecuador and Venezuela, and can be classed as of the "finer" types of cocoa. Of United Kingdom imports only about 10 per cent. can be placed in that category.

162. In the following table are shown the imports of cocoa into the United States, detailing the various countries of consignment during the five years 1925 to 1929 as compared with 1913.

LVI.—Imports of Raw Cocoa into the United States of America.

Imported from	1913.*	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
British West Africa	20	60,010	68,480	63,670	56,130	94,780
Brazil	6,410	32,330	40,700	46,250	33,430	41,080
British West Indies	13,210	16,330	20,030	14,720	17,360	20,790
Germany	2,040	2,910	6,930	8,230	9,910	8,470
Ecuador	6,800	14,140	9,410	7,700	8,380	6,980
Venezuela	1,850	8,690	5,770	5,690	7,120	9,650
United Kingdom..	5,210	4,780	7,120	3,770	5,510	7,540
Netherlands ..	630	2,150	3,250	5,700	4,570	3,260
San Domingo ..	12,160	20,740	19,290	24,370	17,780	20,680
Haiti	620	1,180	980	740	1,510	1,630
Portugal	10,290	720	1,270	830	990	3,310
Costa Rica	30	650	1,590	1,190	1,790	(a)
Panama	40	2,940	1,140	2,060	3,130	(a)
Cuba	1,190	—	800	1,090	80	(a)
Colombia	20	440	170	410	150	(a)
Surinam	1,050	700	230	160	320	(a)
Other countries ..	960	1,830	3,150	3,150	1,140	8,430
Total	62,530	170,540	190,310	189,730	169,300	226,600

(a) Included in "Other countries."

* Fiscal year ended 30th June, 1913.

163. As in the case of the United Kingdom, the enormous increase in imports of raw cocoa in comparison with pre-war days has been absorbed almost wholly by the increased domestic consumption of cocoa products. No figures are available of exports before the war, but even now the total exports of cocoa products amount to only a very small fraction of the United States output. Exports of the various cocoa preparations in the years 1924 to 1928 have been as follows :—

TABLE LVII.—*Exports of Cocoa Preparations from the United States.*

Description.	1924.	1925.	1926.	1927.	1928.
	000 cwt.	000 cwt.	000 cwt.	000 cwt.	000 cwt.
Cocoa powder	37.5	31	21	31	19
Chocolate	13.5	14	10.5	8.5	8
Chocolate confectionery	(a)	24	18	18	18.5
Cocoa butter	7.5	22	6	3	21.5

(a) Not available.

164. Exports of cocoa preparations from the United States appear to be declining. The chief markets are Canada, Cuba, the Philippines, Panama, Newfoundland and the Netherlands (for cocoa powder), and in some of these countries, notably Canada, and the Philippines, the cocoa manufacturing industry seems to be developing.

165. There is a fair and increasing import trade in cocoa preparations into the United States, recent import figures being shown in the following table. No information is available as to imports of chocolate confectionery.

TABLE LVIII.—*Imports of Cocoa Preparations into the United States.*

Description.	1924.	1925.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Cocoa prepared	22.2	28.4	34.9	30.6	44.2
Chocolate	11.3	17.0	26.1	23.5	39.8
Cocoa butter	15.9	0.6	0.8	1.7	0.2

166. Almost all the small quantity of cocoa butter imported is obtained from Holland, and the same country supplies the bulk of the prepared cocoa, and is the chief supplier of chocolate, although Germany was in 1927 a close second; those two countries, with Belgium, account for 80 per cent. of the United States imports of chocolate.

Germany.

167. Germany is the second largest importer of cocoa in the world occupying second place only to the United States. The average imports of cocoa for the quinquennium 1923-27 amounted to 69,000 tons, and in 1928 were 9 per cent. above this average, as will be seen from the table of imports on page 62.

168. About 70 per cent. of the total imports are drawn from British West Africa, and the average imports from that source during the period 1923-1927 amounted to 49,000 tons, while the figures for 1928 were well above the average, amounting to 54,000 tons. Brazil comes next in importance, although imports have declined since 1922, but the 1928 figures show a slight recovery. Imports from Portuguese West Africa, which before the war ranked next in importance to British West Africa as a source of supply, have steadily decreased, amounting to only 3,700 tons in 1928 compared with 11,300 tons in 1913 and 8,500 tons in 1922.

169. Comparatively very small quantities are imported from countries producing the finer grades of cocoa. The decline in imports from the British West Indies is pronounced, and although supplies from Ecuador and Venezuela are steadier, neither country in recent years has reached its pre-war level. Altogether less than 10 per cent. of cocoa imports appear to consist of the recognised finer descriptions.

170. The imports from the various countries of consignment in the years 1924 to 1928, in comparison with 1913 are shown below:—

TABLE LIX.—*Imports of Raw Cocoa into Germany.*

Imported from	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
British West Africa ..	16,330	60,100	55,180	44,360	51,970	54,010
Brazil	6,210	9,000	8,750	4,340	4,640	5,880
Portuguese West Africa ..	11,270	5,430	4,170	4,570	4,210	3,690
Ecuador	7,010	3,820	3,710	2,250	1,980	3,650
Venezuela	1,820	2,520	1,790	1,120	1,470	1,730
Cameroon	1,460	730	740	1,060	1,290	1,510
U.S.A.*	—	140	210	70	30	1,400
Samoa	670	40	60	40	90	80
Netherlands Indies ..	560	920	1,930	1,040	970	870
British India and Ceylon..	460	970	620	460	520	620
Costa Rica	10	70	240	220	250	230
Haiti	310	90	180	110	170	170
British West Indies ..	1,700	2,090	1,460	670	1,070	1,200
Other countries	4,230	780	680	230	760	810
Total	52,040	86,700	79,720	60,540	69,420	75,850

* Including Philippines, Panama Canal Zone and Porto Rico.

171. Germany's export trade in cocoa preparations is small compared with that of Holland, Switzerland and the United Kingdom, but there has been an appreciable increase in the past few years and exports of manufactures other than powder were in 1928 larger than in 1913. Exports in 1913 and in recent years of the various cocoa products are shown below.

TABLE LX.—*Exports of Cocoa Preparations from Germany.*

Description.	1913.	1924.	1925.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Cocoa paste	22·7	8·1	28·6	34·1	7·6	35·3
Cocoa powder	22·0	2·0	1·8	2·8	1·6	4·0
Chocolate	19·0	12·6	13·3	13·7	16·6	24·9
Other manufactures (a) ..	13·2	8·1	7·5	6·9	11·8	13·5
Cocoa butter	39·6	105·0	26·5	9·4	35·3	27·2

(a) Goods made from cocoa paste, cocoa powder, chocolate and chocolate substitutes; acorn cocoa, oatmeal cocoa, etc.

172. The bulk of the cocoa butter is exported to Holland and Belgium, while the United States is the chief market for cocoa paste, powder and chocolate. Germany's import trade in cocoa preparations amounted to about 40,000 cwts. in 1928.

Netherlands.

173. Holland is an important market for cocoa, the imports into that country almost equalling those into the United Kingdom, although between 10 and 20 per cent. of the total imports of raw cocoa are re-exported in the raw state. In the following table are shown the imports into the Netherlands giving details of consigning countries in 1913 and 1925 to 1929 :—

TABLE LXI.—Imports of Raw Cocoa into the Netherlands.

Imported from	1913.	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
British West Africa ..	100	34,570	35,870	33,060	41,160	44,400
Brazil	90	3,930	2,630	3,350	3,240	1,250
Portugal	8,380	2,950	3,520	1,700	1,980	2,730
Dutch Indies	2,090	910	630	470	1,140	1,000
U.S.A.	40	190	430	250	1,040	270
Ecuador	1,040*	1,490	1,600	1,130	780	270
Venezuela		530	320	380	370	460
United Kingdom ..	9,310	2,910	1,350	1,070	770	890
British West Indies ..	—	590	830	1,030	770	(a)
Germany	11,430	2,570	1,700	1,560	710	1,430
Belgium	1,830	190	70	130	100	(a)
France	6,910	190	440	460	90	440
Other countries	1,290	1,230	1,400	1,450	880	1,940
Total	42,510	52,250	50,790	46,040	53,030	55,080
Re-exports	13,000	8,830	7,340	6,910	6,270	6,320

* Includes Colombia.

(a) Included in "Other countries."

174. The foregoing table shows that the retained imports for 1929 were well above the average, but compared with other important consuming countries the increase in cocoa imports into Holland since 1913 has been comparatively small. British West Africa supplied 81 per cent. of the total imports in 1929, compared with 66 per cent. in 1925. There has been a steady growth in the imports from these countries.

this being mainly due to the large export trade carried on by Holland in cocoa butter and cocoa powder, in the manufacture of which increasing use seems to be made of West African cocoa. The only other important sources are Portugal (San Thomé) and Brazil. Imports from the former country in 1927 and 1928 dwindled to less than one-quarter of the 1913 figure while imports from Brazil have considerably increased since pre-war years, but fell in 1929.

175. As regards the superior grades of cocoa, imports are relatively unimportant. Imports from the Dutch Indies have not recovered their pre-war importance, having dropped from 2,100 tons in 1913 to 470 in 1927, but the figures for 1928 and 1929 seem to point to a recovery of the cocoa trade with these islands. There has been a steady drop in the import figures from both Ecuador and Venezuela and the combined imports from the two countries were only 730 tons in 1929.

176. Holland has also an important import and export trade in cocoa husks, the totals in the five years 1925 to 1929 being as follows :—

TABLE LXII.—*Trade of Netherlands in Cocoa Husks and Waste Cocoa Products.*

—	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.
Imports	5,730	5,320	11,940	13,380	13,960
Exports	4,210	6,670	8,790	9,290	14,830

177. Prior to 1929 these products were classified as cocoa husks, but last year they were separated into "cocoa husks" and "waste products from cocoa and chocolate manufactures (cocoa cakes, etc.)." This re-classification shows that in 1929 only 4,140 tons, or 30 per cent. of the imports, and 2,500 tons, or 17 per cent. of the exports, consisted of cocoa husks, the larger proportion in each case being other waste products. Imports are mostly obtained from the United States, the United Kingdom, Germany and Belgium, and exports are consigned to the United States, Switzerland, France, Belgium, and the United Kingdom. Although the volume of the trade is large, its value is relatively unimportant.

178. The Netherlands is easily the world's largest exporter of cocoa preparations, especially of cocoa powder and cocoa butter. Exports of cocoa powder (without sugar) have fallen slightly in

comparison with 1913, although they showed a recovery in 1928. As regards other products, there has been a substantial gain in comparison with the year before the war. Figures for 1913 and the five years 1925 to 1929 are shown in Table LXIII below.

TABLE LXIII.—*Exports of Cocoa Preparations from the Netherlands.*

Description.	1913.	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Cocoa powder (without sugar).	17,450	14,360	13,650	13,490	15,130	14,290
Chocolate (with sugar) ..	1,200	5,010	5,050	4,960	4,740	5,420
Cocoa bars or blocks (without sugar).	30	240	240	360	270	350
Cocoa butter	7,050	12,270	13,460	12,420	13,500	15,130

179. In each of the above products there is an appreciable but declining import trade. Figures for recent years are shown in the following table:—

TABLE LXIV.—*Imports of Cocoa Preparations into the Netherlands.*

Description.	1925.	1926.	1927.	1928.	1929.
	Tons.	Tons.	Tons.	Tons.	Tons.
Cocoa powder	486	610	324	124	93
Chocolate	911	684	655	565	504
Cocoa bars and blocks ..	13	17	398	52	2
Cocoa butter	153	297	772	592	549

The United Kingdom is the main source of the cocoa powder and blocks, Belgium of the chocolate and Germany of the cocoa butter.

180. In view of Holland's place as the world's largest exporter of cocoa products (mainly cocoa powder and butter) it may be of interest to show the distribution of its export trade in 1913 and 1928.

TABLE LXV.—Exports of Cocoa Preparations from Holland.

Exported to	Cocoa Powder.		Chocolate sweetened.		Cocoa Butter.	
	1913.	1928.	1913.	1928.	1913.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Great Britain and Ireland	9,450	1,090	230	2,360	860	2,910
Belgium	2,910	320	430	40	1,280	1,870
Germany	1,790	120	50	60	1,640	60
United States	770	2,690	30	580	1,510	10
Russia	560	—	(b)	(b)	840	40
Denmark	420	560	60	320	100	180
Italy	270	640	(b)	(b)	390	270
Dutch East Indies	210	420	150	550	(b)	(b)
Austria-Hungary	300	(a) 80	(b)	(b)	20	(a) 290
Sweden	170	190	(b)	(b)	20	240
France	90	5,170	—	80	10	990
Poland	—	880	—	(b)	—	860
Switzerland	(b)	240	(b)	(b)	(b)	1,610
Other countries	510	2,730	250	750	380	4,170
Total	17,450	15,130	1,200	4,740	7,050	13,500

(a) Austria. (b) Included, if any, in "other countries."

181. Great Britain and Belgium are the chief buyers of Dutch cocoa butter, Germany and the United States having fallen from the leading positions which they occupied in 1913. Switzerland and France have also assumed prominence, together with Poland, and among countries not shown separately above, New Zealand (710 tons in 1928), Australia (440 tons), Czechoslovakia (390 tons) and Canada (1,250 tons). As regards cocoa powder, France and the United States have replaced the United Kingdom and Belgium. Exports of sweetened chocolate, in powder or blocks and bars are not very large, but are a good deal heavier than before the war. The United Kingdom and the United States of America (each with a very substantial manufacturing industry of its own) are the largest purchasers. Exports of other sorts of cocoa preparations are small, amounting in 1928 to only 270 tons.

France.

182. Although imports of cocoa for home consumption into France in each of the years 1924 to 1926 were much heavier than the average for the years 1909-13, there was a heavy fall in 1927, almost to the pre-war level, followed by only a partial recovery in 1928 and 1929, as is shown in the following table:—

TABLE LXVI.—*Imports of Raw Cocoa into France for Home Consumption.*

	<i>Year.</i>		<i>Tons.</i>
Average	1909-13	.. .. .	25,640
	1924	.. .. .	42,210
	1925	.. .. .	42,960
	1926	.. .. .	40,500
	1927	.. .. .	27,620
	1928	.. .. .	33,550
	1929	.. .. .	35,180

This falling off in imports is partly attributed to the currency situation, but according to some authorities is mainly due to the accumulation of large invisible stocks during 1926.

183. With the exception of the United Kingdom, France is the only important cocoa consuming country with large areas suitable for cocoa cultivation within its own colonies, and a glance at Table LXVII will show the rapid increase in imports from the French Colonial possessions, which supplied only 1,900 tons in 1913. Each year since 1924 has shown a steady increase and in 1928 the quantity obtained therefrom amounted to 26,000 tons, including 6,900 tons from French Cameroon, and 5,900 tons from French Togoland.

184. Although consumption has fallen off in recent years, the imports from the Ivory Coast have steadily increased and with the development of this country there is little doubt that this rate of increase will continue. Little or no supplies of cocoa have been received in recent years from the Dominican Republic, formerly an important source, and the quantity received from Venezuela, once the largest exporter to France, dropped to 2,160 tons in 1928.

185. France is not a very large importer of cocoa from the British Empire, as the following table will show. Imports are practically limited to those from British West Africa, from which the quantity obtained has heavily declined in recent years, and the West Indies, which sends some 3,000 tons each year. In the case of both these countries

the imports were in 1928 less than half the 1913 totals. On the average about 15 per cent. of the raw cocoa is exported, mainly to Switzerland, Holland, Belgium, Italy and other European countries.

TABLE LXVII.—*Imports of Raw Cocoa into France.*

Imported from.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Foreign countries—						
Portugal	1,930	240	460	(a)	(a)	(b)
West Africa	410	1,460	600	1,700	590	600
British West Africa	8,310	12,890	14,830	14,480	3,710	3,640
Venezuela	10,060	4,570	4,680	3,620	2,270	2,160
Brazil	5,440	7,220	5,550	3,860	2,350	3,220
Ecuador	7,720	3,530	3,440	2,180	400	780
British West Indies	7,900	3,760	3,340	2,700	2,610	3,130
Haiti	1,260	650	360	1,190	(a)	(b)
Dominican Republic	5,040	20	(a)	(a)	(a)	(b)
Togo*	—	4,690	4,120	3,670	3,640	5,910
Cameroon*	—	3,210	3,550	4,390	3,870	6,900
Other foreign countries	4,880	3,790	3,850	2,170	1,150	(b)
Total foreign countries	52,950	46,030	44,780	39,960	20,590	(b)
Colonies—						
French Congo	120	250	110	260	(a)	(b)
French Oceania	—	280	590	380	(a)	(b)
West Africa	70	4,090	4,750	5,550	7,660	11,440
West Indies	1,570	1,050	950	960	1,370	890
Other French colonies..	110	230	270	150	670	(b)
Total French colonies..	1,870	5,900	6,670	7,300	9,700	(b)
Total	54,820	51,930	51,450	47,260	30,290	41,940

* French mandates. (a) Included, if any, in other countries. (b) Not available.

186. The French export trade in cocoa butter is negligible. There is a small export of cocoa paste, amounting to 115 tons in 1928 and 129 tons in 1929, mainly to Italy and Holland, while there is an important export of finished chocolate, although the trade (still larger than before the war) appears to be declining. Exports of chocolate in 1913 amounted to 2,100 tons, in 1924 to 8,200 tons, and in 1929 to 4,390 tons. The greater part of the exports of chocolate

go to French possessions, principally Algeria, while Germany, Egypt and Syria also account for fair quantities. Exports of cocoa preparations from France in 1913 and in recent years are given below.

TABLE LXVIII.—*Exports of Cocoa Preparations from France.*

Description.	1913.	1924.	1925.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Cocoa paste	0·6	1·8	1·8	2·7	4·7	2·3
Chocolate	41·9	164·6	105·3	109·8	73·0	75·1

187. France imports considerable quantities of cocoa preparations, but the greater part of these consist of cocoa powder imported from the Netherlands. Imports in 1928 and 1929, respectively, amounted to 4,320 and 4,360 tons of crushed cocoa, 1,180 and 1,190 tons of cocoa butter, and 750 and 660 tons of chocolate. Crushed cocoa is described as "paste or otherwise," and Dutch export returns, and the low average value of the imports, suggest that it consists very largely of waste cocoa products.

Spain.

188. Consumption of cocoa in Spain steadily increased from 1912 to 1924, when the peak was reached with imports of 13,300 tons. The following years registered a decrease, but in 1928 the total amounted to 11,650 tons which is a record figure except for that of the year 1924 as is shown in the following table of imports into Spain for the years 1911 to 1928.

TABLE LXIX.—*Imports of Raw Cocoa into Spain.*

Year.	Tons.	Year.	Tons.
1911	6,340	1920	8,480
1912	5,240	1921	7,910
1913	6,140	1922	8,840
1914	6,840	1923	10,100
1915	6,670	1924	13,330
1916	7,420	1925	9,480
1917	7,900	1926	7,950
1918	8,930	1927	9,150
1919	8,040	1928	11,650

189. Spain absorbs practically the total output of its colony Fernando Po, which is its principal source of supply, and contributes

about two-thirds of the total imports. The remainder is comprised chiefly of supplies from the South American states, and from British countries in Africa. The imports of cocoa into Spain with details of countries of consignment for the four years ended 1928 are given below :—

TABLE LXX.—*Imports of Raw Cocoa into Spain.*

Imported from	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
Fernando Po	5,870	5,660	5,870	8,420
Venezuela	1,000	1,160	1,320	1,050
Ecuador	930	700	910	940
British Africa	610	30	440	370
Brazil	30	250	340	500
British West Indies	80	50	180	240
Cuba	—	20	20	—
Porto Rico	30	30	20	10
India and Ceylon	570	20	10	30
Other countries	360	30	40	90
Total	9,480	7,950	9,150	11,650

Italy.

190. As compared with the average imports immediately before the war, Italy had more than quadrupled her imports in 1928, as may be seen in the following table :—

TABLE LXXI.—*Imports of Raw Cocoa into Italy.*

Year.	Tons.
Average 1909-13	2,080
1923	5,320
1924	6,370
1925	7,920
1926	7,450
1927	6,360
1928	8,400

191. The average imports for the period 1923-27 amounted to 6,680 tons compared with 2,080 tons for the quinquennium 1909-13 ; from 1925 there was a decrease in the amount of cocoa imported, but the year 1928 witnessed a recovery to the highest point yet

reached. The main supplies come from Portuguese Africa, British Africa and Brazil. The imports from the various consigning countries in each of the years 1925 to 1928 are given below :—

TABLE LXXII.—*Imports of Raw Cocoa into Italy.*

Imported from	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
Portuguese Africa	2,180	2,030	1,950	1,570
Brazil	1,910	2,110	1,680	2,210
British Africa	1,530	1,320	1,670	2,920
Ecuador	290	400	370	600
British West Indies	580	340	260	460
Venezuela	520	670	220	170
India	70	60	100	30
Dutch Indies	210	100	70	140
Other countries	630	420	40	300
Total	7,920	7,450	6,360	8,400

Czechoslovakia.

192. Imports of cocoa into Czechoslovakia declined from 7,500 tons in 1925 and 1926 to 6,600 tons in 1927, and 6,800 tons in 1928, but rose to 8,050 tons in 1929. As will be seen from the following table of imports for the years 1925 to 1928, most of the cocoa is imported through the free port of Hamburg, and therefore it is impossible to give the original sources of supply except for minor quantities.

TABLE LXXIII.—*Imports of Raw Cocoa into Czechoslovakia.*

Imported from	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
Hamburg	3,350	6,710	5,890	6,040
Germany	2,820	90	20	—
Netherlands	550	170	300	130
British West Africa	100	160	140	450
Italy (including Trieste)	80	50	30	30
Brazil	110	60	30	60
Other South American Republics	20	20	40	10
United Kingdom	280	100	30	10
India	20	30	10	30
Other countries	200	90	70	80
Total	7,530	7,480	6,560	6,840

Switzerland.

193. Switzerland is the most important of the three European countries importing less cocoa than before the War, the other two being Belgium and Finland. The imports for recent years as compared with the average for the years 1909-13 are shown below :—

TABLE LXXIV.—*Imports of Raw Cocoa into Switzerland.*

Year.					Tons.
Average 1909-13	..	..	..	..	9,100
1924	..	..	..	..	8,090
1925	..	..	..	..	6,760
1926	..	..	..	..	6,600
1927	..	..	..	..	7,420
1928	..	..	..	..	8,650
1929	..	..	..	..	8,470

194. From the foregoing table it will be seen that during 1925 and 1926 there was a considerable drop in imports compared with the pre-war average, and although the figures for subsequent years showed a considerable improvement, they were still below the pre-war quantities. The distribution of imports by countries in the four years 1925 to 1928 is given in the following table :—

TABLE LXXV.—*Imports of Raw Cocoa into Switzerland.*

Country of Origin.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
West Africa	—	3,860	4,080	5,450
Brazil	1,060	860	1,120	1,160
Venezuela	940	830	760	820
British West Indies	460	300	580	650
Ecuador	880	650	800	500
Central America	80	70	60	50
Dutch Indies	40	30	20	10
Congo	3,270	—	—	—
Other countries	30	—	—	10
Total	6,760	6,600	7,420	8,650

195. The above table shows that supplies from West Africa and Brazil have been steadily increasing during recent years, these countries supplying 76 per cent. of the total imports during 1928, West Africa alone supplying 63 per cent. of the total imports.

196. Before the war Switzerland was easily the largest exporter of manufactured chocolate in the world and although its supremacy is now being threatened, it still leads by an appreciable margin. The reduction in exports of chocolate is fairly well distributed with the exception that the United Kingdom is now taking larger quantities than before the war and accounts for well over one-half total exports of Swiss chocolate. Exports of cocoa butter are and have always been negligible and exports of cocoa powder are small. (Switzerland is a substantial importer of cocoa butter and cocoa powder from Holland.) The distribution of exports of chocolate from Switzerland in 1913 and in the five years 1924 to 1928 are shown in the following table. Exports in 1929 declined sharply to 7,280 tons.

TABLE LXXVI.—*Exports of Chocolate from Switzerland.*

Destination.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	4,420	4,760	5,970	5,170	4,970	4,880
Germany	1,730	1,120	170	190	630	650
United States	150	160	300	300	230	550
Italy	2,190	230	250	170	220	280
Denmark	190	240	270	290	270	230
China	20	100	70	120	140	180
South Africa	120	120	140	160	180	180
Turkey	590	50	110	90	170	160
France	1,150	140	270	90	70	140
Yugo Slavia	—	40	60	100	190	140
Egypt	110	60	110	100	90	120
India	70	50	70	100	110	120
Australia	1,360	60	70	80	70	40
Russia	780	(a)	(b)	(b)	(b)	(b)
Belgium	480	40	80	10	(a)	10
Other countries	2,300	640	770	610	680	830
Total	15,660	7,810	8,710	7,580	8,020	8,510

(a) Less than 5 tons.

(b) Included, if any, in "Other countries."

Belgium and Luxemburg.

197. Imports of cocoa into Belgium in recent years have been considerably below the pre-war figure, and although increasing

during the past few years, amounted in 1929 to only 8,200 tons as compared with 11,400 tons in the year 1913. The imports for the years 1924 to 1929 as compared with 1913 are given below :—

TABLE LXXVII.—*Imports of Raw Cocoa into Belgium.*

<i>Year.</i>	<i>Tons.</i>
1913	11,440
1924	8,370
1925	7,670
1926	7,710
1927	5,730
1928	6,460
1929	8,160

198. In the following table are shown the principal sources of supply in 1927, 1928 and 1929. So great a proportion of the raw cocoa is obtained from Holland and other continental countries that little information can be gained as to the original sources of the cocoa imported.

TABLE LXXVIII.—*Imports for Consumption of Raw Cocoa into Belgium.*

Imported from	1927.	1928.	1929.
	Tons.	Tons.	Tons.
Belgian Congo	810	630	1,120
Brazil	470	680	690
France	850	800	1,370
Hamburg	250	320	280
Netherlands	2,010	2,890	2,700
Other countries	1,340	1,140	2,000
Total	5,730	6,460	8,160

199. Belgium has a moderate export trade in chocolate, and this trade is considerably larger than before the war, but during the five years 1924 to 1928 declined by about 60 per cent., and 1929 figures show a further decline to 1,230 tons. Distribution of exports of chocolate in 1913 and recent years is shown in the following table. Exports of other cocoa preparations are unimportant.

TABLE LXXIX.—*Exports of Chocolate from Belgium.*

Country to which Consigned.	1913.	1924.	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
United Kingdom	10	160	350	760	840	430
Denmark	(a)	130	30	190	160	230
Netherlands	20	520	620	520	330	170
Egypt	(a)	270	290	290	110	100
France	20	680	330	100	80	60
Germany	(a)	1,190	530	120	140	50
Other countries	250	520	630	590	410	360
Total	300	3,470	2,780	2,570	2,070	1,400

(a) Included in other countries.

Sweden.

200. Sweden is now the principal market for cocoa among the Scandinavian countries, although prior to the War this position was held by Denmark. Imports have declined from 4,300 tons in 1924 to 3,800 tons in 1929, but this quantity is still more than double the average for 1909-13. The following table gives the imports in recent years :—

TABLE LXXX.—*Imports of Raw Cocoa into Sweden.*

Year.	Tons.
Average 1909-13	1,350
1924	4,320
1925	3,630
1926	3,580
1927	3,310
1928	3,470
1929	3,770

201. Most of the supplies of cocoa come through Germany, the United Kingdom, Denmark and Holland, and details of quantities according to countries of origin are not available. Brazil is the only cocoa growing country whence cocoa is consigned to Sweden, with a total of about 500 tons annually, but the fact that Germany and the United Kingdom are shown as supplying over 50 per cent. of imports of raw cocoa suggests that a considerable proportion of total imports originates in British West Africa.

202. Sweden's imports of cocoa powder and chocolate, which amounted to 200 and 85 tons respectively in 1913, totalled in 1927 about 270 and 190 tons and in 1928 about 230 and 230 tons respectively. The bulk of the powder comes from Holland and the United Kingdom, and of the chocolate from Switzerland, followed by Holland, Germany and Belgium.

Norway.

203. Norway is not an important market for raw cocoa, although consumption has considerably increased since the War. The imports for the years 1924 to 1929 and the average for 1909 to 1913 are shown below :—

TABLE LXXXI.—*Imports of Raw Cocoa into Norway.*

Year.		Tons.		
Average	1909-13	..	..	980
	1924	..	..	2,360
	1925	..	..	2,070
	1926	..	..	2,310
	1927	..	..	2,040
	1928	..	..	2,150
	1929	..	..	2,100

204. It will be noticed from the foregoing table that imports have remained more or less at the same level in recent years. West Africa appears to be the chief source of supply, although almost equally large quantities come from Germany and Brazil, as may be seen in the following table of imports in the year 1927 and 1928 :—

TABLE LXXXII.—*Imports of Raw Cocoa and Cocoa Butter (a) into Norway.*

Imported from—		1927.	1928.
		Tons.	Tons.
West Africa	.. ..	710	910
Germany	.. ..	540	460
Brazil	.. ..	440	430
United Kingdom	.. ..	190	200
Holland	.. ..	160	100
Belgium	.. ..	20	} 80
Other countries	.. ..	20	
Total	.. ..	2,080	2,180

(a) The imports of cocoa butter in 1927 amounted to 36 tons and in 1928 to 29 tons.

Denmark.

205. Imports of raw cocoa into Denmark have shown a fairly steady increase in recent years and are rather above the 1913 figure. Imports in the pre-war five years period averaged about 1,700 tons annually, while in the last five years they have averaged about 2,500 tons, with a rising tendency. South America and Germany are the chief sources of supply, as may be seen in the following table of imports from the principal countries of consignment :—

TABLE LXXXIII.—*Imports of Raw Cocoa into Denmark.*

Imported from	1913.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
Germany	980	520	550	510
Great Britain	80	140	380	470
Holland	—	200	270	170
France	60	30	180	90
Portugal	50	70	30	80
West Indies	80	—	30	40
Brazil	640	1,190	880	1,000
Other South American countries ..	70	170	320	350
Other countries	70	40	60	70
Total	2,030	2,360	2,700	2,780

206. Denmark is a fairly important market for cocoa preparations, principally chocolate, from Germany, Switzerland, Holland and Belgium. Imports of cocoa preparations into Denmark are shown below.

TABLE LXXXIV.—*Imports of Cocoa Preparations into Denmark.*

Description.	1913.	1926.	1927.	1928.
	000 cwts.	000 cwts.	000 cwts.	000 cwts.
Cocoa powder	5·8	8·2	8·2	8·1
Chocolate (a)	7·0	25·9	25·9	25·7
Other products (c)	(b)	3·0	4·7	5·5
Cocoa butter	(b)	5·7	5·8	4·5

(a) Including household chocolate and chocolate coating.

(b) Not available.

(c) Cocoa paste and cocoa husks.

Poland.

207. In relation to its population of slightly over 30 millions, the consumption of raw cocoa in Poland is very small, as the following figures of imports for the years 1924 to 1928 show :—

TABLE LXXXV.—*Imports of Raw Cocoa into Poland.*

<i>Year.</i>						<i>Tons.</i>
1924	..	..	..	..	..	4,370
1925	..	..	..	..	..	3,710
1926	..	..	..	..	..	3,040
1927	..	..	..	..	..	4,320
1928	..	..	..	..	..	4,830

Supplies are mostly received through other European countries, principally Holland, which is shown as the country of consignment of 70 per cent. of the imports, other countries specified being France, the United Kingdom, Germany, Brazil and British West Africa.

208. Poland also imports considerable quantities of cocoa butter, mainly from Holland, and the chocolate manufacturing industry appears to be developing. Imports of cocoa preparations are not large, amounting only to about one half-ounce per head per annum.

Austria.

209. Although the consumption of cocoa in Austria fell to a very low level after the War, it now appears to be recovering. During each of the three years 1925 to 1927 imports were stable at 4,700 tons and in 1928 rose to 5,300 tons. The most important sources of supply are Brazil, British Africa and Holland. British West Africa is now receiving a considerable amount of the business which formerly went to Brazil, and in the years 1927 and 1928 was the main source of supply. The details of the countries of consignment in the years 1925 to 1928 are as follows :—

TABLE LXXXVI.—*Imports of Raw Cocoa into Austria.*

Imported from	1925.	1926.	1927.	1928.
	Tons.	Tons.	Tons.	Tons.
Germany	40	240	310	80
Switzerland	340	310	420	540
German free ports	200	80	180	—
Holland	640	980	930	990
British Africa	570	920	1,230	1,420
Brazil	2,110	1,820	1,190	1,170
British West Indies	80	40	70	440
Other countries	720	310	370	650
Total	4,700	4,700	4,700	5,290

Rumania.

210. Imports of cocoa into Rumania have remained more or less stationary during recent years at about 800 tons, as compared with an average of 290 tons for the years 1909–13. Imports for the years 1924 to 1927, and the average for 1909–13 were as follows :—

TABLE LXXXVII.—*Imports of Raw Cocoa into Rumania.*

<i>Year.</i>	<i>Tons.</i>
Average 1909–13	290
1924	790
1925	800
1926	800
1927	790

Practically the whole of the cocoa imported is shown as coming from other European countries, and it is not possible to indicate the country of origin. France, Germany and the United Kingdom, in the order named, are the chief countries of supply.

Portugal.

211. Although Portugal imports large quantities of cocoa from her colony San Thomé and Principe, only a small amount is retained

for home consumption. The quantities entered for home consumption from sources other than San Thomé are insignificant. The retained imports in 1913, and in 1924-27 were as follows :—

TABLE LXXXVIII.—*Imports of Raw Cocoa for Home Consumption into Portugal.*

<i>Year.</i>							<i>Tons.</i>
1913	..	..	..	..	..	..	220
1924	..	..	..	..	..	..	370
1925	..	..	..	..	..	..	440
1926	..	..	..	..	..	..	670
1927	..	..	..	..	..	..	430

Jugo-Slavia.

212. Although at present only of minor importance as a cocoa market, consumption has increased considerably in Jugo-Slavia. Most of the cocoa imported comes from other European countries. The imports for the years 1924 to 1929 were as follows :—

TABLE LXXXIX.—*Imports of Raw Cocoa into the Serb-Croat-Slovene State.*

<i>Year.</i>							<i>Tons.</i>
1924	..	..	..	..	..	..	290
1925	..	..	..	..	..	..	390
1926	..	..	..	..	..	..	450
1927	..	..	..	..	..	..	530
1928	..	..	..	..	..	..	650
1929	..	..	..	..	..	..	850

Russia.

213. Although imports of cocoa into Russia are still below the pre-war figure, they have been increasing during recent years. The following table shows the imports from 1924 to 1927. For purposes of approximate comparison the average for 1911-13 is also given, but owing to territorial changes the figures are not strictly comparable.

TABLE XC.—*Imports of Raw Cocoa into Russia.*

	<i>Year.</i>					<i>Tons.</i>
Average	1911-13..	..	..	..	..	4,510
	1924	..	..	..	..	1,910
	1925	..	..	..	..	3,560
	1926	..	..	..	..	1,980
	1927	..	..	..	..	3,650

214. Until the past two or three years, imports consisted mainly of cocoa re-exported from other European countries, chiefly the Netherlands and the United Kingdom, but in 1926-27 and the following year, imports from both the United Kingdom and Holland fell to small dimensions and Germany and "Other countries" have bulked much more prominently in the total. In the following table are shown the imports by countries in recent years.

TABLE XCI.—*Imports of Raw Cocoa into Russia. European frontier only.*

Imported from	1925-26.	1926-27.	1927-28.
	Tons.	Tons.	Tons.
Netherlands	1,220	580	180
U.S.A.	130	440	490
United Kingdom	1,110	120	70
Germany	—	90	890
Turkey	—	20	210
Other countries	340	1,510	2,730
Total	2,800	2,760	4,570

Argentina.

215. Imports of cocoa into the Argentine Republic have shown an increasing tendency, and figures for 1927 were exceptionally heavy. The imports in the years 1924 to 1928 are given below :—

TABLE XCII.—*Imports of Raw Cocoa into Argentina.*

Year.	Tons.
Average 1909-13.. .. .	1,160
1924	3,000
1925	3,800
1926	3,520
1927	4,640
1928	4,540

216. The bulk of the cocoa is imported from Brazil, only minor quantities being imported from Ecuador, Venezuela and other countries. The details are shown in the following table of the imports by countries in the years 1924 to 1927.

TABLE XCIIL.—Imports of Raw Cocoa into Argentina.

Imported from	1924.	1925.	1926.	1927.
	Tons.	Tons.	Tons.	Tons.
Brazil	2,630	3,000	3,050	3,890
Cuba	—	300	160	50
Ecuador	—	110	100	220
Venezuela	50	40	70	160
United Kingdom	40	100	40	(a)
British Possessions	50	60	20	(a)
U.S.A.	90	70	20	(a)
Chile	60	30	20	(a)
British West Indies	40	—	—	(a)
Other countries	40	90	40	320
Total	3,000	3,800	3,520	4,640

(a) Included in "Other countries."

Philippines.

217. The bulk of the cocoa imported into the Philippines comes from Ceylon, but small quantities are also received from the Dutch East Indies. The imports for the years 1926 and 1927 were as follows :

TABLE XCIV.—Imports of Raw Cocoa into the Philippines.

Imported from	1926.	1927.
	Tons.	Tons.
British East Indies	1,330	1,190
Dutch East Indies	210	160
Germany	40	—
U.S.A.	40	—
Total	1,620	1,350

218. Cocoa is also grown in the Philippines, although not in sufficient quantities to meet home requirements. Production in recent years is shown in the following table :—

TABLE XCV.—Production of Cocoa in the Philippines.

Calendar Years.	Tons.
1924	1,140
1925	1,090
1926	1,070
1927	1,070
1928	1,150

Production could be considerably increased if it were not for the violent storms which frequently arise in this locality.

CONCLUSION AND SUMMARY.

219. The past thirty years have wrought enormous changes in the relative importance of the various cocoa growing countries, and former leaders in production, such as Ecuador, San Thomé and Trinidad have now been eclipsed by the Gold Coast, Brazil and Nigeria, owing to the extremely rapid development of the industry in the latter countries. In the five years immediately preceding the war, four countries—Ecuador, San Thomé, the Gold Coast and Brazil—competed for first place among the world's cocoa producers, each having an average export of over 30,000 tons per annum, although by the end of the quinquennium the Gold Coast had gone well ahead with an export of over 50,000 tons in 1913.

220. In the post-war years the Gold Coast has gone still further ahead, and in the past five years has regularly furnished between 40 and 50 per cent. of the world's cocoa exports. Brazil, although development has been rapid, exports only about one-third of the quantity shipped from the Gold Coast.

221. Following the example of the Gold Coast, Nigeria and the neighbouring colonies of French West Africa are doing their utmost to increase their output. Nigeria is approaching the stage reached by the Gold Coast just before the war, and the French possessions in West Africa are within measurable distance of Nigerian production, and appear to be developing at a more rapid rate. The very rapid development of cocoa production in French West and Equatorial Africa suggests that these French colonies may before long challenge Brazil and Nigeria for second place among the cocoa producing countries of the world.

222. All these countries produce cocoa of ordinary quality, and it is noticeable that only San Thomé among the important producers of ordinary cocoa has failed to show a substantial advance in production in comparison with pre-war years. Annual exports of ordinary cocoa from all producing countries have in recent years exceeded 400,000 tons, or fully three times the pre-war average. On the other hand, production of the "fine" types of cocoa is definitely declining, and combined exports from all countries producing these finer sorts, which for some years after the war were in excess of the pre-war average, have since fallen until in 1926 and 1927 they were about 10 per cent. below the average exports for the five years 1909-13.

223. The following table shows the net exports of these two groups by calendar years, and although these figures cannot be taken as a sure guide to production, for the reason that the main harvesting season in most countries runs from the latter part of one calendar year into the early part of the next, they clearly show the diminishing output of the first group and the increasing output of the second.

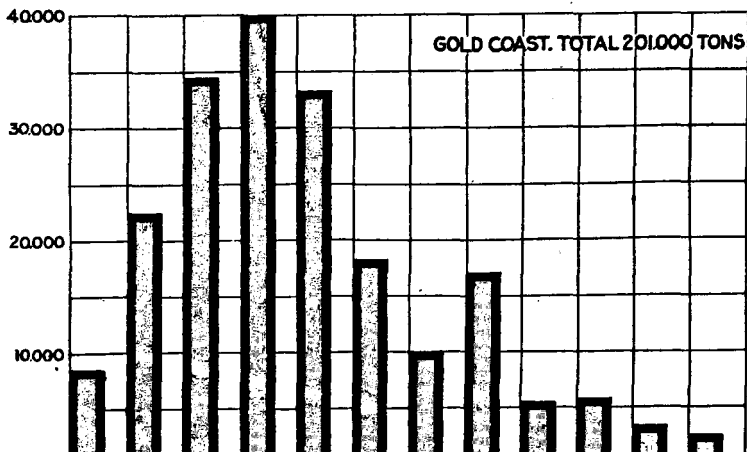
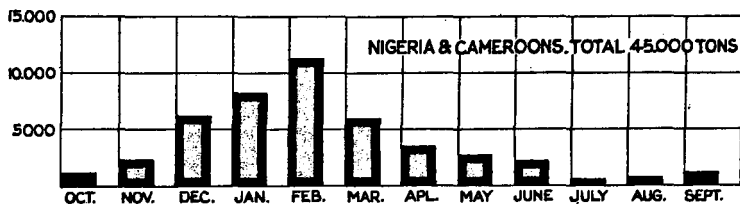
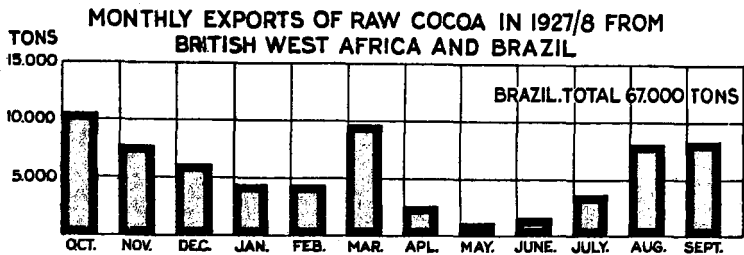
TABLE XCVI.—*Net Exports of Raw Cocoa from Countries producing "Fine" and "Ordinary" sorts.*

	1909-13.	1922.	1923.	1924.	1925.	1926.	1927.
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
<i>Fine Cocoa.</i>							
Venezuela ..	15,800	20,560	22,070	17,050	22,580	14,810	15,160
Ecuador ..	36,760	43,550	30,390	32,720	32,380	21,430	23,200
Trinidad ..	22,540	22,880	30,320	25,080	21,840	22,000	23,030
Grenada ..	5,330	3,640	3,890	4,270	3,660	4,170	5,020
Ceylon ..	3,540	4,160	3,040	3,470	3,440	3,240	4,040
Dutch East Indies	2,310	1,240	1,300	1,600	1,180	1,080	960
Jamaica ..	2,600	3,840	2,160	2,960	2,620	3,010	2,860
Costa Rica ..	280	2,060	4,190	3,620	4,080	5,230	3,370
Dutch Guiana ..	1,580	1,540	1,390	730	800	130	210
Other countries..	4,560	6,380	4,280	6,070	5,990	7,240	7,150
Total ..	95,300	109,850	103,030	97,570	98,570	82,340	85,000
<i>Ordinary Cocoa.</i>							
Gold Coast ..	34,350	159,300	197,660	223,330	218,150	230,840	209,910
Brazil ..	31,140	44,560	64,300	67,780	63,510	62,310	74,350
Nigeria ..	3,320	31,260	32,820	37,200	41,070	36,000	36,090
San Thomé ..	34,080	20,350	12,710	21,630	20,530	12,270	16,500
San Domingo ..	17,990	18,690	19,520	22,780	23,110	19,770	26,090
Haiti ..	2,440	1,970	1,990	1,620	1,510	2,160	1,600
French Equatorial and W. Africa.	4,170*	9,460	10,380	15,210	15,710	17,330	23,400
British Cameroons	—	3,210	1,640	3,170	3,640	3,100	3,120
Fernando Po ..	3,590	5,920	7,090	9,480	5,870	5,670	5,870
Other countries..	1,750	4,510	5,180	6,560	6,930	6,900	7,080
Total ..	132,830	299,230	353,290	408,760	400,030	396,350	404,010
Grand Total ..	228,130	409,080	456,320	506,330	498,600	478,690	489,010

* Includes pre-war exports from territories now under British and French mandates.

To face page 85.

DIAGRAM II.



224. The predominant position of the Empire in the world's cocoa production is revealed by this table. The Gold Coast and Nigeria together accounted for over 60 per cent. of total exports of ordinary cocoa in 1927, as compared with a proportion of less than 30 per cent. in 1909-13. In the case of fine cocoa, Ceylon and the three West Indian islands shown in the table now account for about 40 per cent. of total exports as compared with about 35 per cent. before the war, although this increase is the result rather of the substantial decline in production in Ecuador than to any material increase in production in the Empire. Only Costa Rica among producers of fine cocoa has shown a marked increase in production, and exports from that source are not yet large although they bid fair to become more important as time goes on.

225. Altogether ordinary cocoa now accounts for 83 per cent. of all the raw cocoa entering into world trade, whereas in the five years from 1909 to 1913 the proportion of ordinary cocoa in the total was less than 60 per cent.

226. In many producing countries the main cocoa harvest overlaps the end of one calendar year and the beginning of the next, but there are usually one or more secondary harvests and cocoa is actually gathered almost throughout the year. The Gold Coast, furnishing little less than one-half the world's annual supply of raw cocoa, exports relatively little from June to October. In Diagram II are shown monthly exports of cocoa from the three chief producing countries in 1927-28.

227. The consumption of cocoa in consuming countries has of course kept pace more or less regularly with increasing world production. There have been fluctuations from year to year in the world output of raw cocoa, and these have been reflected in the prices ruling for the product. At times production appears to be outstripping demand and the result is a fall in prices, apparently out of all proportion to the surplus production of the period. But there are also occasions when a comparatively slight deficiency in crops is sufficient to bring about a very sharp increase in world prices.

228. Figures are not available for the actual consumption of cocoa in the various consuming countries, owing to the substantial export trade in manufactured cocoa products enjoyed by a number of them. An approximate idea of consumption can be gathered from the import figures, but in the case of Holland and Switzerland, to a smaller

extent in the United Kingdom, and to a still smaller extent in other countries, the export trade in cocoa preparations is important in relation to raw cocoa imports. In the following table are shown average imports of raw cocoa into the leading consuming countries in the world in the quinquennium before the war, and for periods of three years in post-war years.

TABLE XCVII.—Average Net Imports of Raw Cocoa.

	1909-13.	1919-21.	1922-24.	1925-27.
	Tons.	Tons.	Tons.	Tons.
U.S.A... ..	58,400	139,600	163,300	177,500
Germany	47,700	72,800 ^(a)	73,000	69,800
United Kingdom	26,900	57,900	48,700	54,700
Holland	24,600	30,100	36,000	43,100
France	25,500	43,700	39,200	37,100
Switzerland	9,100	11,600	5,500	6,900
Italy	2,100	4,900	5,600	7,200
Belgium	5,600	7,700	8,400	6,600
Spain	5,800	7,900	10,300	8,900
Czechoslovakia	—	2,700	6,300	7,200
Canada	1,900	7,000	7,600	6,600
Other countries	17,900	25,100	27,200	40,900
Total	225,500	411,000	431,100	466,500

(a) 1920-21.

229. Imports actually reached their peak in 1924 and declined during the three following years, but this cannot be taken as definite evidence of any actual decrease in consumption, as the variations in imports have not been greater than could be readily explained by fluctuating stocks.

230. In comparison with pre-war years, the United States, in the last period shown above, has increased its imports by 200 per cent., imports into the United Kingdom have doubled and the increases in imports into Germany, Holland and France have also been very heavy. Imports into the large number of countries not shown separately above have also more than doubled; the chief of these "other countries" are Austria, Argentina, Australia, Poland, Sweden, Colombia, Denmark, Norway, Hungary and the Philippines, which have an average annual importation of between 1,500 and 5,000 tons.

231. In general, as has been stated, the import figures may be taken as reflecting fairly truly the increase in consumption within the importing country. Actually international trade in cocoa products is considerably larger than before the war, but the increase is in most cases on a smaller scale than the increase in imports of the raw material. The Swiss export trade in chocolate has suffered considerably, and the trade of the United Kingdom in cocoa preparations in general is very little larger than before the war. It seems evident that the increasing supplies of raw cocoa are not only leading to larger consumption in the main manufacturing countries, but are also causing countries which previously imported manufactured products to develop manufactures for their own domestic requirements.

232. Exports of cocoa products and of cocoa butter from the leading countries, so far as it is possible to group them, are shown below for 1913, 1924 and 1928.

TABLE XCVIII.—Exports of Cocoa Preparations from certain countries.

Description.		U.K.	U.S.A.	Holland.	France.	Switzerland.	Belgium.	Germany.
		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Cocoa powder ..	1913	(a)	(a)	17,450	30	890	—	1,100
	1924	3,825 (c)	1,875	17,300	99	190	50	100
	1928	4,650 (c)	950	15,130	110	220	10	200
Chocolate	1913	(a)	(a)	1,230	2,100	15,660	300	2,080
	1924	1,225	675	4,450	8,230	7,810	3,470	1,030
	1928	1,225	400	5,010	3,760	8,510	1,400	3,010
Confectionery ..	1913	(a)	(a)	—	—	—	—	660 (d)
	1924	2,900	(a)	—	—	—	—	410 (d)
	1928	2,550	925	—	—	—	—	680 (d)
Total cocoa preparations	1913	8,250 (d)	(a)	18,680	2,130	18,550	300	3,840
	1924	5,430 (b)	2,550	21,750	8,320	8,000	3,520	1,540
	1928	6,950 (b)	2,275	20,140	3,870	8,730	1,410	3,890
Cocoa butter.. ..	1913	(a)	(a)	7,050	4	20	30	1,980
	1924	1,420	375	11,700	30	2	20	5,250
	1928	775	1,075	13,500	4	6	40	1,360

(a) Not available.

(b) Excluding exports to Irish Free State.

(c) Cocoa preparations, unsweetened.

(d) Includes cocoa butter.

(e) Goods made from cocoa, chocolate, etc.

233. It has already been remarked that prices of raw cocoa have fluctuated extensively in recent years. Trinidad cocoa, for example, which was quoted at under 55s. per cwt. in June and July in 1924,

had advanced to over 80s. by the end of the year, fell to 60s. early in 1926, but by the end of that year had again passed 80s. per cwt. It reached 90s. in March, 1927, but by the end of 1928 had again fallen to below 60s. It recovered slightly in the year 1929 until it was quoted in December at 62s. to 65s. per cwt. Gold Coast cocoa has fluctuated somewhat similarly, but the decline continued throughout 1929, and December prices were only about 45s. per cwt., or about the average level in 1925. Prices in London for Trinidad and Accra cocoa are shown in Table XCIX from 1924 onwards. The quotations are shown graphically in Diagram III.

234. But although the price movements of Gold Coast and Trinidad cocoas have been on similar lines, there has been a significant narrowing of the margin between the two kinds, which may be taken as typifying respectively "ordinary" and "fine" cocoa, although there are a number of cocoas such as the best products of Ceylon, Ecuador and Western Samoa, which secure very much higher prices than Trinidad cocoa. In 1924 and 1925 Accra cocoa was realising only about 60 per cent. of the price of Trinidad fine cocoa; in 1926, the "ordinary" cocoa was valued at 76 per cent. of the "fine"; while in 1927 and 1928 the premium paid for Trinidad was even smaller, quotations for Gold Coast being 87 and 86 per cent. respectively of those for Trinidad. The gap tended to widen again during 1929, but Gold Coast cocoa, even at the time of the greatest difference during the year was still priced at over 70 per cent. of the Trinidad product.

235. So far the success of cocoa growing in West Africa has been due not only to suitability of soil and climate, but to the fact that it has flourished without any regular cultural attention. This appeals strongly to the natives, who have always been used to working in a desultory fashion. The native West African is able to establish his cocoa with hardly any capital expenditure, as he is able to subsist, until the cocoa trees begin to bear, on the native crops which are interplanted with the trees.

236. The planter in the more highly civilized countries of South America and the West Indies, finds some difficulty in meeting the competition of cocoa produced under the foregoing conditions.

237. It would appear that the striking development of cocoa growing in West Africa has only failed to render entirely unremunerative the production of this crop in the West Indies owing to

DIAGRAM III

MONTHLY AVERAGE PRICE OF GOLD COAST & TRINIDAD COCOA IN LONDON, 1924-1928

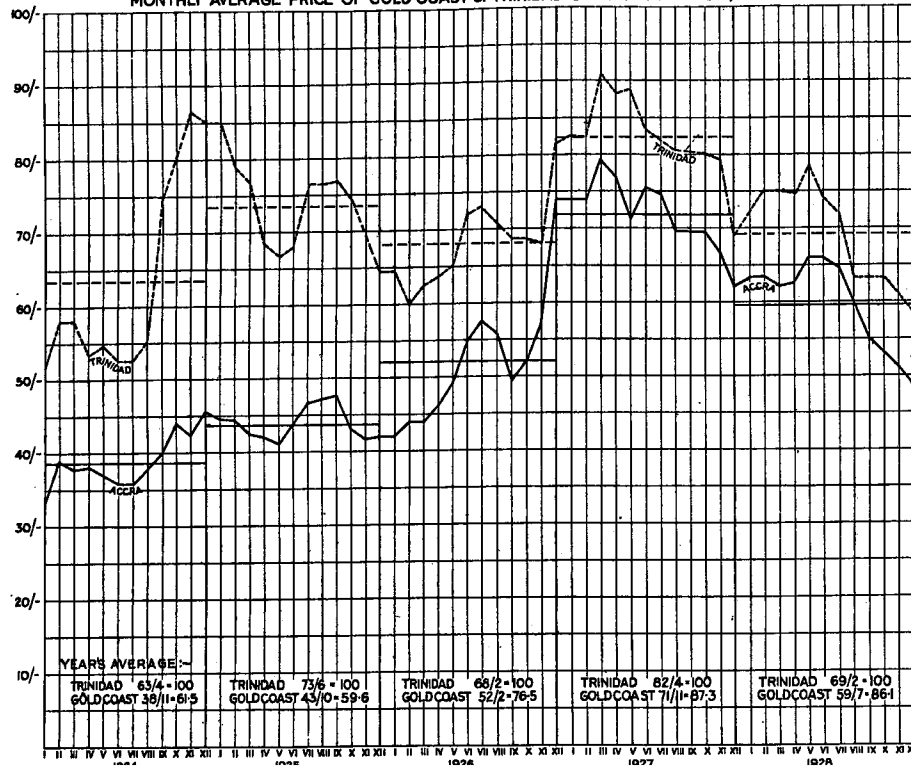


TABLE XCIX.—Cocoa Prices in London per cwt.

Month.	1924.				1925.				1926.				1927.				1928.			
	Accra.		Trinidad.		Accra.		Trinidad.		Accra.		Trinidad.		Accra.		Trinidad.		Accra.	Trinidad.		
January ..	32/-	34/-	51/-	52/-	44/-	45/-	84/-	86/-	41/6	42/6	64/-	65/-	72/-	76/-	82/-	83/-	62/-	65/-	72/-	73/-
February ..	38/-	40/-	57/-	59/-	44/-	45/-	78/-	80/-	43/-	45/-	59/-	61/-	72/-	76/-	82/-	83/-	62/-	65/-	74/-	76/-
March ..	37/-	39/-	57/-	59/-	42/-	43/-	76/-	78/-	43/-	45/-	62/-	63/-	77/-	82/-	90/-	92/-	61/-	63/-	74/-	76/-
April ..	37/6	39/-	53/-	54/-	41/-	43/-	68/-	69/-	45/-	47/-	63/-	64/-	75/-	79/-	88/-	89/-	61/-	64/6	73/-	76/-
May ..	36/-	38/-	54/-	55/-	40/-	42/-	66/-	67/-	48/-	50/-	64/-	66/-	70/-	73/-	88/-	90/-	64/-	68/-	77/-	80/-
June ..	35/-	37/-	52/-	53/-	43/-	44/-	67/-	69/-	54/-	56/-	71/-	73/-	73/-	78/-	83/-	84/-	64/-	68/-	73/-	75/-
July ..	35/-	37/-	52/-	53/-	45/-	46/-	76/-	77/-	56/-	59/-	72/-	74/-	72/-	77/-	81/-	83/-	62/-	67/-	71/-	73/-
August ..	36/-	39/-	54/-	56/-	46/-	48/-	76/-	77/-	54/-	58/-	70/-	72/-	67/-	72/-	80/-	81/-	58/-	61/-	62/-	65/-
September ..	39/-	41/-	73/-	75/-	47/-	48/-	77/-	77/-	48/-	51/-	68/-	69/-	67/-	72/-	80/-	81/-	54/-	56/-	62/-	64/-
October ..	43/-	45/-	78/-	80/-	42/6	43/6	74/-	75/-	51/-	53/-	68/-	69/-	67/-	72/-	79/-	81/-	52/-	54/-	62/-	64/-
November ..	42/-	43/-	85/-	88/-	41/-	42/6	68/-	69/-	56/-	58/-	67/-	69/-	65/-	68/-	78/-	80/-	50/-	52/-	60/-	61/-
December ..	45/-	46/-	84/-	86/-	41/6	42/6	64/-	65/-	72/-	76/-	81/-	82/-	61/-	63/-	68/-	70/-	47/-	50/-	58/-	59/-
Average ..	38/11		63/4		43/10		73/6		52/2		68/2		71/11		82/4		59/7		69/2	

the premium that the product of the latter group of countries enjoys as a consequence of its superior quality. Since they first came into prominence, West African, Brazilian and other "ordinary" cocoas have been looked upon mainly as bulk cocoas, with which it is necessary to combine some proportion of the finer types to secure the requisite fine flavour. Ordinary cocoas have had an additional use as the source of cocoa-butter (needed for chocolate manufacture) while the resultant large quantities of cocoa powder, although it is cheap and its nutritive qualities high, have been disposed of with some difficulty.

238. The narrowing of the price margin between fine and ordinary cocoas is the result partly of an improvement in the quality of West African cocoa, and partly of development of manufacturing methods enabling chocolate manufacturers to limit the amount of fine cocoa used in their output or indeed to dispense with fine cocoa altogether ; to some extent the latter cause is linked up with the former. Having once adopted a formula which enables a sufficiently high grade chocolate to be produced with a minimum of the more expensive kinds of raw material, manufacturers hesitate to vary it, and may, indeed, in times of temporary shortage even pay a premium for ordinary cocoa rather than change their formula.

239. A further factor in the narrowing of the price difference between fine and ordinary cocoa may be the gradual deterioration in quality of the former, owing to the crossing of the "criollo" variety (which produces the very finest type of cocoa) with the hardier but rather inferior "forastero." In plantations where both varieties are grown, the "criollo" tends to assume the characteristics of "forastero." In so far as the reduction in the price of "fine" cocoas is due to a change from criollo to forastero it may be that growers are making up in quantity for what they lose in average price. But the narrowing margin between ordinary and fine cocoas, when taken in conjunction with the steady growth in the production of the former and the decline in the production of the latter, suggests that West African and other producers of ordinary cocoas are likely to occupy a still more prominent place in the cocoa world in the future than they have done in the past.

240. Yet all the important chocolate manufacturing countries still find it necessary or desirable to import a certain proportion, albeit a diminishing proportion, of the finer cocoas. Fully 23 per cent. of

imports into Switzerland and about 20 per cent. of those into the United States and Spain can be definitely classed as fine cocoas, with France and Italy having a proportion of about 16 per cent., the United Kingdom and Germany 10 per cent. and Holland 6 per cent. In the case of the last-named country, the importation of ordinary cocoas is on account of the large export trade in cocoa-butter, for which almost any inferior cocoa is a suitable raw material.

241. It is apparent, either that the practice of using the finer cocoas to improve the general quality of the finished product still largely persists, or that some manufacturers continue to use the finer kinds of cocoa for producing superior kinds of chocolate and chocolate confectionery. In all probability both explanations are correct, and the finer cocoas may consequently be expected to continue to enjoy a premium over the ordinary grades, unless production of the fine sorts should show an unexpected increase.

242. As regards future production, every indication appears to point towards a further reduction in the supply of fine cocoas. Ecuador seems to be going the way of Surinam, a standing example of the damage that may be caused by the "witch-broom" disease; Venezuela is slowly reducing its output; the British West Indies and Ceylon are barely maintaining their production; and only Costa Rica, among the countries of Latin America, seems to be making progress. The reduction is due to lack of power to compete with the cheaper products of countries producing ordinary cocoa; and to the competition from alternative crops—coffee, bananas—which may be more remunerative or more easily produced. But any improvement in demand for the finer sorts of cocoa, any depression in prices of the competitive crops, or any successful research tending to increase output per tree and thus reduce cost of production might check the decline in production and even lead to a recovery. None of these possibilities is remote. Those manufacturers of chocolate who use mainly fine cocoas are understood to be well maintaining their share of the chocolate and confectionery trades, at any rate in this country; among competitive crops, coffee (the most favoured competitor in South America) shows signs of over production; while the development of tropical agricultural research may have enormous results upon cocoa production.

243. Turning to ordinary cocoas, indications appear to point quite as definitely towards a further increase in production. Nigeria, the Ivory Coast, and other West African possessions and mandated

territories of Britain and France have all substantial areas yet suitable for cocoa production, and all are making determined efforts to develop the industry. In South America, Brazil is in the same position, with large areas suitable for cocoa, and a determination to build up an export trade in agricultural products additional to coffee. Only in the Gold Coast is the position obscure. There are still substantial and suitable areas not yet planted to cocoa, but established plantations are falling out of cultivation, and any appreciable further increase in output is problematical, being dependent upon an improvement in conditions of production—greater attention to the requirements of the soil, a check to deforestation, and more effective control over disease and insect pests. Given these conditions, the Gold Coast can produce even larger quantities of cocoa in the future than in the past. But even if the Gold Coast makes no further progress, it is evident that the future production of ordinary cocoa in the world is likely to increase rapidly.

244. The capacity of the world to absorb very substantially larger supplies of cocoa can hardly be doubted. Of the total retained imports of raw cocoa into the various countries of the world, averaging in the three years 1925–27 some 466,000 tons, five countries (United States, Germany, United Kingdom, Holland and France) together accounted for over 80 per cent. and only in one case (Holland) among these is the net export trade in cocoa products of importance in relation to imports of raw cocoa. Disregarding the export trade in products, imports of raw cocoa into the United States are equivalent to only about $3\frac{1}{2}$ lb. per head per annum, or about one ounce per week. In other leading importing countries imports per head of the population are smaller, Germany importing about $2\frac{1}{2}$ lb., the United Kingdom about $2\frac{1}{2}$ lb. and France rather under 2 lb. per head, on the average of the three years 1926–28. Holland's net imports of raw cocoa amount to 13 lb. per head, but fully 7 lb. of this are exported in the form of cocoa powder and cocoa butter, apart from exports of manufactured chocolate.

245. Consumption of cocoa in these and some other countries has risen with surprising rapidity, but the rate of increase has recently suffered a check, which may be attributed to an approach towards saturation point, and to changes in fashions of food, drink and habits. It seems certain that contributory causes to the slowing up of demand for chocolate have been the increase in the use of tobacco among women; dieting and the increased consumption of fruit; the development of the

soda fountain and the increased demand for ice cream and fruit syrups (although a certain amount of cocoa powder is also utilised in these products); and possibly the greater variety of choice confectionery of other kinds. To these may be added the fact that chocolate confectionery tends to use less chocolate and more varied fillings than in the past, but as against this may be set the apparent increase in the demand for sweetened chocolate bars and cakes. As regards cocoa powder, as a beverage, it is doubtful whether at any time since the development of the West Africa cocoa industry it made the striking advance that chocolate and chocolate confectionery recorded. There are no figures available to show how the increased consumption of cocoa in the various countries is apportioned as between cocoa powder as a beverage, and chocolate as a confection or food; but in this country, at any rate, the development of the latter is self-evident, while there appears to be an over-production of cocoa powder in the world resulting from the increase in the demand for cocoa butter arising from the larger manufacture of chocolate. Consumption of cheap cocoa powder appears to be much heavier among the poorer classes of some European countries such as France, Germany and Belgium than it is in this country.

246. It does not seem likely that even in the countries which are the largest importers of cocoa, the consumption of chocolate or other cocoa preparations has yet nearly reached saturation point. In other countries consumption is decidedly less. South America, and other countries where cocoa is grown, consume very large quantities of the product, but in many European countries, in Russia, and throughout Asia, the consumption of cocoa preparations is almost negligible. There would appear to be considerable possibility of developing in the course of time a trade in cocoa with some of these parts of the world.

247. The difficulty of assessing the actual average consumption per head of raw cocoa in any country has already been mentioned, but approximate figures may be calculated showing the net imports of raw cocoa and net imports or exports of cocoa products. The diverse methods of classification in import and export statistics offer some obstacle to an adequate presentation of these facts, but the following table shows approximate average figures for a number of cocoa importing countries, separating (a) raw cocoa, (b) cocoa butter, (c) cocoa powder and paste and (d) chocolate for the years 1926 to 1928. The table should, however, be read in conjunction with the note which immediately follows it.

TABLE C.—Average Net Imports (+), or Exports (—) of Raw Cocoa, and Cocoa Preparations, per head of Population (1926 to 1928).

Country.	Raw Cocoa.	Cocoa Butter.	Cocoa Powder and Paste.*	Chocolate and other Cocoa Preparations*
	lb.	lb.	lb.	lb.
United Kingdom	+2.70	+0.06	-0.19	+0.26
Canada	+1.60	+0.54	+0.16	+0.15
Australia	+1.30	+0.43	+0.09	(a)
New Zealand	+0.90	(a)	+0.46	+0.87 (c)
Union of South Africa ..	+0.06	+0.04	+0.11	+0.32
Irish Free State	+0.18	(a)	(a)	+1.31
U.S.A.	+3.30	-0.01	+0.03	-0.02
Germany	+2.37	-0.04	-0.02	-0.09
Holland	+13.06 (b)	-3.69	-3.98	-3.77
France	+1.85	+0.05	+0.21	-0.20
Spain	+0.86	(a)	+0.02	—
Italy	+0.40	+0.02	+0.03	—
Switzerland	+4.29	+0.89	+0.04	-4.51
Belgium	+1.76	+0.59	+0.08	-0.54
Sweden	+1.26	(a)	+0.06	+0.07
Norway	+1.73	-0.01	+0.03	-0.13
Denmark	+1.60	+0.52	+0.28	+0.78
Czechoslovakia	+1.07	+0.07	+0.01	-0.01
Poland	+0.31	+0.07	+0.05	—
Austria	+1.64	+0.08	+0.11	-0.09
Hungary	+0.51	+0.02	+0.04	—
Portugal	+0.16	(a)	+0.02	—
Rumania	+0.12	+0.03	+0.06	—
Russia	+0.04 (d)	(a)	—	(a)

(a) Not available.

(b) Net import trade in cocoa husks omitted.

(c) 1928 only.

(d) 1925-27.

* The classification of cocoa products in the different countries shown above does not permit of exact comparability in the last two columns of the table. Thus under the heading cocoa powder and paste are included chocolate, other than confectionery, in the United States, New Zealand, and the Union of South Africa; potable chocolate in Australia; chocolate paste in Switzerland; and cocoa butter in Spain. Chocolate and other cocoa preparations include sugared cocoa powder in Norway; cocoa in blocks in Sweden; cocoa paste in Czechoslovakia; and all cocoa preparations in the Irish Free State.

248. These figures can only give a very approximate indication of the consumption of cocoa products, in the absence of information as to the form in which the raw cocoa imported is actually consumed. The third British Census of Production gave an output of about 110 million lb. of cocoa and chocolate, and 160 million lb. of chocolate confectionery in Great Britain in 1924, apart from any production of chocolate or cocoa by bakers and biscuit makers, or by the confectionery trade in Northern Ireland. Yet only 120 million lb. of raw cocoa were entered for home consumption in Great Britain and Northern Ireland in that year. But the figures in Table C do show how small is the consumption of cocoa and its products in a number of European countries.

249. Most countries into which cocoa is imported impose import duties on the commodity, and many producing countries tax exports as a source of revenue. Hence there are considerable obstacles to the distribution of the commodity both outward and inward. The export and import duties in a number of countries are shown below, with conversions at current rates of exchange.

TABLE CI.—*Export Duties on Raw Cocoa.*

Brazil	Duties levied by States, ranging up to 10 per cent. <i>ad valorem</i> .
Ecuador	0·08 sucres per kg. (3s. 4d. per cwt.).
Dominican Republic ..	\$3·0 per 100 kg. (6s. 4d. per cwt.).
Haiti	11·425 gourdes per 100 lb. (10s. 6d. per cwt.).
Ceylon	1·00 rupee per 100 lb. (1s. 8d. per cwt.).
Gold Coast	} 1s. 2d. per cwt.
Nigeria	
Grenada	1s. per cwt. (when cocoa is above 40s. and not exceeding 50s. per cwt. in London), up to 2s. (when over 80s. per cwt.), and 3d. per cwt. for each 10s. above 90s.
St. Lucia	<i>Estate Cocoa</i> .—Nil while f.o.b. price is below 45s. per cwt. <i>Ordinary Cocoa</i> .—Nil where f.o.b. price is below 35s. per cwt. From 35s. up to 40s., 4d. per cwt., and on a graduated scale up to 2s. 5½d. per cwt. when f.o.b. price is 95s. to 100s. per cwt.
St. Vincent	6d. per cwt.
Trinidad	5d. per cwt.
	} Cocoa valued up to 270 fr. per 100 kg.—4 per cent. <i>ad valorem</i> .
Guadeloupe	
Martinique	
	} Cocoa valued at 270–400 fr. per 100 kg.—4½ per cent. <i>ad valorem</i> .
	} Cocoa valued at over 400 fr. per 100 kg.—5 per cent. <i>ad valorem</i> .

TABLE CI.—*Export Duties on Raw Cocoa*—continued.

<i>Madagascar</i>	3 per cent. <i>ad valorem</i> .
<i>Belgian Congo</i>	3 per cent. of official valuation.
<i>San Thomé and Príncipe</i>	·012 gold escudos per kg. (2s. 8d. per cwt.) in Portuguese ships to Portuguese ports. ·025 gold escudos per kg. (5s. 8d. per cwt.) in Portuguese ships to foreign ports. ·040 gold escudos per kg. (9s. 0d. per cwt.) in foreign ships to foreign ports plus overtax of 50 per cent. on all exports.
<i>Fernando Po</i>	10 pesetas per 100 kg. (2s. 8d. per cwt.) exported to Spain and Spanish possessions. 15 pesetas per 100 kg. (4s. 0d. per cwt.) exported to foreign countries.
<i>Western Samoa</i>	2s. per cwt.
<i>French West and Equatorial Africa</i>	} Nil.
<i>Dutch Guiana</i>	
<i>Jamaica</i>	
<i>Costa Rica</i>	
<i>Venezuela</i>	

Import Duties on Raw Cocoa.

<i>United Kingdom</i>	General, 14s. per cwt. ; British preferential, 11s. 8d. per cwt.
<i>United States</i>	Free.
<i>Switzerland</i>	3 fr. per 100 kg. (1s. 3d. per cwt.).
<i>Germany</i>	<i>Raw</i> .—35 reichsmarks per 100 kg. (17s. 5d. per cwt.). <i>Roasted</i> .—Unshelled 60, shelled 150 reichsmarks per 100 kg. (29s. 10d. and 74s. 8d. per cwt.).
<i>Italy</i>	30 gold lire per 100 kg. (12s. 1d. per cwt.).
<i>Argentina</i>	5 per cent. of official valuation.
<i>Holland</i>	Free.
<i>Spain</i>	150 gold pesetas per 100 kg. (60s. 7d. per cwt.).
<i>Czechoslovakia</i>	40·60 kr. per 100 kg. (2s. 6d. per cwt.).
<i>Sweden</i>	0·05 kr. per kg. (2s. 10d. per cwt.).
<i>Denmark</i>	0·06 kr. per kg. (3s. 4d. per cwt.).
<i>Norway</i>	0·15 kr. per kg. (8s. 5d. per cwt.).
<i>France</i>	180 fr. per 100 kg. (14s. 10d. per cwt.). French Colonial produce free (up to a fixed quota for some colonies). Internal tax, 120 fr. per 100 kg. (9s. 11d. per cwt.), and turnover tax of 2 per cent. of duty paid value, are also imposed on all imports.

TABLE CI.—*Import Duties on Raw Cocoa*—continued.

<i>Belgium</i>	..	..	100 fr. per 100 kg. (5s. 10 <i>d.</i> per cwt.) plus transmission tax, 2 per cent. <i>ad valorem</i> .
<i>New Zealand</i>	..	..	} Free.
<i>Australia</i>	..	..
<i>Canada</i>	..	..
			General, 2 dollars per 100 lb. (9s. 4 <i>d.</i> per cwt.); British preferential, free, except British West Africa, west of Niger, which pays 1½ dollars per 100 lb. (7s. 0 <i>d.</i> per cwt.). Sales tax of 2 per cent. of f.o.b. value plus duty is also imposed on all imports.
<i>Rumania</i>	..	..	Green, 2·50 gold lei per 100 kg. (1s. per cwt.); roasted, 32·50 gold lei unshelled and 75·00 gold lei shelled per 100 kg. (13s. 2 <i>d.</i> and 30s. 4 <i>d.</i> per cwt., respectively).
<i>Poland</i>	..	..	25 zlotý per 100 kg. (5s. 10 <i>d.</i> per cwt.) plus manipulation tax of 10 per cent. of the duty.
<i>Austria</i>	<i>Raw</i> .—50 gold krone per 100 kg. (21s. 1 <i>d.</i> per cwt.). <i>Roasted</i> .—60 gold krone per 100 kg. (25s. 4 <i>d.</i> per cwt.).

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TABLE OF CONTENTS.

	<i>Page</i>
PREFACE : Progress in Empire Marketing	5
I. GRANTS FOR RESEARCH AND DEVELOPMENT	12
Biological and Agricultural Sciences	12
Tropical and Sub-Tropical Development	13
Low Temperature Research	22
Animal Husbandry	25
Animal Breeding	31
Animal Health	33
Export of Pedigree Live Stock	36
Entomology	38
Mycology and Plant Pathology	45
Plant Breeding	48
Horticulture	52
Economic Botany	54
Dietetics	56
Forestry and Forest Products	58
Mechanical Transport	59
Fisheries	60
Wool	63
Flax	65
Dairying	66
Poultry	69
Animal Ecology	72
Agricultural Meteorology	73
Oenology	73
Geophysics	73
Miscellaneous	74
Travellers	75
II. ECONOMIC INVESTIGATION AND MARKETING ENQUIRIES	76
Marketing of Home Agricultural Produce	76
Statistics and Market Intelligence	79
Wastage in Imported Fruit	81
Experimental Consignments and Trade Enquiries	81
Retail Surveys	82
III. PUBLICITY	82
Newspaper Advertisements	82
Posters	83
Leaflets	84
Lectures	85
Broadcasting	85
Exhibitions and Shopping Weeks	86
Trade Meetings	87
Cinema	87

Appendix I.—Lists of Members of the Board and of its Committees.

Appendix II.—Publications of the Empire Marketing Board.

Appendix III.—Reports of the Imperial Economic Committee.

PROGRESS IN EMPIRE MARKETING.

The Empire Marketing Board is a non-political body upon which all three parties are represented. It was established in 1926 by Parliament. Its duty is to further the marketing in the United Kingdom of Empire (including home agricultural) products.

ATTENTION was drawn in the last Annual Report of the Empire Marketing Board to a number of Empire-grown foodstuffs, shipments of which into the United Kingdom had surpassed all previous records in 1927 and 1928. The list was long and comprehensive. In spite of this, the year now under review showed further evidence of progress in the consumption of Empire produce in the United Kingdom. Some foodstuffs, record shipments of which were noted in the last Report, arrived in even greater quantities, while other commodities established records. The following table shows the articles affected, with their volume and countries of origin:—

RECORD IMPORTS INTO THE U.K. FROM THE EMPIRE IN 1929.

Commodity.	Country of Origin.	Quantity in 1929.	Previous Record.
Raisins and Sultanas.	Australia ..	720,000 cwt.	565,000 cwt. in 1927
Currants ..	Australia ..	240,000 "	183,000 " " 1924
Cheese Butter	New Zealand {	1,802,000 "	1,612,000 " " 1927
		1,313,000 "	1,255,000 " " 1925
Eggs..	Australia ..	3,780,000 dozen	3,350,000 dozen in 1926
	South Africa..	3,940,000 "	3,720,000 " " 1927
	New Zealand..	220,000 "	140,000 " " 1928
Grapefruit	South Africa..	26,400 cwt.	19,050 cwt. in 1928
	West Indies ..	41,100 "	31,700 " " 1928
	Palestine ..	3,000 "	640 " " 1928

Commodity.	Country of Origin.	Quantity in 1929.	Previous Record.
Oranges ..	South African	670,000 cwt.	534,000 cwt. in 1928
Bananas ..	British West Indies.	4,015,000 bunches	3,581,000 bunches in 1926
Plums	South Africa {	250,000 boxes	240,000 boxes in 1927
Nectarines		58,000 "	36,000 " " 1927
Grapes		520,000 "	500,000 " " 1927
Apples		10,500 "	6,700 " " 1927
Frozen Pork	New Zealand..	169,000 cwt.	122,000 cwt. in 1928
Poultry ..	Irish Free State.*	127,000 "	112,000 " " 1927
Tea ..	India ..	307,600,000 lb.	303,500,000 lb. in 1927
	Ceylon ..	153,200,000 "	142,500,000 " " 1927
Raw Sugar {	Australia ..	4,464,000 cwt.	3,029,000 " " 1928
	South Africa..	1,927,000 "	1,430,000 cwt. in 1928
	Mauritius ..	5,443,000 "	4,460,000 " " 1923
Canned Pine-apple.	British Malaya	654,000 "	604,000 " " 1925
Wines ..	South Africa..	459,000 galls.	288,000 galls. in 1928

* Since 1924 when separate returns were first issued.

Such figures throw, of course, only a very partial light on Empire trade, and it would be impossible to assess, even approximately, the influence of the Empire Marketing Board upon them. Many factors—some, like the failure of crops, wholly or partially beyond human control—would have to be taken into account before a complete analysis was reached. It may, however, be said that the Empire Marketing Board has been encouraged by its experience in the past year. There has again been an appreciable quickening of interest in the theme of Empire buying among men and women in the United Kingdom.

Purpose of the Board.

The purpose of the Empire Marketing Board is clear and definite. It is to improve the quality and increase the quantity of Empire products marketed in the United Kingdom and to make Empire

buying a national habit. From this centre radiate all the diverse activities of the Board. The scientist at his laboratory table serves its central purpose no less than does the salesman at his shop counter. For modern marketing is an enormously complex machine and, unless every cog of it is in smooth running order, the perfection of many isolated parts is without value. It is a commonplace to say that no advertising, however skilful, will sell poor goods. Even if the advertising and the quality are beyond reproach, marketing will still fail unless the many problems of distribution have been studied and solved.

The Board aims at seeing that no factor contributory to the growth of Empire Marketing is neglected. The public of the United Kingdom has been approached from many angles. There is, first, the need of making a busy, island, industrial people aware of the realities of the scattered Empire of which they are citizens. Such educational publicity can neither achieve its objects swiftly nor have an immediate and measurable effect upon sales. Nevertheless, if the habit of Empire buying is to be permanently established, educational publicity is essential. The more vividly people appreciate the achievements, the possibilities and the needs of the Dominions and Colonies, the more naturally will they choose to do their business within the Empire.

But other approaches to the consumer had equally to be explored. Here, again, is a complex problem. The active sympathy of the great corporate bodies, powerful as purchasers of raw materials and foodstuffs in bulk, has been sought by the Board. Individually so weak in comparison with these bodies but collectively even more effective are the housewives whose goodwill the Board has taken every opportunity of enlisting. The diversity of consumers in the United Kingdom goes far beyond these broad differences. Varying standards of wealth present another problem. Local habits have had to be taken into account. It is a mistake to suppose that easy communications have broken down the barriers behind which the various regions of the United Kingdom still lead distinctive lives. What London likes may prove to be what Lancashire refuses. The exporter from the Oversea Empire who means to serve a nation-wide market with his goods has to study the distinctive taste of districts.

No amount of persuasion brought to bear upon the consuming public in all its forms would succeed unless it was supported by the wholesale and retail traders. The Board has, accordingly, endeavoured

to secure the fullest co-operation of all kinds of traders concerned with Empire marketing. Happily, the task has been made easy and encouraging by the loyal response with which it has been met. There has, without question, been a marked advance in the habit of Empire buying in the past year. For this the readiness of the wholesale and retail traders of the United Kingdom to further, in their businesses, the ends of the Board has been to no small extent responsible. The Board's officers seek to work in close daily touch with the trades, and this Annual Report would be misleading if it failed to bring out emphatically the value of the services rendered by the trades to the cause of Empire marketing.

Behind all approaches to traders and consumers stretch the innumerable fascinating problems of production and transport. The Empire as a productive entity is young. New sources of wealth are being opened up every year. The Empire is scattered about the world. These facts give it a marvellous economic strength, enabling it to grow almost every kind of natural product. But the need of patient attention to every link in the chain between prairie and fruit farm, ranch and plantation and the retail shops of the United Kingdom is thereby vastly increased. It is natural that the Board should have been invited to lend its aid in many and in contrasted activities. The Board has reviewed all applications with the sense which four years' work has given it of the complexity and of the seeming remoteness of many factors which bear ultimately upon the sale of Empire produce in the United Kingdom. A bull shipped to one part of the oversea Empire and an insect to another may each in its own way do a service to Empire marketing.

The detailed sections of this Report should, then, be read in the light of this diversity which gives such scope for service to all citizens of the Empire and, at the same time, affords the strongest grounds for optimism as to the issue of their endeavours.

Changes of Chairmen.

The change of Government after the General Election in May, 1929, led to alterations in the political membership of the Board and of its committees. Lord Passfield, the new Secretary of State for Dominion Affairs and for the Colonies, succeeded Mr. Amery as Chairman of the Board. Dr. Drummond Shiels, Under Secretary of State for the Colonies, became Chairman of the Research Grants Committee in

place of Major Elliot, and Mr. Lunn, Under Secretary of State for Dominion Affairs, Chairman of the Publicity Committee in place of Mr. Ormsby-Gore. Mr. Thomas was compelled by the pressure of his new duties as Lord Privy Seal to retire from the Board. The retiring Conservative ministers have accepted invitations to retain their membership of the Board or of its Committees, and the Board remains happily representative of all the three political parties in the United Kingdom.

The Board, encouraged by the marked goodwill shown to its purpose by the distributive trades of the country and anxious to take the fullest advantage of trade experience, has lately strengthened its machinery by the appointment of a new main Committee, to be known as the Marketing Committee. It believes that this Committee will secure a regular and continuing contact between itself and the complicated system by which Empire products are distributed to the consumers of the United Kingdom.

Scientific research, conducted with the aid of grants from the Empire Marketing Fund, is now in progress in the United Kingdom, in each of the Dominions and in numerous Colonies. Particulars of each grant and of the progress made in the investigations thus financed are given later in this Report.

The range of Empire industries and commodities which these grants are designed to assist is considerable and it would scarcely be practicable to summarise what is being done under any watertight divisions. Some grants, as, for instance, those concerning entomology and Low Temperature Research, are relevant to more than one industry and to many commodities.

The essential part which scientists are playing in the development of Empire marketing may, however, be seen from the detailed section of this Report. The veins of special knowledge and of enthusiasm which are being tapped are not the least enheartening features of the situation. The past year has witnessed a striking advance in the practice of intellectual co-operation within the Empire. Some scientific research schemes are being carried on with assistance from the Board's Fund in the United Kingdom and others in the oversea Empire countries. Frequently, the problem is being tackled by a team of workers, closely in touch with one another but scattered through the Empire. In all cases, the results achieved are at the disposal of the Empire as a whole.

Arrangements have been made and have proved perfectly satisfactory to prevent the overlapping of the work of the Board and that of the newly formed Colonial Development Advisory Committee. The main functions of the two bodies are essentially complementary and no difficulty has been experienced in ensuring co-ordination in agricultural research and the marketing of Colonial products in which each is interested. Sir Basil Blackett, Chairman of the Colonial Development Advisory Committee, has accepted a seat on the Research Grants Committee of the Board.

Marketing Extensions.

The year has seen a steady extension, on the marketing side, of the services provided by the Board. The rise of the "National Mark" as a factor of prime importance in placing home grown foodstuffs on an orderly marketing basis has been actively assisted by the Board. The direct initiative and responsibility for the "National Mark," as for all schemes for improving the condition of agriculture in the United Kingdom falls, of course, on the Ministry of Agriculture and Fisheries, and the Scottish Department of Agriculture. The Board has co-operated with these departments by providing the necessary funds as well as by advertisement and other channels of publicity. In all its activities the Board has continued to put first the interest of the home producer.

The systematic survey of the wastage in imported Empire fruits has been continued in the Liverpool and in the London docks and further reports have been issued and circulated among the oversea producers concerned. Trade enquiries to estimate the extent and nature of competitive supplies and to obtain information on market requirements in regard to quality, grading and packing have also been undertaken. A series of retail market surveys has been carried out both nationally and in selected areas.

The publication of weekly intelligence notes, giving full marketing information for fresh fruit and for dairy produce, has been extended. An interesting development made possible by the support of the trade is the inclusion of statistics of approximately ninety per cent. of the butter held in cold storage. A promising activity is the issue of statistical surveys of the world position as regards the production and consumption of various foodstuffs.

The Board has employed, as means of furthering the sale in the United Kingdom of Empire produce from home and overseas, seven methods of publicity. It directed during the year an advertisement campaign in the principal national and trade papers. The general theme of Empire buying was kept in the foreground in all advertisements and was illustrated by specific appeals to buy, among other commodities, Canadian apples, New Zealand dairy produce, Australian dried fruit and South African oranges and soft fruits.

The use of special frames for the display of posters was extended, so that the Board now has these frames, with their regularly changing sets of posters, in 450 towns in the United Kingdom. Specimen frames have been erected in several oversea Empire countries. Posters were also shown, in connection with exhibitions, on the commercial hoardings. Suitable posters were reproduced in half size and in colour, and were issued, together with leaflets telling the story of the Empire industry or scene depicted, to over 20,000 schools in the United Kingdom that applied for them.

The issue of other leaflets and of display material, including shop window bills and popular recipes, was very considerably increased. The total number of leaflets distributed by the Board in the year was nearly two million.

Lectures—the fourth method of publicity employed—were given under the Board's auspices to audiences totalling 500,000.

The British Broadcasting Corporation made it possible for the Board to give out a number of talks to housewives.

The value of exhibitions and shopping weeks was so apparent to the Board that it took part vigorously on many of these occasions. A pavilion was erected and given over to changing displays of Empire produce throughout the six months of the North East Coast Exhibition. Space was taken at fourteen other exhibitions, and assistance was rendered at fifteen shopping weeks in various parts of the United Kingdom.

A new and extremely fruitful experiment is being tried at Glasgow, where the Board has rented a shop in a central position for six months and gives it over, for periods of a fortnight each, to individual Empire countries. The direct contacts thus formed with traders and with the public are proving most effective in opening up new and in broadening established lines of Empire trade.

Lastly, the Board has added to its experience of the cinema as an instrument of publicity. The first of its films to be released for public display has been exceptionally well reviewed and has secured satisfactory bookings. Other films are nearing completion. A beginning has been made with the preparation of a number of Empire interest films for display to school and other audiences.

Such in outline is the ground covered in the past year by the Empire Marketing Board. More detailed accounts of each activity will be found later in this Report.

The new Government announced early in the year under review that they proposed to continue the Empire Marketing Board. This preliminary announcement was confirmed in February, when it was stated that the work of the Board would be continued on its existing general lines, and that the practice, already adopted in 1929, of voting annually such supplies only as were estimated to be required for the year's work, would be continued. A total provision of £800,000 for the year 1930-31 is being proposed to Parliament.

A White Paper, giving a note on the finance of the Board up to March 31st, 1930, will be presented to Parliament in July.

I. GRANTS FOR RESEARCH AND DEVELOPMENT.*

BIOLOGICAL AND AGRICULTURAL SCIENCES.

Development of Biological and Agricultural Departments of the University of Cambridge.

Grant: *University of Cambridge.* £10,000 p.a. for 5 years.
(The total cost of the scheme is £1,179,000 so that £1,129,000 is to be provided from other sources.)

MENTION was made in last year's Annual Report of the grant to the University of Cambridge in aid of the scheme for the development of the University's Biological and Agricultural Departments. The offer of the International Education Board of the

* Provision was made in the Estimates for 1929-30 for an expenditure on research of £482,000.

In all cases where a grant from the Empire Marketing Fund is shown at the head of a section, the amount so indicated is a maximum figure.

Rockefeller Foundation to contribute £700,000 in aid of the scheme was conditional on the University finding £479,000 from other sources.

From its own resources the University has promised £250,000 ; a Committee in London, with Lord Melchett as Chairman and Sir Kynaston Studd as Vice-Chairman, has, up to the time of writing, raised a sum of approximately £50,000 ; the Cambridge University Association has itself raised sums amounting to £21,000 apart from approximately £10,000 in payments and promises from senior resident members of the University, whilst contributions promised from the Empire Marketing Fund and the Exchequer together amount to £100,000.

Until the required balance is raised it will not be possible to proceed with the developments in the scientific departments financed by the scheme, but as the International Education Board consented to release £250,000 for the Library since the University had promised a similar sum, the plans for the new Library, prepared by Sir Gilbert Scott, were approved by the University in January last and preparations for building are now proceeding.

TROPICAL AND SUB-TROPICAL DEVELOPMENT.

Imperial College of Tropical Agriculture, Trinidad.

Grant : £21,000 capital and £55,000 spread over a period of 4 years.

(£21,000 capital provided by Lancashire Cotton interests.)

Substantial grants have been made from the Empire Marketing Fund since the Board's establishment towards the maintenance and development of the Imperial College of Tropical Agriculture, Trinidad. The objects of the College are to provide training in the science and practice of tropical agriculture to students intending to become tropical planters, agricultural officers or specialists in different branches of agricultural science, and to offer facilities for the study of tropical agriculture to graduates of other colleges and universities. An important feature of the College is the provision for research which its laboratories and fields afford. Past students of the College are now employed in India, the Union of South Africa, Swaziland, Southern and Northern Rhodesia, East and West Africa, Ceylon, Malaya, the West Indies and other parts of the Empire.

During the past year Mr. (now Professor) F. L. Engledow of Cambridge University visited the College at the invitation of the Empire Marketing Board to report upon the future policy of the College so far as research and teaching are concerned. Professor Engledow emphasised the interconnection between post-graduate training and research and made certain recommendations for the future development of the College which are now being considered by the Governing Body.

Banana Research.

Grant : *Imperial College of Tropical Agriculture, Trinidad.*
£5,774 capital and £3,806 p.a. for 5 years.

In 1927 and 1928 the Board made grants for carrying out at the Imperial College of Tropical Agriculture research into the production of a variety of banana immune from Panama Disease or more resistant than the Gros Michel, while at the same time retaining the commercial attributes of the latter variety. The problem is being tackled from the botanical, pathological and physiological aspects. The botanical part involves the collection and examination of as large a collection of bananas as possible and hybridisation work. The collection now comprises about 100 varieties and species. Dr. Wardlaw, the Pathologist, has continued his studies into the causal fungus of Panama Disease and has visited the banana growing countries of the West Indies, Central and South America. His observations indicate that the numerous failures of plantations recorded in the past are not invariably due to Panama Disease but that unsuitability of soil, location and cultivation methods have, in many instances, proved the decisive factors. These conclusions have been confirmed by Dr. McGuire, the Physiologist. The reports of both these scientists have been published by the Empire Marketing Board. Dr. McGuire has lately devoted his attention to ripening problems in connection with which a Low Temperature Research Station has been erected at the College at the charges of the Empire Marketing Board.

It is essential that varieties of bananas from other countries should not be imported direct to Trinidad for fear of introducing diseases of bananas not hitherto known in the West Indies, and, as a safeguard against this, a quarantine house has been erected at the Royal Botanic Gardens, Kew, where root-stocks imported from other countries may be grown and from which off-sets, certified free from disease, may be sent to Trinidad.

During the past year a consignment of suckers propagated from material in the quarantine house has been despatched to Trinidad. There remain 11 varieties of the collection of bananas obtained by an officer of Kew who visited the East in 1928 and these will be despatched as soon as suckers can be propagated from the existing stools. Fresh propagating material is being sent from Malaya and a collection of stools of bananas of the Cavendish type has been obtained from Brazil.

East African Agricultural Research Station, Amani.

Grant : £6,000 p.a. for 3 years.

(Contributions estimated at £12,000 p.a. are provided by the East African Governments.)

A grant was approved in 1927 towards the cost of maintenance of the East African Agricultural Research Station at Amani which serves as a centre of research into tropical agricultural problems in Africa.

The research programme of the Station includes (1) surveys of the basic types of East African soils ; (2) the collection and correlation of data regarding climate ; and (3) a study of the results of the interaction of soil and climate as expressed in the natural vegetation. Investigations proposed relate to coffee problems ; problems connected with the conservation or restoration of soil fertility ; plant breeding with particular reference to coconuts, cinchona and such crops as tea, coffee, cotton and sugar cane ; the collection and cultivation of a wide range of plants used as fish poisons, etc., for the study of the production and use of their active principles as insecticides in co-operation with work on this subject at the Rothamsted Experimental Station ; virus diseases of tropical plants ; and investigations on problems presented by specific pests and diseases.

Colonial Agricultural Service.

Grant : £22,000 p.a. for 5 years.

(Contributions from Colonial Governments are provisionally estimated at £110,000 p.a.)

The Board in 1928 approved a contribution from the Empire Marketing Fund towards the cost of a Colonial Advisory Council of Agriculture and Animal Health and the formation of a Colonial

Agricultural Service with a specialist wing for research work and an agricultural wing for administrative work. The headquarters Council has now been established in London and an Agricultural Adviser appointed. It is hoped to appoint an Adviser in Animal Health in the near future. The Council is able to give authoritative advice to the Empire Marketing Board in its consideration of applications for grants from Colonies and Protectorates and the Council's appointment will, it is felt, secure great advantages to Colonial Agriculture.

Experimental Fruit Farm in Sierra Leone.

Grant : £1,500 capital and £1,500 p.a. for 5 years.

(Similar sums provided by Government of Sierra Leone.)

A grant was made to the Government of Sierra Leone in 1927 for the establishment of an experimental fruit farm in that Colony with the object of testing the economic cost of growing and shipping bananas and grape fruit, and of interesting native growers and Europeans in the possibilities of growing fruit for export on a commercial scale.

A European Manager and assistant Manager have been engaged to start the farm and a programme of work has been drawn up in consultation with Professor Clark Powell, the citrus expert from South Africa, who visited Sierra Leone at the Board's charges. An area of approximately 55 acres has been set aside for carrying out a citrus programme which will embrace nursery work, root stock, variety, fertiliser and irrigation trials. The first set of fertiliser trials will be to test the value of individual mineral fertilisers and the second set to test the value of the various forms of nitrogen.

Experimental Oil Palm Plantation in Sierra Leone.

Grant : £1,500 p.a. for 2 years.

(The Sierra Leone Government have already spent upon the plantation £3,500 in 1927, £12,000 in 1928 and £7,000 in 1929, and propose to continue contributing at the rate of approximately £6,000 p.a. in 1930 and 1931. The African and Eastern Trade Corporation are providing in addition £8,000 in four instalments of £2,000 p.a.)

The Government of Sierra Leone, aided by grants from the Empire Marketing Board and the African and Eastern Trade Corporation, is establishing an experimental oil palm plantation of some 2,500 acres

in Sierra Leone. The plantation is designed to provide an object lesson in improved cultivation to local chiefs and to demonstrate whether or not plantation methods can be established on a commercial basis in Sierra Leone.

Drying of Copra in the Federated Malay States.

Grant : £1,150 p.a. for 4 years.

(Similar sum provided by Government of the Federated Malay States.)

This grant will enable research to be carried out in Malaya into the best methods of preparing copra of high quality for export. The results of this work should be of interest not only to Malaya, but also to those Colonies and Dependencies where the climatic conditions render artificial drying of the coconut meat necessary. Both New Zealand and Australia have intimated their desire to be kept in touch with this work as it will be of interest to the Pacific Islands administered by them.

Marketing of Copra in Fiji.

Grant : £750 p.a. for 2 years.

In 1926 the Governor of Fiji appointed a Committee to consider the question of the improvement of the quality of copra exported from that Colony. Following the Report of that Committee a copra Ordinance was passed by the Legislative Council which provided for the appointment of Inspectors whose special functions it would be to secure improved methods of marketing, handling, drying, grading, etc. The Board in December, 1927, approved a grant to enable three Inspectors to be appointed. Under the Fiji Ordinance an Inspector is empowered to grade copra before export either as "Fiji First" or "Fiji Second" and the bags containing graded copra are marked with an export trade mark according to grade.

Citrus Industry in Palestine.

Grant : £1,000 p.a. for 3 years.

(Similar sum provided by Government of Palestine.)

This grant was approved in 1928 to enable the Government of Palestine to engage a citrus specialist and one or two assistants for

improving citrus fruit cultivation and marketing in that country. The scheme of work is being specially directed to improvements in methods of packing, grading and shipment as being of more immediate practical importance to the orange export trade than experimental work on problems of cultivation, but the specialist will work out his own proposals for future developments in the way of experimental planting and research.

Citrus Industry in British Honduras.

Grant : £280 p.a. for 3 years.

(Similar sum being provided by Government of British Honduras.)

Professor Clark Powell recommended in his report on his visit to British Honduras the appointment to that Colony of an Agricultural Officer who should devote special attention to the development of a citrus industry. The Board accepted this recommendation and in 1928 made a grant to meet half the cost of the officer's salary. The officer's duties are to advise the Government and the agricultural community on questions relating to agriculture with special reference to the cultivation, packing and export of citrus fruit. The results of his first year's work hold out much promise for the future.

Investigation of Insecticidal Plants in British Guiana.

Grant : £200 p.a. for 5 years.

The Department of Agriculture in British Guiana have for some time been investigating, in co-operation with the Rothamsted Experimental Station, the value of certain local plants which are known to possess strong insecticidal properties. These preliminary examinations have resulted in an effort being made to collect and cultivate the more important of these plants with a view to studying their habits under cultivation and ascertaining whether they could be economically utilised. It is possible that some of these plants may prove of value commercially, provided regular supplies of standardised material can be depended upon. The Board made a grant in 1929 towards the expenses incurred in the collection and investigation of such plants.

Sugar Research in Mauritius.

Grant : £2,000 p.a. for 5 years.

(Similar sum to be provided by Government of Mauritius.)

On the advice of the Colonial Advisory Council of Agriculture and Animal Health the Board during the past year made a grant to the Government of Mauritius to meet half the recurrent expenditure on a scheme for the development of sugar research in Mauritius. The research problems which demand early attention in Mauritius relate to the genetics, physiology and general biology of the sugar cane, and the present scheme provides for the appointment of a Senior Geneticist, a Research Botanist strong on the physiological side and a Biochemist and Soil Physicist. These three officers will be provided with the necessary assistants and it is intended that this staff shall concentrate on continuous research work and shall not be used for teaching and advisory duties.

Lac Research and Marketing.

Grant : Government of Bihar and Orissa. £500 p.a. for 5 years.

(Similar sum to be provided by the Government of Bihar and Orissa.)

The Imperial Council of Agricultural Research in India, soon after its appointment in the summer of 1929, recommended to the Board an application by the Government of Bihar and Orissa for a grant to meet half the cost of appointing a Marketing Expert in England to supplement lac research being carried out in India. This application was approved by the Board.

Much work has already been done on research into the propagation and cultivation of the lac crop by the Lac Research Institute at Namkum and it is anticipated that research to improve methods of manufacture will shortly be taken up. Research into the standardisation of quality has not, however, yet been started and the first step necessary in this matter is the appointment of an expert in England to keep in touch with consumers, to ascertain their needs and the particular qualities required for each industry, and to arrange for the supply of samples from India and their testing at technical laboratories in England with a view to fixing the standards towards which manufacturers in India should work. It is claimed that the scheme, if successful, would result in increasing the supplies, as well as in improving and standardising the quality, of lac available for export to the United Kingdom market.

Tea Research in India.

Grant : *Indian Tea Association* £3,125 capital and £687 p.a. for 5 years.

(Similar sums to be provided by Indian Tea Association.)

A grant was approved in 1929 on the recommendation of the Indian Imperial Council of Agricultural Research to the Indian Tea Association towards the cost of establishing and developing at Tocklai a laboratory of plant physiology where problems connected with the constitution and composition of the tea plant can be studied.

Although considerable work has been done upon the study of soil and fertility problems, it is clear that this has only touched the fringe and that more research work on these problems is needed. It is now proposed to investigate the changes that can occur, or that can be brought about by various modifications of manurial treatment, soil reaction, soil moisture and the like, in the composition of the tea plant (especially the leaves), and how such changes will affect resistance to insects and fungi and will modify the quality of the finished tea. These are problems the solution of which would be of fundamental value not only to the Empire tea planting industry but to other permanent plantation crop industries throughout the tropics.

Tea Research in Ceylon.

Grant : *Tea Research Institute of Ceylon.* £1,000 capital.

A capital grant has been made in the past year to the Ceylon Tea Research Institute for the purchase of experimental small scale machinery and plant for the factory of the Institute.

The present staff of the Institute is qualified to undertake investigations in all the major branches of research as applied to the tea industry. Special attention is being paid to the fundamental physical properties of the soil, its degree of laterisation and the inter-relationships between soil type, basic exchange and soil reaction. Already certain fundamental differences between average tea soils and other tropical soils are beginning to emerge. A comprehensive programme of research on the changes accompanying tea manufacture is in hand and a detailed study is being made of the composition of the fresh leaf including the variation in composition from plucking to plucking, and at different times of day, over a pruning cycle.

The additional plant and machinery at the Institute's factory will make possible a more complete study of the withering and subsequent processes of rolling, fermentation and drying, and render possible the manufacture of tea from small quantities of leaf from the experimental plots and allow of comparisons being made between different treatments.

Sericulture.

(a) *In Jamaica.*

Grant : £1,900 spread over a period of 3 years.

(Similar sum to be provided by Government of Jamaica.)

The climatic conditions of Jamaica are well suited to the silkworm and considerable areas in the Colony are favourable for the cultivation of the mulberry tree. The silk so far produced is of a promising character but no real progress can be expected until modern methods of egg selection, cocoon production and silk reeling are fully understood and adopted in the Island.

The object of the grant approved during the past year is to encourage a larger output of silk, to enable a sericulturist to be trained in European methods and to allow of instruction and demonstration being given on the subject.

There is a steady demand for raw silk of good quality in the world's market; and, if Jamaica can produce such silk at a price comparing not unfavourably with standard silks, it is considered that it would be readily absorbed in the United Kingdom.

(b) *In Palestine.*

Grant : £100.

(A sum of £300 is being provided by the Government of Palestine.)

Experiments have for some time been carried out in Palestine with a view to reviving silkworm culture in that country. Specimen cocoons and fabric woven locally from the silk were examined by the Imperial Institute in 1927 and the cocoons were found to be promising and the silk fabric a material of good quality, clean in the thread. Under skilled management sericulture should be successfully carried out in Palestine but experiment on a larger scale is required to determine the feasibility of establishing a local industry. The Board's grant has

enabled mulberry saplings to be purchased for the propagation of mulberry plants and will permit of demonstrations and field experiments.

Tung Oil Production and Research.

Grants : *Royal Botanic Gardens, Kew.* £700. *Research Association of British Paint, Colour and Varnish Manufacturers.* £750 p.a. for 5 years.

Supplies of tung oil seeds obtained from China and Florida have already been sent by Kew to those countries in the Empire where climatic conditions appear suitable, and experimental cultivation trials are now in progress in twelve or more of the Dominions and Colonies. The grant made to Kew during the past year is to enable further distribution of seeds to take place. There are a number of other problems, chiefly of a chemical nature, arising specifically out of the Imperial development of tung tree cultivation which require elucidation. These include a comparative study of the physical and chemical properties and technical value of present supplies of Chinese tung oil, oil from cultivated American seed and oil from Empire seed as this becomes available. This investigation is necessary in order to demonstrate that Empire-produced tung oil will meet the requirements of manufacturers. Equally essential is a detailed investigation of the oil of *Aleurites montana* in comparison with that of *Aleurites Fordii*. It is also essential that prospective growers of tung oil seeds in the Empire should be assured that a remunerative market can be found for all seed likely to be produced. At present the oil is chiefly employed in varnish manufacture and it is stated that this industry is capable of absorbing much larger quantities. It is probable that further study of the oil and its properties may result in a wider application, as, for example, in the manufacture of linoleum.

LOW TEMPERATURE RESEARCH.

Development of the Work of the Low Temperature Research Station, Cambridge.

Grant : *Department of Scientific and Industrial Research.* £38,500 capital and £8,000 p.a. for 5 years.

The extension of the Low Temperature Research Station, Cambridge, has been completed, and experience has already shown that the enlarged Station admirably meets its purpose.

For the past two years an intensive study has been made of "bloom" in meat, and during the year under review thirty-one carcasses of mutton, which had been stored in the frozen state for eighteen weeks at the Low Temperature Research Station, were shown in Smithfield Market in order to demonstrate how far control of the conditions of storage can preserve the freshly-killed appearance. The carcasses aroused great interest in the trade, and their condition was favourably commented upon. The experiment proved that "bloom" is controlled by the temperature and humidity during storage, and the opinion of the trade so exactly confirmed the expectations formed on theoretical grounds that the ideal conditions of storage can now be safely stated on the basis of laboratory experiments alone.

For the past three years a survey has been made of the wastage in fruit passing through Covent Garden Market. The main types of wastage have now been determined, and the object of the survey thus attained. It is hoped to continue the work, though perhaps not on so complete a scale, with a view to detecting any new types of wastage which may appear, and any changes in the prevalence of the types already known.

The investigations on the transport of fruit by means of "split" consignments, which have been carried out in co-operation with the New Zealand Department of Scientific and Industrial Research and certain shipping companies, have produced results of great practical utility, and afford a basis for comparison between different systems of cooling and air-circulation employed in ships' holds.

In the course of the fundamental investigation into the physiology of fruits which is being carried out at the Low Temperature Research Station, the volatile substance, acetaldehyde, was studied as an intermediary substance in normal metabolism. It was found that traces of this substance in the air inhibited the growth of fungal spores and even killed them, but had no harmful effect on the fruit. This discovery may clearly be of general scientific and economic interest, and is being followed up.

The optimum conditions for the storage of English Bramley Seedling apples have been approximately determined as regards temperature and concentration of oxygen and carbon dioxide, and gas-storage by regulated ventilation is now being tested on a commercial scale.

A good deal of attention is being devoted to the determination of those biological constants, such as the rate of production of heat by living material in store, and the rate of evaporation of water, which the refrigerating engineer requires no less than such physical constants as the rate of leakage of heat through insulation, etc.

A small Canning Laboratory has been established at the Low Temperature Research Station, the main purpose of which is to assist in the investigation of the corrosion of tin-plate by foodstuffs. During the investigation of substances which accelerate or retard acid corrosion, a discovery of economic interest was made. It was found that, though certain sugars definitely increased the rate of corrosion, a sample of refined English beet-sugar definitely retarded it. Samples of refined beet-sugar from most of the English factories also exhibited this property, though in varying degrees. The property seems to belong, not to beet sugar itself, but to some unidentified substance present in the mother liquor. The economic interest of the discovery lies in the fact that there has been a tendency on the part of the canning industry to avoid beet-sugar.

Erection of New Station at East Malling, Kent, for Cold Storage Experiments on a semi-commercial scale.

Grant : *Department of Scientific and Industrial Research.*
£55,000 capital and £34,000 spread over 5 years.

The erection of the new Station at East Malling, Kent, for research on the storage of fruit, both on the small and on the semi-commercial scale, is nearing completion. This Station will be known as the Ditton Laboratory.

Survey of Trade in Frozen Mutton and Lamb.

Grant : *Department of Scientific and Industrial Research, £1,250.*
(£750 provided by New Zealand Meat Producers' Board.)

In September, 1929, a small expedition left for New Zealand to make a scientific survey of the trade in frozen mutton and lamb from the abattoir in New Zealand to the wholesale market in London. The expedition was under the leadership of Dr. Ezer Griffiths, F.R.S., of the National Physical Laboratory. On arrival in New Zealand he was joined by representatives of the New Zealand Department of

Scientific and Industrial Research and the Australian Commonwealth Council for Scientific and Industrial Research, who are participating in the survey.

ANIMAL HUSBANDRY.

Research into the Mineral Content of Natural Pastures.

Grants: *Rowett Research Institute, Scotland.* £25,000 spread over a period of 5 years (mostly for work in Kenya).

Australia. £3,000 capital and £1,875 p.a. for 5 years (a similar grant is being provided by the Commonwealth Council for Scientific and Industrial Research and in addition a considerable sum has been contributed by a private benefactor).

New Zealand. £2,000 p.a. for 5 years (a similar grant is being provided in equal proportions by the New Zealand Government and the Cawthron Institute, New Zealand).

Southern Rhodesia. £2,500 capital and £2,500 p.a. for 3 years (a similar grant is being provided by the Government of Southern Rhodesia).

Previous Annual Reports of the Empire Marketing Board have dealt with the investigations into the mineral content of natural pastures which are being carried out on a co-operative basis in different parts of the Empire with general direction from the Rowett Research Institute at Aberdeen and with the aid of grants from the Empire Marketing Fund.

Scotland.

At the Rowett Research Institute, where much of the initial work was carried out, experiments are in progress to throw light on such problems as the effect of mineral fertilisers on pasture grass and grass cut for hay, the amount of minerals assimilated and retained by the animal under different conditions, the relative merits of feeding minerals as fertilisers or direct to stock, and the best form in which to feed them. An interesting fact which has come to light is that in the hot, dry areas of the world phosphorus seems to be the element most deficient, whereas in wet, temperate regions, calcium is generally the missing mineral. Tests are being made in the West of Scotland

to find whether it is possible, by the supplementary feeding of small amounts of special substances, deficient in the pastures, to winter ewe hogs on hills instead of sending them down to arable farms for winter grazing, which is expensive. In order to carry out tests on a larger scale, and obtain control of the animals, a small sheep farm has been taken at Garrochoran in Argyllshire. Here it will be possible to get accurate data which will enable the economic value of the results to be worked out on an exact financial scale. Costings are being taken for both the old system and the new experimental method. As a result of past experiments mineral rations have been worked out which form the basis of mineral supplements now added to pig and cattle meal by the main meal manufacturers in the United Kingdom. A study is also being made of the influence of diet on resistance to disease, and the influence of diet on the composition of wool. Feeding experiments are carried out at the Rowett Institute, and the wool is passed on to the workers at Leeds, who are studying the differences in fibre which may be correlated with diet. (*See p. 63.*)

Kenya.

In order to test in practice the results of smaller experiments, a special investigation has been carried out in Kenya Colony, where there are large areas of low grade pastures. A team of workers from the Rowett Research Institute was sent to Kenya in 1926. Analyses of samples of soil and herbage from four selected areas were made at the Rowett Institute and feeding experiments were carried out on cattle and sheep in Kenya to obtain a clear picture of the effect on animals of feeding the minerals believed to be deficient. These experiments were completed in the autumn of 1929. The pasture of all four districts was found to be markedly deficient in sodium and chlorine. In one district—Naivasha—the grass was otherwise nearly as rich as a good English pasture; in the other three there were deficiencies in all the minerals and in proteins, but most of all in phosphorus. In certain deficient areas, minerals were given, and the result was a 30 per cent. increase in the milk yield of dairy cows, about 10 per cent. increase in the rate of growth of lambs and about 10 per cent. increase in the fleece weight of sheep. In addition, the general condition of all classes of stock was greatly improved, calves were healthier, and the animals stood up to drought better and gave relatively much more milk towards the end of the lactation

period. In the most deficient area fertilisers were applied and gave an increased yield of grass of 25 per cent. where common salt was used, and up to 400 per cent. where nitrogen and phosphates were employed. It was particularly significant that the pastures remained green during the drought for a longer period, and analysis showed that, when the rains began, the soil phosphates were more readily used by the young grass on the fertilised plots than on the control plots. A special study was made of a disease known as "Nakuruitis." The symptoms were found to be very similar to those of "bush-sickness" in New Zealand, which is due to lack of iron in the diet. Accordingly, cattle in the Nakuru area were fed with iron salts, and it was found that this supplement entirely prevented the appearance of the disease, whereas "controls" grazing with them showed advanced symptoms of "Nakuruitis." As a result of this, it is now becoming the practice to feed these salts to stock in the district, and where this is done the disease is eliminated. These results show clearly that minerals are often the limiting factor in milk and wool production. Other feeding and fertiliser experiments pointed to the need for a further study of diet in relation to production on pastures in Kenya. The Kenya Government has, therefore, equipped a farm at Naivasha. Two workers from the Rowett Institute have been seconded for three years to carry on experimental work, with the object of applying on a commercial scale the experimental results already obtained.

Australia.

In Australia research work is being conducted at the Waite Agricultural Research Institute at Adelaide, the main part of which has consisted of a study of the nutrition of sheep, with special reference to the influence of various dietary factors on wool quality. Fundamental research involving a great deal of highly technical chemical work has been done on the composition of wool. Following on chemical and botanical analyses of different pastures, on which sheep show marked differences in nutrition, feeding experiments are being carried out in which the pasture deficiencies are balanced up by salt licks. One of the main deficiencies is in phosphorus, and experiments are in progress to find the most suitable method of administering phosphorus-rich substances. An investigation has been carried out on the iodine content of thyroid glands of sheep. Differences exist in the size of the thyroid and in the percentage of iodine present. This

may give indication of whether or not there is an iodine deficiency in certain pastures. A study has been made of the extent to which deficiencies in soils affect the rate of loss of moisture in plants. Plants growing in phosphorus deficient soils lose more water by transpiration than similar plants in the same soil with phosphates added. This result is of great practical importance in connection with drought. If this can be confirmed in the field, it supplies a further and unexpected reason for improvement of pasture by mineral fertilisers. An interesting piece of work allied to the problem of minerals in pastures has been done on a disease "grey speck" in oats. It has been found that this disease, similar to a wheat disease reported in Denmark, is due to a deficiency of manganese, and can be prevented by the application of manganese salts.

New Zealand.

The main investigations in New Zealand, which are being carried out at the Cawthron Institute at Nelson and by the Department of Agriculture, relate to a study of the mineral content of New Zealand soils and pastures.

Work on "bush sickness" has been continued and extended and it has been shown that application to the soils of sulphate of iron, and iron plus superphosphate, prevents the disease and keeps animals in excellent condition. In another district, in which sheep did so badly that the land was regarded as being almost worthless, there was a calcium deficiency, and the application of lime to pastures has resulted in marked improvement in the condition of the sheep. Arrangements have been made to instal a portable plant for grinding the local limestone. Feeding experiments on the same lines as those in Scotland have been done with sheep. Experimental pellets containing all the nutrients likely to be deficient in calcium-poor pastures are being made by an Auckland firm to meet the growing demand and special machinery has been fitted up. At the Cawthron Institute a systematic investigation has been made on the effect of manurial treatment on the yield and mineral content of pastures in the Nelson area, and also on seasonal variation in the mineral content of pastures. There is, it appears, a marked seasonal variation, mineral content being highest in October (spring). This suggests

that the feeding value of pastures is much superior during spring and early summer. Lambs make the most rapid increase in weight up to the middle of January. Tests on the influence of top dressings on poor pastures have shown that the application of lime and basic slag result in an increase of up to 100 per cent. in the calcium content of treated pastures compared with untreated. Beneficial results have been obtained from experiments carried out to test the effect of licks of bone meal, supplying calcium and phosphorus, plus a protein supplement. Treatment of pastures with lime and basic slag has also proved beneficial to the stock.

Southern Rhodesia.

Two workers from Southern Rhodesia have been trained at the Rowett Institute and have now returned. Two farms have been taken over, and preliminary observations have been completed. These show that the pasture deficiencies are much the same as those in parts of South Africa and Kenya. Experiments are in progress to test the effect of different fertilisers on the bulk and nutritive value of pastures. Further tests are being planned to find the effect of feeding minerals found to be deficient direct to stock.

A feature of this Empire-wide scheme of work is the interchange and training of workers from overseas. The first definite exchange resulting from the recommendations of the Imperial Agricultural Research Conference was made between a worker on iodine deficiency from the Rowett Institute and a member of the New Zealand Department of Agriculture staff who is studying the place of copper in animal nutrition. This exchange was arranged for two years. The Chief Agricultural Chemist of Southern Rhodesia was previously a member of the Rowett Research Institute staff, and, as indicated above, two Southern Rhodesian workers have recently studied methods of technique at the Institute. Other workers from Scotland are now stationed in Australia, Nigeria, and the Falkland Islands, whilst workers from New Zealand, Palestine, the Federated Malay States, India, and elsewhere have visited Aberdeen for varying periods to study methods and theories pursued there. Dr. J. B. Orr, Director of the Rowett Research Institute, has himself visited Canada, Australia, New Zealand, Kenya and Palestine.

Investigations upon the Physiology of Reproduction and Growth of Farm Animals.

Grant : *School of Agriculture, Cambridge.* £5,000 capital, £400 p.a. for 5 years and £500 guarantee.

(The capital grant of £5,000 is subject to £11,000 being contributed from other sources.)

In August, 1927, the Board made grants as shown above to the Faculty of Agriculture of the University of Cambridge in aid of (1) the work of Dr. Marshall and Mr. Hammond on the physiology of reproduction and growth of farm animals ; (2) the publication of Mr. Hammond's monograph on the growth of sheep ; and (3) the provision of facilities for studying the metabolism of pigmented animals.

The first grant is to enable all the animals to be concentrated at Howe Hill farmstead which will be devoted entirely to the investigation of problems of the physiology of reproduction and other functions of farm animals and will become in effect the nucleus of a central institute for research in animal physiology. Experiments are being conducted on the physiology of the spermatozoon of the rabbit. The practical objective of this research is the maintenance of the fertilizing capacity of semen outside the body for a sufficient time to enable the semen of valuable sires to be transmitted to a distance. Rabbit semen has been kept up to six days, but further research, which is now in progress, is necessary to enable the method to be applied to the larger domesticated animals. Experiments on the oestrous cycle of the mare and on the physiology of reproduction in the rabbit are also being carried out.

The publication of Mr. Hammond's monograph on the growth of sheep is a matter of interest to all concerned in the investigation of sheep problems and arrangements have now been made for 500 copies to be published. The monograph embodies the results of Mr. Hammond's exhaustive study of the literature, and the results of his own observations and of his extensive investigations into the phenomena of growth in sheep of various breeds.

Grass and Fodder Crop Conservation.

Grant : *School of Agriculture, Cambridge.* £200 capital.

A grant to the Animal Nutrition Research Institute of the School of Agriculture, Cambridge University, was approved in 1928 to enable a full sized silo to be erected on the University Farm, for trials of the economic value of silage made from grass.

Stock Rearing Experiments in Palestine.

Grant : *Zionist Organisation.* £4,900 spread over 3 years.

(Similar sum being provided by Zionist Organisation.)

This grant enabled a scheme of experiments to be carried out in Palestine to test whether recently acquired knowledge in nutrition and management of farm stock could be applied under the conditions prevailing in Palestine. The results obtained show that, so far as feeding is concerned, calves can be reared as cheaply in Palestine as in Britain. The lines of investigation opened up in these preliminary tests are being continued and extended to include tests on similar lines with milk cows and beef cattle. Feeding tests are also being carried out with different local breeds to determine how they will respond to similar methods of feeding.

Good progress is being made with these investigations and an income of some £100 per month is accruing from the sale of milk produced on the farm.

Milk Yield, etc., of cows crossbred from the Indian Zebu : Visit of Mr. John Hammond to Trinidad and Jamaica.

Grant : *School of Agriculture, Cambridge.* £250.

This grant was made to enable Mr. John Hammond of the Cambridge University School of Agriculture to visit Trinidad and Jamaica for the purpose of investigating the inheritance of milk yield, fat percentage and other characters of cows crossbred from the Indian Zebu. The results of this investigation are likely to be of considerable interest to many Empire countries.

ANIMAL BREEDING.

*Animal Breeding Research Department, University of Edinburgh :
Chair of Genetics.*

Grant : *University of Edinburgh.* £10,250.

(Contributions from other sources in aid of the scheme, which included buildings and equipment, amounted to a total of £60,000.)

The Empire Marketing Board were satisfied, from the reports which they received, that the establishment of a Chair of Genetics and an Animal Breeding Research Department at the University of

Edinburgh was likely to prove of benefit to the Empire livestock industry and they accordingly approved in April, 1927, a grant in aid of an endowment fund for the provision of maintenance expenditure in connection with the establishment of the Chair of Genetics.

Professor F. A. E. Crew was appointed to the Chair and a number of different aspects of animal breeding are engaging the attention of the Department. One of the staff is making a special study of the part inbreeding has played in the building up of modern breeds of cattle, in particular the Shorthorn (beef type) and the Jersey. It has been found that whereas Shorthorn prize-winners are slightly more inbred than average animals, the amount of inbreeding in the Jersey breed has been comparatively small. This has led to a particular investigation of the inheritance of milk yield. From a study of the records of pedigree Ayrshires it has been deduced that factors governing milk inheritance are sex-linked; capacity for heavy milk yield is, therefore, passed from father to daughter but not from father to son. If these results, which have been worked out statistically with the assistance of the Rothamsted statistical department, can be established experimentally, they will lead to a revision of existing ideas on pedigree breeding.

The pig-testing scheme, started in 1928, has proved an unqualified success. This is modelled on the scheme which has played so large a part in improving the standard of pig production in Denmark and elsewhere. Four average pigs are bought from the farmers co-operating and fed on standard rations. After slaughter a report is furnished to the breeder and the pigs are classified according to prolificacy, economy of liveweight gain, and quality of carcass. As a result several strains which mature earlier have been detected. Other experiments are directed to find the ideal type of bacon pig, and certain crosses are being exactly compared with this object in view.

A study has been made on the genetics of the Clydesdale horse and the evolution of the breed. A monograph on the genetics of the horse is to be published shortly.

In the Gold Coast there is a herd of humpless cattle (the indigenous African beast is humped) living in the heart of the tsetse-fly area and apparently quite immune to trypanosomiasis. Recent work indicates that disease-resistance is correlated with blood composition, and it is proposed to make blood tests on these cattle, by means of

a special technique, evolved in Poland, in order to compare their blood composition with susceptible animals. Two of these Gold Coast cattle are being brought to Edinburgh.

Work of great fundamental significance to fertility problems of all mammals is proceeding on the secretions of the endocrine glands and their influence on the ovarian function. Dr. Weisner has recently succeeded in isolating two new hormones, secreted by the anterior pituitary gland, which play an important part in the regulation of ovulation, "heat" and lactation. This work, which is of a highly technical nature, should lead to a better understanding of the whole question of fertility in animals and its implications in practical animal breeding. Professor Crew and his assistants are keeping in close touch with Professor Collip at McGill University in Canada, who is working along the same lines and is now isolating certain of these hormones and employing them in the treatment of certain diseases.

Other investigations are also in progress on rabbit breeding and wool production, the genetics of the fowl, tumour growth, contagious abortion, and the sex physiology of fowls with special reference to the influence of testis and ovary grafts on the secondary sex characteristics, and the secretions of the fowl's endocrine glands.

A small grant has been made to establish at the Animal Breeding Research Department a museum for the preservation of books, documents, illustrations and other material of historical and scientific value to animal breeding. The museum will be particularly valuable to post-graduate workers from oversea countries of the Empire who are attracted to the Department and the facilities available will be at the service of all accredited agricultural workers throughout the Empire.

ANIMAL HEALTH.

Onderstepoort Veterinary Research Station, South Africa.

Grant: £10,000 capital and £11,000 p.a. for 5 years.

Last year's Annual Report referred to the scheme for the development of the Onderstepoort Veterinary Station in South Africa in accordance with the recommendation made by the Imperial Agricultural Research Conference of 1927.

Agreement has now been reached with the Union Government authorities as to the subjects most urgently requiring investigation. These relate to virus diseases ; deficiencies in nutrition ; methods of controlling ecto-parasites ; tse-tse fly control and eradication ; toxic principles of poisonous plants as they effect stock animals ; and East Coast Fever. Three further research workers will be required at Onderstepoort to carry out the extended scheme of research and the Union Government have agreed that these appointments should take the form of Research Fellowships to be established by the Board. The selection and nomination of candidates will be entrusted to a special Selection Committee in London consisting of the President of the Royal Society, the High Commissioner for the Union of South Africa, the Chariman of the Research Grants Committee of the Empire Marketing Board, and the Director of the Imperial Bureau of Animal Health.

Investigations into the Use of B.C.G. Vaccine in the Protection of Calves against Tuberculosis.

Grant : *Department of Animal Pathology, University of Cambridge.*
£3,000 capital.

Preliminary investigations carried out on behalf of the Medical Research Council and the Department of Animal Pathology, Cambridge, indicated that B.C.G. vaccine, when suitably administered, would produce a very high degree of immunity in calves as evidenced by their surviving the test dose.

It was represented to the Empire Marketing Board that the accommodation at the Department of Animal Pathology of the University of Cambridge, where these preliminary experiments had been carried out, was inadequate for the continuation of the work along more extensive lines and the Board, in 1928, made a grant to provide additional accommodation. The additional buildings are now ready for occupation. At present a test is being made on twenty calves immunised by this method and it is anticipated that the result will definitely establish its efficacy. It will then be necessary to determine the duration of the immunity thus set up and the fate of the organisms employed in vaccinating, as well as the fate of virulent organisms which may gain entrance to the bodies of vaccinated animals.

In addition to the work on this subject at Cambridge, investigations are being conducted at the Pathological Laboratory of the English Ministry of Agriculture at Weybridge. The respective lines of investigation at each centre are being vigorously pursued and close touch is being maintained between the workers. The investigation gives prospect of benefit both to the stock-raising and dairying industries and to human health, and may be regarded as having importance for practically all parts of the Empire.

Provision of Additional Laboratory Accommodation at the Department of Animal Pathology, University of Cambridge.

Grant : £4,250.

(Similar sum provided by Development Commission.)

The Board, in March, 1930, approved a grant to meet half the cost of the provision of additional laboratory accommodation at the Field Station of the Department of Animal Pathology, University of Cambridge.

The organisation of the Department has been gradually elaborated with a view to developing facilities for team work. The Department's limited income does not allow of a staff sufficient to provide representatives of each branch of science for the formation of such a team, but conditions at Cambridge make it possible to secure the support of collaborators.

The Department is frequently called upon to give lectures and demonstrations to agriculturists, poultry keepers and others. Where the use of living or dead animals is entailed, these can only be given at the Field Station, and at present there is no room suitable for this purpose. The increased accommodation now to be provided will, in addition to overcoming this difficulty, provide adequate facilities for oversea workers who desire to visit and study at the laboratory.

Research in Metazoan Immunity.

Grant : *Liverpool School of Tropical Medicine.* £3,000 p.a. for 3 years.

(Similar sum being provided by Liverpool School of Tropical Medicine.)

This grant was made in 1927 to the Liverpool School of Tropical Medicine to enable an investigation into the nature and general

principles of metazoan immunity to be carried out at their West African Laboratory in Sierra Leone. The most recent experiments have been designed to ascertain the nature of enzymes present in *Cordylobia* larvae, to test their potency, and to produce antibodies by injection of them. Injections of emulsions of entire larvae and of antigens prepared from various parts of them (e.g., skin, glands, intestine) have resulted in immunity in a few instances. When immunity is successfully produced, it is found that death of an invading larva in the immune animal is closely associated with reaction between the gut-contents of the larva and the serum of the immune animal.

Bacteriological investigations have also been made to determine the degree to which the larvae are themselves infected by bacteria, both on the surface and within the intestine.

EXPORT OF PEDIGREE LIVESTOCK.

" Assisted Passages " Scheme.

Grants : *Australia.* £5,000 p.a. for 2 years.

Southern Rhodesia. £2,280, £2,000 and £1,200 in each of 3 years.

Northern Rhodesia. £600 for 1 year.

Kenya. £3,000, £1,500 and £1,500 in each of 3 years.

(In each case amounts equal to the Board's contributions are provided by the Governments concerned and in the case of Australia equal amounts, namely £5,000 p.a., are provided both by the Commonwealth Government and, in equal proportions, by the State Government concerned and the importer.)

Schemes for the export of pedigree livestock from the United Kingdom are now operating in the case of Australia, Southern and Northern Rhodesia and Kenya with the aid of grants from the Empire Marketing Fund. A grant has also been promised to the Government of British Columbia, but the details of the scheme are still under consideration by that Government.

The table on page 37 gives the number and types of animals which have been exported under these schemes.

CATTLE.	Australia.	Kenya.	Northern Rhodesia.	Southern Rhodesia.	PIGS.	Australia.	Kenya.	Northern Rhodesia.	Southern Rhodesia.
Aberdeen Angus :					Berkshire :				
Bulls	4	2	—	3	Boars	6	5	—	—
Heifers	20	—	—	—	Gilts	—	4	—	—
Ayrshire :					Sows	8	—	—	—
Bulls	—	24	—	9	Large Black :				
Heifers	—	15	—	22	Boars	—	2	—	2
Blue Albion :					Gilts	—	1	—	3
Bulls	—	2	—	—	Sows	2	—	—	—
Dairy Shorthorn :					Large White :				
Bulls	—	15	—	—	Boars	4	—	—	—
Heifers	—	11	—	—	Gilts	—	—	—	5
Friesland :					Sows	4	—	—	—
Bulls	—	11	—	—	Middle White :				
Galloway :					Boars	1	—	—	—
Unclassified	—	4	—	—	Sows	2	—	—	—
Guernsey :					Tamworth :				
Bulls	4	—	—	—	Boars	3	—	—	—
Heifers	14	—	—	—	Gilts	—	1	—	—
Hereford :					Sows	4	2	—	—
Bulls	8	—	4	4	Unclassified :				
Heifers	4	—	—	2	Boars	—	4	—	—
Jersey :					Sows	—	5	—	—
Bulls	4	2	—	1		34	24	—	10
Heifers	23	2	—	10					
Lincoln Red :					SHEEP.				
Bulls	—	1	—	3	Border Leicester :				
Red Poll :					Ewes	6	—	—	—
Bulls	1	16	—	10	Rams	4	—	—	—
Heifers	4	3	—	34	Cheviot :				
Scotch Shorthorn :					Ewes	—	2	—	—
Bulls	—	1	—	—	Dorset Horn :				
Shorthorn :					Ewes	3	18	—	—
Bulls	8	4	6	20	Rams	2	2	—	—
Heifers	7	—	7	14	Romney :				
South Devon :					Ewes	—	1	—	—
Bulls	4	—	—	3	Rams	—	7	—	—
Sussex :					Southdown :				
Bulls	—	—	—	7	Ewes	66	—	—	—
Heifers	—	—	—	2	Rams	8	—	—	—
Welsh Black :					Suffolk :				
Bulls	—	2	—	—	Ewes	2	—	—	—
Unclassified	—	2	3	—	Rams	1	2	—	2
	105	117	20	144		92	32	—	2

London Quarantine Station.

Grant : £7,750 capital and £3,250 p.a. for 5 years.

The London Quarantine Station is continuing to prove of great assistance in facilitating export of British stock to Empire countries at times when export would otherwise be suspended owing to outbreaks of foot-and-mouth disease. Since its opening on the 4th April, 1928, 1,051 animals have passed through the station.

ENTOMOLOGY.

Breeding of Beneficial Parasites.

Grant : *Parasite Laboratory, Farnham Royal, England.* £15,000 capital and £30,000 spread over 5 years.

The laboratory was established by the Imperial Bureau of Entomology in 1927 by means of a grant from the Empire Marketing Fund. The principal object of the laboratory is the furtherance of the control of insect pests of agriculture and forestry by biological methods.

The response of the Dominion and Colonial Entomologists has amply proved that the creation of the Laboratory met a real need in Imperial entomology. Requests for assistance were received even before the Laboratory had been opened for work, and since that time the list of injurious insects and plants it has been asked to investigate in the hope of finding parasites and predators, which can be utilised in their control, has rapidly increased until it now comprises about sixty species.

Investigations suggested by the Canadian Government are now proceeding on the parasites of the Pear Slug, the Codling Moth, the Wheat Stem Sawfly, the Oriental Peach Moth, the Carrot Rust Fly, the Larch Case Bearer, the Pine Tortrix, and the Beech Coccus, and in practically every case a great deal of valuable information concerning the natural enemies of these species has already been obtained. A total of fourteen shipments of parasites of the Earwig, the White Fly, the Hawthorn Scale, and the Pine Shoot Moth, including a total of over 53,000 parasites or parasitised individuals have been made up to the present time, and shipments of the parasites of the Wheat Stem Sawfly will be made early in this year.

All of the shipments have been successful and have provided a considerable number of parasites for liberation. Two of the parasites of the Pine Shoot Moth were recovered in the following year after their liberation and can now be regarded as established.

During the past two years accommodation has been provided at the Laboratory for three entomologists of the Commonwealth Entomological Service of Australia, who are working under the supervision of the Superintendent on three major Australian problems. Four shipments, comprising in all about 10,800 puparia of the Sheep Blowfly and cocoons of the Pear Slug, both of which contained parasites, were shipped to the Entomologist for New South Wales in 1927 and 1928. Parasites were successfully reared from both these lots of material and those from the Blowfly have since been used for large scale breeding work in New South Wales. A shipment of 500 specimens of the Sheep Blowfly parasite (*Alysia manducator*), were sent to Western Australia late in 1927.

The Government Entomologist for South Africa requested parasites of the Sheep Blowfly, and a consignment comprising 800 individuals was sent to him in November, 1928. He has successfully reared a large number of individuals of the parasite.

Fifteen shipments, comprising a total of about 23,800 specimens of the Sheep Blowfly, the Earwig, the Pear Slug, the Wood Wasps, Wood Lice, and their parasites have been despatched to New Zealand. The parasite of the Blowfly sent out is now being reared on a large scale. The parasites of the Earwig and the Wood Wasps were both reared successfully and distributed in the field.

A consignment of *Vedalia* ladybirds was obtained from California and trans-shipped in April to the Madras Presidency for use against a citrus fruit pest. Enough material to start breeding operations was obtained from the shipment and colonies of the ladybird have been liberated in infested areas. At the request of the Deputy Director of Gardens, Saharanpur, United Provinces, India, a small consignment of *Aphelinus mali*, the parasite of the Woolly Aphis, was shipped to him in 1928. Two consignments of this parasite were shipped to Kenya Colony in 1927. At the request of the Government Entomologist of Barbados, a consignment of an important parasite of the Pink Bollworm was obtained for him from the Sudan, and sent to Barbados in April, 1929. A number of living parasites were obtained from this shipment. A lot of 300 specimens of *Alysia manducator*,

the Blowfly parasite, was shipped to the Falkland Islands in 1927, for use against the Blue-bottle Fly, and sufficient material was obtained from this shipment to start breeding work on a fairly large scale in the Islands.

Eight lots of *Aphelinus mali*, the parasite of the Woolly Aphis, have been sent to various points in England, and one consignment of the parasite of the White fly, a colony of which is established in the Laboratory's greenhouses, was sent out. (See page 45.)

In all, up to the present date, a total of about 58 shipments, comprising in all about 100,000 specimens of parasites or insects for rearing parasites, have been shipped from the Laboratory to various parts of the Empire. The great majority of the shipments have been successfully completed.

Work on the entomological control of noxious weeds, undertaken in Europe on behalf of the New Zealand Government, was centralised at Farnham Royal on April 1st, 1929. (See page 44.)

In addition to the practical work and the scientific investigations a number of problems of fundamental interest are being studied at the Laboratory.

Biological Control of Insect Pests in the West Indies.

Grant : *Imperial Bureau of Entomology.* £2,000 p.a. for 3 years.

Following a resolution passed by the Imperial Agricultural Research Conference in 1927 that work on the biological control of insect pests should be extended to tropical insects, the Board approved a grant to the Imperial Bureau of Entomology to enable Dr. J. G. Myers to visit the West Indies and parts of South American to investigate the biological control of insect pests in those countries. Dr. Myers has made his headquarters at the Imperial College of Tropical Agriculture in Trinidad and has visited the Leeward Islands, British and Dutch Guiana, Jamaica, Barbados, Haiti, Surinam and Cuba.

Many thousands of insect pests have been dissected or reared in captivity in order to ascertain what parasites were already present in each country and the percentage of parasitism.

Campaign against Desert Locust.

Grant : *Imperial Bureau of Entomology.* £500.

This grant, approved during the past year on the recommendation of the Locust Sub-Committee of the Committee of Civil Research, is to enable the Imperial Bureau of Entomology to undertake the collection and collation of information from all possible sources regarding the Desert Locust.

Considerable loss is caused to various tropical territories of the Empire by recurrent outbreaks of the Desert Locust, and it is proposed to disseminate the information collected to all interested territories as a preliminary measure pending the preparation of a definite scheme of sustained anti-locust research.

Insect Nutrition.

Grants : (a) *London School of Hygiene and Tropical Medicine.*
£1,500 spread over 3 years.

This grant, made on the recommendation of the Dietetics Sub-Committee of the Committee of Civil Research, is to enable the London School of Hygiene and Tropical Medicine to conduct research work on the digestion of meat by the larvae of flies and on the part played by micro-organisms in the nutrition of the larvae. The economic loss due to the "blowing" of butchers' meat by flies is, in the aggregate, very serious, as is also the widespread infestation of living sheep by maggots in sheep rearing countries, notably Australia.

(b) *Hebrew University, Jerusalem.* £75 Capital and £227 10s. 0d.
p.a. for 3 years.

The Board, in March, 1930, approved a grant to the Hebrew University, Jerusalem, to enable the University's Zoological Laboratory to undertake a preliminary survey of the problems of insect nutrition. The Dietetics Sub-Committee of the Committee of Civil Research, which recommended the proposal to the Board, consider that the proposed work will throw valuable light on the directions in which fundamental investigations of great value might later be directed. Very little is at present known of the physiology of insects and work in this field might, in the opinion of the Sub-Committee, prove of far-reaching importance alike to agriculture and medicine.

Stored Products Research.

Grant : *Imperial College of Science and Technology.* £10,775 capital and £15,936 spread over 5 years.

(A sum of £300 towards the cost of the Rhodesian Tobacco enquiry referred to below has been promised from Southern Rhodesian sources.)

A crop which escapes destruction by one of the numerous field pests still has to face possible infestation in ships, docks, wharves, warehouses, and even in the factory to which it is finally consigned. A study of the various insects which attack food in these stages is the function of the newly equipped biological field station at Slough which the Imperial College of Science and Technology has established with a grant from the Empire Marketing Fund.

This station is now tackling on a long-range basis the general question of infestation which involves three things. The first is a survey, such as that on cacao pests recently completed and published by the Empire Marketing Board,* to find out which problems are the most serious and which insects the most active. The second is biological research on the life-histories of the insects concerned. The third is a comparative study of practical control measures, culminating in advice to shippers, wharfingers, manufacturers, etc., on how to eliminate insect pests.

Campaign against Warble Fly.

Grant : *Leathersellers' Company of London.* £1,000.

(Similar sum promised by various interests represented on the Warble Fly Committee of the Leathersellers' Company.)

Serious loss is caused in various parts of the Empire by the damage done to the hides, meat and milk of cattle through the ravages of the Warble Fly. The Leathersellers' Company are undertaking a campaign in England by means of controlled experiments and educational propaganda. They have formed a Committee representative of British agricultural interests, butchers, dairymen, hide organisations, tanners and leather-users, and workers' organisations

* "Report on Insect Infestation of Stored Cacao," by J. W. Munro and W. S. Thomson. E.M.B. 24.

to co-ordinate the efforts of all those working on the problem and to extend existing work. This Committee has made definite recommendations with regard to the treatment of cattle, and the ultimate object is to establish that treatment against the Warble Fly should be generally adopted throughout the country. If, as a result of concerted effort, success is achieved in this country, the experience obtained would be available for application in countries such as Canada, India and Ireland where considerable losses are caused by the Warble Fly.

Identification and Accommodation of Entomological Specimens.

Grant: *Natural History Museum, London.* £30,000 capital.

The increased activity in the entomological field has brought with it a corresponding increase in the numbers of specimens which are sent to the Natural History Museum for identification and accommodation and has resulted in growing congestion. The much needed additional accommodation which is now being provided by means of the grant made by the Board in 1927 will make possible the proper housing of the Museum's entomological collection and library.

Establishment of Entomological Research Organisation in Australia.

Grant: *Commonwealth Council for Scientific and Industrial Research.* £25,000 capital and £39,052 spread over 5 years.

(The Commonwealth Government are providing a capital sum of £25,000 and maintenance expenditure amounting to £57,673 spread over 5 years.)

The Board's last Annual Report notified the grant for assisting the establishment and maintenance of an entomological division based on Canberra. During the past two years accommodation has been provided at the Parasite Laboratory in England for three entomologists of the Commonwealth Entomological Service who are working under the supervision of the Superintendent on three major Australian problems. One worker is studying the Blowfly problem, another the insects attacking St. John's Wort, and the third worker is studying the method of mass breeding as applied to the egg parasite of the Codling Moth.

Control of Noxious Weeds.

Grant: *Cawthron Institute, New Zealand.* £1,333 capital and £2,000 p.a. for 5 years.

(In addition the Cawthron Institute is providing £200 capital and £2,000 p.a. for 5 years, and the New Zealand Government £667 capital and £2,000 p.a. for 5 years.)

Work on the entomological control of noxious weeds, undertaken in Europe on behalf of the New Zealand Government, was centralised at the Parasite Laboratory in England in April, 1929. This comprises the study of the biological control of Gorse, Blackberry, Ragwort and other injurious plants with a special view to the discovery of phytophagous insects likely to be of use in controlling these weeds in New Zealand. In all, fourteen shipments of the insects attacking noxious weeds comprising a total of 154,000 specimens had been sent at the time of preparing this Report.

Tsetse Fly Control.

Grant: *Government of Tanganyika Territory.* £2,000 p.a. for 5 years.

(Substantial expenditure will continue to be borne by the Government of the Tanganyika Territory.)

This grant, approved in 1928 on the recommendation of the Tsetse Fly Sub-Committee of the Committee of Civil Research, takes the form of a contribution towards the cost of the Tsetse fly research and reclamation being carried out in the Tanganyika Territory. New methods of Tsetse fly control and reclamation have been tried, and the Territory has in the past made a material contribution, both in money expended and scientific work achieved, to the campaign against Tsetse fly. In the areas affected the health of the people and the existence of the cattle are alike dependent on the success of anti-Tsetse fly measures, and the work in Tanganyika has economic importance not only for that territory but for other British territories in Africa.

Control of Pests and Diseases of Glasshouse Produce.

Grant : *Cheshunt Experimental and Research Station, England.*
£1,600 capital and £1,760 p.a. for 5 years.

Early in 1927 the Board approved a grant to the Experimental and Research Station, Cheshunt, for investigations into the control of the Red Spider and other mites ; the distribution of a Chalcid parasite of White Fly ; investigations into the control of Cladosporium; and into the control of Mosaic disease by means of seed selection. The White Fly is a serious pest of tomatoes and other plants grown under glass. A very important Chalcid parasite was first noticed in the spring of 1926 which subjected the White Fly on cucumbers and tomatoes to complete control. A colony of the parasite has been successfully reared at Cheshunt and distribution of the parasites has been singularly effective during the past year. Over 1,000 applications for the parasite have recently been received and it is estimated that at least 2,000 consignments will have been distributed from February to June of the present year.

MYCOLOGY AND PLANT PATHOLOGY.

Erection of New Building for the Imperial Bureau of Mycology.

Grant : £8,000.
(£4,000 provided by Imperial Bureau of Mycology.)

The work of erecting a new building to house the Imperial Bureau of Mycology upon a site which will enable it to retain close connection with the Royal Botanic Gardens at Kew is proceeding satisfactorily.

Investigation of Dry Rot Disease of Swedes and Turnips.

Grant : *Ministry of Agriculture and Fisheries.* £1,320 spread over 3 years.

Dry Rot Disease of swedes is an important problem in New Zealand, and extensive investigations have confirmed the earlier discovery that infection can be carried in the seed. As much of this seed is imported from the British Isles, studies have been carried out in

England and the Irish Free State, as well as in New Zealand, which confirm the belief that seed infection does occur. Under New Zealand conditions it is held that the fractional percentage of seed infection present is sufficient to contaminate the bulk of the crop during the growing period, but in England this is regarded as of minor importance as compared with other methods of infection. Attempts to find a satisfactory method of seed disinfection are being continued.

Study of Fungal Wastage of Fresh Fruits exported from Palestine.

Grant : *Zionist Organisation.* £1,520 spread over 3 years.

(£170 to be provided by Government of Palestine.)

At the Zionist Executive Experiment Station, Tel Aviv, Palestine, an investigation is being conducted on the fungal wastage of fresh fruits intended for export. Two reports have so far been submitted from which it appears that the main damage to citrus fruits is caused by the *Diplodia* rot and the blue-green moulds due to *Penicillium*. Other, and less frequent, rots are due to *Colletotrichum gloeosporioides*, *Alternaria citri*, and *Oospora citri-aurantii*, all of which are known as citrus rotting organisms in other countries. The *Diplodia natalensis* rot develops during storage and transit on fruit which is apparently sound when picked but is actually either contaminated with spores or already in the incipient stages of infection. Experience in other countries has shown that the wastage from this disease can be reduced by 50 per cent. or more by orchard sanitation and pruning and it is, therefore, proposed to extend the experimental work in this direction during the current year. For the blue-green moulds orchard treatment is of no avail, but successful control has been secured in the United States by dipping the fruit in borax. As the use of borax is not permissible on fruit intended for introduction into England, experiments on other chemical treatments (of which sodium bicarbonate has already given good results in the United States) will be extended in the current season. If these two sources of decay can be considerably reduced, a great improvement in the condition of the Palestine shipments will be effected.

Other work includes studies of the fruit rots of bananas and grapes.

Virus Diseases of Plants.

- Grants : (i) *Rothamsted Experimental Station.* £1,835 capital and £12,800 spread over 5 years.
(ii) *Cheshunt Experimental and Research Station.* £1,040 capital and £6,350 spread over 5 years.
(iii) *Scottish Society for Research in Plant Breeding.* £4,450 capital and £8,000 spread over 5 years.
(iv) *University College, Dublin.* £3,250 capital and £5,500 spread over 5 years.

During recent years the importance of virus diseases of plants has increasingly been recognised, but in spite of a considerable amount of research, carried out in various countries, the fundamental nature and properties of plant viruses are still to a very large extent unknown. At the Imperial Agricultural Research Conference of 1927 a recommendation was adopted that :—“ In view of the urgency of the problem no time should be lost in the provision of funds for the more extended study of the fundamental nature of virus diseases in plants.”

Schemes for extending the work on the fundamental nature of plant viruses at Rothamsted Experimental Station and at the Experimental and Research Station at Cheshunt have been approved by the Empire Marketing Board. At the former station a particular study has been made of “intra-cellular inclusions,” small bodies visible in the cells of hairs of diseased plants, which are believed to be part of the plant's response to virus infection. Under the Board's grant insect-proof houses have been built and an Entomologist is studying the transmission of infection by insects. Potato and tomato virus diseases, for instance, are carried by aphids. A scheme of research dealing with the genetical aspects of potato virus diseases, submitted by the Scottish Society for Research in Plant Breeding, has also been approved. The Board has also provided assistance to the University College, Dublin, for the extension of investigations on virus diseases of the potato, and a technique has been worked out which should provide a much more certain means of determining the presence or absence of virus infection in the potato, and probably of distinguishing one disease from another, than at present exists. This should prove of great importance in the practical diagnosis of diseases and in the inspection of potato crops for pure seed purposes.

Cotton Disease Research.

Grant : *Rothamsted Experimental Station.* £600 capital and £200 p.a. for 4 years.

The subject of this investigation is the "Black Arm" or "angular leaf spot" disease of cotton with special reference to its relation to soil and air temperatures, atmospheric humidity and other environmental factors. The organism causing the disease, *Bacterium Malvacearum*, is being studied, and several strains, some of which attack the cotton plant, some of which are innocuous and some of which appear to be intermediate, have been isolated. Six tanks in which plants are grown under controlled environmental conditions were completed in February, 1929, and it is now proposed to repeat and confirm the experiments already carried out and to follow up a number of promising lines of research. The results are likely to be of value to the Sudan, Nigeria and Uganda and co-operation with the authorities in these countries is being maintained.

PLANT BREEDING.

Prosecution and Co-ordination of Research in Grasses and Clovers.

Grant : *Welsh Plant Breeding Station, Aberystwyth.* £4,350 capital and £23,375 spread over 5 years.

The main object of this station's work is to produce high-yielding, persistent, and leafy strains of certain grasses and clovers. These will, it is hoped, both increase the yield of pastures and of hay and prolong the grazing season, especially in regions of low natural fertility.

A number of such strains have now been established by means of the selection of ecotypes from a collection of grasses obtained from all over the world, and careful breeding during the past ten years. The time has now come when these are to be "grown-on" under contract in various parts of the country in order to obtain seed in sufficient bulk for eventual distribution to farmers, and to compare on a practical scale the behaviour of the pedigree strains with that of ordinary commercial grasses. This summer will see the first harvest from "growing-on" areas. A special thresher has been installed on a lorry, with engine attached, to tour these areas and to thresh the pedigree grasses. Samples of seed of the established strains have been despatched to Canada, Australia, New Zealand and Natal for tests.

During the year twenty-five greenhouses have been erected in the Station's farm under the Empire Marketing Board's grant, in which both grasses and clovers are bred, and a considerable bulk of seed obtained, with practically no danger of contamination by pollen carried on the wind and by bees. This is of great importance in order to maintain absolutely pure strains at the Station as, under practical conditions, a certain amount of deterioration is inevitable.

Particular attention has been paid to cocksfoot, and extra-leafy strains both for grazing and for hay have been bred. Plot trials have shown that whereas the yield of commercial cocksfoot drops by about 50 per cent. in the third year after sowing (its place being filled by weeds), the pedigree strains maintain a constant yield, and a marked preference for them is shown by sheep. Perennial rye-grass and timothy have also reached the "growing-on" stage, and other families of wild white clover, broad and late-flowering red clover, meadow foxtail, red fescue, and smooth-stalked meadow grass are now being bred. Birdsfoot trefoils from New Zealand and hay grasses from Australia are also being studied.

Close co-operation is maintained with the new Plant Breeding Station at Palmerston North, New Zealand (see below). A senior member of the Aberystwyth staff was loaned to New Zealand for two years and is now working at the Palmerston North Station.

Plant Breeding and Seed Research in New Zealand.

Grant: *New Zealand Department of Scientific and Industrial Research.* £2,500 capital and £2,500 p.a. for 5 years.

(£9,500 capital and £5,670 p.a. for 5 years is being provided by the New Zealand Government.)

The New Zealand Government have established at the New Zealand Agricultural College at Palmerston North, with the aid of a grant made by the Board in 1927, a Plant Breeding and Seed Research Station where grassland problems are being studied. Research on the question of strain in the more important species is particularly promising. A beginning has been made in the selection of the most persistent strains from amongst the true perennials. This work is being planned on an extensive scale. There are approximately 1,000 lines of perennial rye-grass under test, and work of a similar nature

on cocksfoot, red clover and white clover is also in progress. It has been found that the perennial rye-grass grown and harvested for seed in the Dominion is very mixed and that the ordinary seed of commerce consists of either (1) true perennial, (2) pseudo-perennial, or (3) samples in which Italian rye-grass is dominant.

Attention is also being paid to the general problems of seed production of herbage species, such as the differences in germinating capacity which appear to exist between seed crops taken from different districts. Certain strains and species of grasses are receiving special attention in connection with control of weeds and secondary growth in areas of low fertility.

Manurial trials on grassland are being conducted at a number of centres. A technique is being used by which it is hoped to correlate pasture yield and botanical composition with animal production.

Investigations into the flowering period of gorse (*Ulex europaeus*) and Ragwort (*Senecio Jacobaea*) throughout the Dominion should have an important bearing upon the control of these plants by appropriate insects. This side of the work is being undertaken by the Cawthron Institute. (See page 44.)

In the Agronomy Section the programme is the production of pure lines of superior seed to replace those now in cultivation. Extensive yield trials have been carried out in the Wheat Section on the progeny of a selected number of single plants. Pure smut-free seed of a number of varieties has been issued to the Canterbury Seed Company for multiplication and subsequent distribution. Similar measures are being taken to improve the strains of barley, peas, linseed, onions and potatoes. In the case of potatoes the object is to raise virus-free stocks.

The Mycological Section is endeavouring to provide disease-free strains of cereal and other crop seeds. This has already resulted in the elimination of smut from malting barley grown in the Canterbury district, and it is estimated that 11,000 acres are now smut-free. Considerable areas of wheat have also been freed from loose smut. Propaganda in favour of the use of copper carbonate against wheat bunt and of formalin against oat smut has resulted in a steady reduction in the losses caused by these diseases. Work on similar lines with other cereal diseases is in progress.

*Experiments with Plants of the Tidal Zone with special reference to
Spartina Townsendii.*

Grant : *East Anglian Institute of Agriculture, Essex.* £220.

The Rice Grass *Spartina Townsendii* is a plant probably of hybrid origin which, by its resistance to submersion in sea water, has proved valuable in binding coastal soils and preventing erosion. In addition the plant has the advantage of being a moderately good fodder crop. The grant made by the Board to the East Anglian Institute of Agriculture in 1928 has enabled a plantation of about 14 acres of this grass to be laid down at Hadleigh, near Southend. A second centre is being developed at Goldhanger, near Harwich, where the sea has recently broken through the sea wall and an area of land abandoned. *Spartina Townsendii* is under trial in New Zealand at the Plant Breeding Station referred to above, and it may well prove of value on the tidal mud flats of the North Island.

*Appointment of Plant Breeding Expert for Study of Empire Grassland
Problems.*

Grant : *Welsh Plant Breeding Station, Aberystwyth.* £3,850.

The Board have recently approved a proposal submitted to them by the Welsh Plant Breeding Station that a senior member of the staff of that Station (the officer referred to above as being at present on loan to New Zealand) should be made available for the study of grassland problems of the Empire. The expert will be available for conducting investigations in oversea countries of the Empire where grassland research is proceeding, but he will return at intervals to the home country for "refresher" courses in order to keep abreast of advances made in the United Kingdom. He will therefore become a liaison officer between the various Empire grassland centres and thus link up the work. The scheme will be tried for a limited period in the first instance starting from January, 1931.

HORTICULTURE.

Fruit Research and Standardisation of Horticultural Material.

Grants: *East Malling Research Station, Kent.* £9,050 capital and £27,300 spread over 5 years; and £13,200 capital and £8,100 spread over 3 years.

The team of workers added to the East Malling Staff two and a half years ago has greatly assisted the extension of the Station's programme. One important piece of work concerns the development and functioning of known root-systems of fruit trees, growing under different soil conditions. The root-systems of some 24 ten and eleven year old apple trees have been excavated in their entirety. The effect of various soil factors such as texture, aëration, moisture, etc., upon different varieties of rootstocks has been carefully studied, with a view to the selection of suitable root-systems for specific conditions. A preliminary report on this work was published in October 1928 (East Malling Res. Sta. Ann. Rep. 14th and 15th years, 1926-27, II Supplement).

Considerable progress has been made in the studies of stock scion relationships in other directions. Four new races of apple stocks, proved to be immune to Woolly Aphis, are now being multiplied in order to test their suitability as rootstocks in comparison with Northern Spy, which, under conditions prevailing at East Malling, has been shown to be an unsatisfactory root-system from many points of view. The "Double Ivory" stock of New Zealand has also remained immune to Woolly Aphis after a year's test.

A statistical summary of ten years' records of the field trial plots has made possible a much more comprehensive review of the apple rootstock position than ever before. The particular suitability—or the reverse—of particular rootstocks for individual scion varieties has been revealed; whilst the modifications of rootstock influence which can be brought about by special nutritional factors have been demonstrated. Special studies are being made of the fundamental principles underlying stock scion relationships.

Progress has been made with regard to knowledge of the transmission and spread of "Mosaic" disease in raspberries. It has been found possible to establish in the field stocks of disease-free canes of a number of varieties.

During the past year the Board has approved a further grant to provide for the extension of facilities for research at East Malling and for the provision of accommodation for the Imperial Bureau of Fruit Production which is established there. This allows, *inter alia*, for the accommodation of a maximum of four post-graduate workers from overseas.

The results obtained by this station have been followed by an increasing demand from growers and research workers for further extension of its work. The number of visitors from overseas during the past two years has increased considerably and the station is thus rapidly assuming an Imperial aspect.

Investigations into the keeping quality of fruit and its relation to the nutrition of the tree and soil conditions.

Grant: *Long Ashton Horticultural Research Station, Bristol.*
£7,025 capital and £12,975 spread over 5 years.

The grant made in 1927 to the Long Ashton Station is enabling a study to be undertaken of a number of factors influencing the growth of fruit trees, such as climatic factors (producing seasonal effects); soil; rootstocks; orchard practices, including cultural operations, systems of manuring, pruning methods, bark ringing, blossom and fruit thinning, time of picking; and the position of the fruit on the blossom truss. The main tests have been carried out on apples but samples of soft fruits, plums and pears have also been considered.

Certain tentative conclusions have been drawn from the results of these enquiries which show that the storage life of fruit can be materially affected by the treatment of the tree. The nitrogen content of fruit, for instance, can be increased by manuring with nitrogenous fertilisers, or decreased by replacing clean cultivation by a permanent overcropping system such as "grassing down"; and reduction of nitrogen content considerably prolongs the storage life of the fruit. Bark-ringing, again, appears to favour the development of Bitter Pit in ordinary temperature store; and potash starvation, while lengthening the life of fruits in ordinary temperature store, encourages premature breakdown in low temperature store.

Fruit Research Investigations in New Zealand.

Grant: *New Zealand Department of Scientific and Industrial Research.* £2,000 capital and £1,500 p.a. for 5 years.

(The New Zealand Government have promised to contribute £4,080 capital and £1,500 p.a. for 5 years and the New Zealand fruit industry £850 p.a. for 5 years.)

It has recently been decided in New Zealand to establish a Fruit research organisation to which the Department of Agriculture, the Department of Scientific and Industrial Research, the Cawthron Institute and representatives of the fruit growers have guaranteed their full support. This organisation, to which the Board has also given its support, will co-ordinate the whole of the research work on fruit at present being carried out in New Zealand, and the organisation will embrace investigations into cool storage and transport of fruit, disease and insect control, nutritive and physiological diseases and the development of rootstocks and propagation.

ECONOMIC BOTANY.

Visits of Economic Botanists to Dominions and Colonies and Employment of Botanical Collectors for Oversea Work.

Grant: *Royal Botanic Gardens, Kew.* £20,000 spread over 5 years.

During the past year a botanical collector from Kew has been working on the botany of the boundary between British and Italian Somaliland, another collector has been at work in the British Solomon Islands, while a third botanist has been exploring in British Guiana in connection with the proposal to compile a Flora of that Colony. The Economic Botanist has visited West Africa to attend the West African Agricultural Conference and to study agricultural problems there. The Keeper of the Herbarium has paid visits to Herbaria and Botanical Institutions in South and East Africa and another officer has returned from a collecting trip to South Africa and the Transvaal on which he set out in the previous year. In all these cases the Herbarium and the Gardens at Kew have been greatly enriched.

Classification of Herbarium Specimens.

Grant: *Royal Botanic Gardens, Kew.* £15,567 spread over 5 years.

The collections of herbarium specimens at Kew comprise Empire material of considerable economic interest and it is important, if the fullest use is to be made of them, that they should be accurately classified as soon as possible after they are received. The collections which had accumulated a few years ago have now practically all been "poisoned" and mounted by the extra staff appointed as a result of the grant made by the Board in 1927. There has, however, in the meantime, been a large influx of new collections owing to the interest stimulated by Kew officers who have visited various parts of the Empire. The Board have, therefore, during the past year continued their assistance to Kew for this important work of identification.

Expedition to Iraq and Persia to collect species of Prunus.

Grant: *John Innes Horticultural Institution.* £400.

(Similar sum provided by John Innes Horticultural Institution.)

This expedition was made in 1929 by Dr. J. M. Cowan of Kew and Dr. C. D. Darlington of the John Innes Horticultural Institution, Merton. The object was to obtain plants from districts on the western borders of Persia which had not hitherto been explored botanically. More particularly it was desired to obtain species of *Prunus* and *Tulipa* from this region, since there are grounds for supposing that the cultivated plums, etc., and the garden tulips originated somewhere in or near this area. The expedition travelled by way of Baghdad, Hamadan, Isfahan, Qum, Tehran, Tabriz to Lake Urmya, the main objective of the expedition, and thence home by way of the Russian experimental station at Sukhum, and Constantinople.

The expedition penetrated into two districts hitherto unexplored, but its work was hindered by repeated attacks of fever, etc., experienced by both members. A large amount of herbarium material, bulbs and seeds was sent home, and the latter are growing at Kew and Merton. As regards *Prunus* the finds were somewhat disappointing but contacts have been established with residents who have promised further seed.

Cuttings of the seedless pomegranate, hitherto unknown outside Persia, were safely transmitted to Kew, where they are now growing.

It will be some time before the results of the expedition can be worked up ; even the bulbs, having been collected in full growth, will flower this year in only a few cases.

Botanical Nomenclature.

Grant : *Ministry of Agriculture and Fisheries.* £100.

At the Imperial Botanical Conference, 1924, a Standing Committee was appointed to deal with the question of botanical nomenclature, and to formulate a series of proposals which could be placed before the International Botanical Congress to be held at Cambridge in 1930 as the official view of the botanists of the Empire.

The Standing Committee have now drawn up proposals representing the official view and the Board's grant has been made to meet the cost of printing these proposals.

DIETETICS.

Research on the Vitamin Content of Fruits, Vegetables and Dairy Products.

Grant : *Medical Research Council.* £24,000 spread over 5 years.

A general study is being made at the Lister Institute of the vitamin content of apples, dairy produce, honey, etc. With regard to apples, the investigation aimed at finding whether factors such as variety of apple, type of soil, age of tree, season, and length and conditions of storage, played a part in determining the Vitamin C content of the fruit. It has been found that only two of these factors, variety and storage, affect the quantity of vitamins present. Of the six English varieties tested (Bramley's Seedling, King Edward, Cox's Orange Pippin, Worcester Pearmain, Dabinett and Woodbine), Bramley's Seedling was found to contain a larger quantity of Vitamin C than the other varieties, and it was shown that the vitamin is not destroyed by cooking. The eating apples were lower in vitamin C than the cooking varieties. Length of storage appears to affect, to some extent, the vitamin content, and this is much more marked in the case of gas than of cold storage.

Results point to the conclusion that apples kept too long tend to lose their vitamin C potency. This work has been carried out in close co-operation with the Horticultural Research Station at Long Ashton and the Cambridge Low Temperature Research Station and the results of the inquiry is being published in a Monograph of the Medical Research Council.

Work has also been done on the vitamin content of Jaffa oranges, British Honduras grapefruit, South African orange juice, Australian sultanas, honey, and dairy produce. A study has been made of the effect of feeding cod liver oil to cows and extensive comparative tests on Australian, New Zealand, and home butters are being carried out.

Research into the Physiological and Pathological Conditions associated with certain Rationed and Specialised Diets, with special reference to Kenya native tribes.

Grant: Rowett Research Institute, Aberdeen. £3,000 p.a. for 3 years.

This special study, carried out as a pendant to the mineral content enquiry described above, has been made in co-operation with the Kenya Medical Service. The diet of the Masai tribe consists of meat, blood, and milk, whilst that of the Kikuyu tribe is mainly composed of cereals, tubers, legumes, etc., and practically no milk or meat is consumed. A survey of the two tribes was made to observe the effect of these diets on general health and physique. Results proved beyond dispute the great superiority in weight, stature, and fitness of the milk-nourished Masai to the cereal-eating Kikuyu. The Kikuyu men showed a state of health much on a par with that of the Masai women.

An interesting point was the marked physical superiority of the Kikuyu women to the men, and this was correlated with the greater amount of green leaves and edible earths consumed by the women. The Kikuyu diet as a whole is deficient in calcium and sodium, but the leaves, which are eaten mainly by women, are very high in these minerals. The calcium and sodium intake is therefore much larger in the women than in the men and this seems to have a direct bearing on their superior health.

Analyses were also made of diets in prisons and it was found that these were generally deficient in calcium. This element was added to the ration and a marked improvement in condition took place.

A study of the incidence of ulcers and blood content of ulcerous natives was made. It was found that about 33 per cent. of the Kikuyu suffered from ulcers, which were almost unknown among the Masai. Bronchitis was also much more common among the Kikuyu, but about 35 per cent. of the Masai appeared to suffer from arthritis as against 2 per cent. of the Kikuyu. It was found that the calcium content of the blood was higher in the case of natives with ulcers than of those without, and that the blood of ulcerous natives showed an exceptionally high phosphorus content. A detailed report of these results is to be published shortly.

Work on the nutrition of natives is now being continued and extended in West Africa by the Nigerian Medical Service, which was kept informed of the results obtained in Kenya.

FORESTRY AND FOREST PRODUCTS.

Imperial Forestry Institute, Oxford.

Grant : £4,750 p.a. for 2 years.

The Imperial Forestry Institute was established at Oxford in 1926 upon the recommendations of the Imperial Forestry Conferences of 1921 and 1923 for the higher training of Forest Officers, for the provision of special and "refresher" courses for officers already serving in the Empire overseas and for research into forest production. The needs of the Institute outran the contributions at present made by Empire Governments and the Board made a grant in 1929 to the Institute to enable it to carry on its work until consideration had been given to the proposal of the Imperial Forestry Conference of 1928 "that steps be taken forthwith to obtain from the Governments of the Empire such financial and other support as will place the Institute on a permanent footing and fully equip it for its work".

Utilisation of Empire Timbers.

Grant : *Forest Products Research Laboratory, Princes Risborough.*
£30,000 capital and £7,500 spread over 2 years.

The Forest Products Research Laboratory at Princes Risborough was established in 1925 and its work covers the whole range of forest products research. Up to the present it has been organised on a

national, and not on an Empire, basis and the Imperial Economic Committee, in their Timber Report, expressed the opinion that an important service to the Empire would be rendered if funds could be provided to enable the Laboratory to include the testing of Empire timbers as one of its normal functions. It is to this end that the Board's grant has been made available. The Board's grant has enabled the buildings and plant of the laboratory to be considerably enlarged and additional staff to be employed for the purpose. The new work is being supervised by a specially appointed Empire Timbers Committee which includes representatives of the Board and of the Dominion Governments immediately affected.

Empire Forestry Handbook.

Grant : *Empire Forestry Association.* £100.

A tentative list of standard trade names for Empire timbers was prepared by the Empire Forestry Association for discussion by the Empire Forestry Conference held in Australia in 1928. The Conference appointed a Committee to prepare a final list. This was accepted by the Conference and a resolution was passed asking the Empire Forestry Association to take steps to publish the list after final checking by the authorities of the Royal Botanic Gardens, Kew, and to distribute it.

The first issue of this book, which has just been published by the Empire Forestry Association, contains in addition the names and addresses of members of the Empire Forestry Association, Forest Officers of the Empire and other data of general use from a forestry and timber marketing point of view. It is hoped that the publication of this information will be of considerable assistance in the marketing of Empire timber.

MECHANICAL TRANSPORT.

Development of Mechanical Transport suitable for use in undeveloped parts of the Empire.

Grant : £60,000 spread over 5 years.

(Similar sum to be provided by Oversea Governments of the Empire over a period of 4 years.)

The appointment by the Secretary of State of a Directing Committee to study Oversea Mechanical Transport Problems was recorded in

the last Annual Report. The Council, to whom the Directing Committee are responsible has since been constituted and consists of representatives of the various contributing oversea Governments and of the Board. The Parliamentary Under-Secretary of State for the Dominions has been elected Chairman and the Australian representative Vice-Chairman.

The Directing Committee hope to evolve two units, both fitted with heavy oil engines and consisting of a tractor and a number of trailers, to handle useful loads of 15 tons and 40 tons respectively. The general design of the smaller unit has been approved and the first experimental tractor is being put into production as fast as possible. The axle load is being kept below three tons and the component vehicles will all be mounted on large section moderate-pressure tyres, with a view to minimizing the wear caused on unmetalled roads and to allow for the strength of existing bridges and culverts. An experimental eight-wheeled trailer to form part of this unit is now being tested, and is proving satisfactory.

The design of the large unit, which will be mounted on tracks, involves a number of experimental problems, and the Directing Committee are investigating the various alternative components and have a number of experiments and tests under observation.

The Committee are also directing their attention to various ways in which motor transport overseas might be rendered cheaper or more efficient.

FISHERIES.

Research into the Preservation and Transport of Fish.

Grant: *Department of Scientific and Industrial Research.*
£33,300 spread over 3 years.

During 1927 and 1928, the possibility of landing from existing fishing vessels, and under the general conditions obtaining in them, an increased proportion of fish in first-class condition was investigated. A technique was worked out by which it was possible to land fish which showed an improvement in freshness of the order of 100 per cent. as judged by experienced members of the industry in accordance

with standards which they themselves prescribed. A report* on this investigation, embodying a full description of the new technique and the appliances required, with their cost and an estimate of additional running costs, has been published, and arrangements have been made with the British Trawlers' Federation for the discussion of these results, and of the best means of turning them to practical account.

At Aberdeen, the adaptation of two existing buildings for research on fish is finished, and the staff are in occupation. A brine freezing plant has been installed. The Station will be known as the Torry Research Station.

Dr. A. G. Huntsman of the Biological Board of Canada visited this country in the autumn of 1929, and the opportunity was taken to show him the work in progress at Torry Research Station, and to discuss plans for further research on fish with him.

Cod Liver Oil Research.

Grant: £3,000.

The Imperial Economic Committee, in their Report on Fish, recommended that further research should be undertaken into the qualities of cod liver oil and the possibility of improving the market qualities of the oils produced at home and in Newfoundland which had already proved to be of exceptionally high vitamin content.

The investigations begun two years ago by Professor J. C. Drummond of London University and Professor T. P. Hilditch of Liverpool University have now been completed and the results are prepared for publication. The problem of the origin of vitamins in cod liver oil has been exhaustively re-examined and a study made of the feeding habits of the cod in the waters of the North Sea and Newfoundland. The vitamin value of the oil varies greatly, mainly according to the food of the cod and the proportion of oil in the liver. Much attention has been paid to assaying of vitamin value which at present, in the absence of international agreement, is in a state of some confusion. A thorough investigation has been made of the methods of preparing cod liver oil, including cleaning and purifying. Other

*"The Handling and Stowing of White Fish at Sea," by Adrian Lumley, J. J. Piqué, A. M. and George A. Reay, B.Sc., Ph.D., Food Investigation Special Report, No. 37.

aspects such as storage and bottling have also been fully examined, and for the first time a detailed examination of the composition of various liver oils has been made. During the past summer a visit was paid to Newfoundland in the fishing season and a thorough inspection of cod liver oil preparation in the country was made. The tour revealed that medicinal cod liver oil is prepared with great care and that conditions in most of the factories leave little to be desired. Certain recommendations were made which should lead to the production of medicinal oil of even higher grade.

Great Barrier Reef Expedition.

Grant : *Great Barrier Reef Committee.* £2,500.
(£2,500 provided by Commonwealth Government of Australia and £2,500 from scientific bodies in Great Britain.)

The work of the Great Barrier Reef Expedition, towards the cost of which the Board made a grant in 1928, has consisted of a detailed examination of those primary factors on which the fertility of the sea depends. For a year exact estimations of plankton and the quantities of nutrient salts in the sea near the Reef were made. The population of the sea bottom was investigated, the life history, breeding and habits of animals of economic importance, such as trochus, beche-de-mer, pearl oysters and sponges, were studied with a view to the conservation of the present fisheries and their possible farming in the future. A solid foundation of scientific work was laid and a permanent marine station has now been established by the Queensland Government. The work of the expedition in its various aspects has been an unqualified success. Consideration is now being given to the form of publication of the results of the Expedition.

Fishery Research in Newfoundland.

Grant : *Government of Newfoundland.* £5,000 capital and £5,000 per annum for 5 years.

(Similar sums promised by Government of Newfoundland.)

The Board took advantage of the visit to England last summer of Sir Richard Squires, Prime Minister of Newfoundland, to discuss with him the development of fishery research in Newfoundland. As a result it is proposed that the Government of Newfoundland and the

Empire Marketing Board should jointly finance a scheme of research directed to the economic development of Newfoundland fisheries with a view to the marketing of Newfoundland fish and fish products in the United Kingdom. The scope of the work will embrace the preservation, handling and marketing of fish (including brine freezing); the utilisation and marketing of surplus fish and fish by-products; and a systematic and statistical review of fishery resources. In the first instance a marine biologist of high standing will proceed to Newfoundland to survey the position and prepare detailed plans and estimates for submission to the appropriate authorities, and the cost of this preliminary visit will, like the scheme itself, be shared equally between the Government of Newfoundland and the Empire Marketing Board.

WOOL.

Standardisation of Wool Quality.

Grant : *British Research Association for the Woollen and Worsted Industries, Leeds.* £7,800 capital; £2,200 for 1 year and £3,250 p.a. for 4 years.

A scheme of research on the determination of effective standards of raw wool is being carried out by the British Research Association for the Woollen and Worsted Industries, Leeds, under a grant made by the Board in 1927.

The standardisation of wool quality is being fundamentally investigated. It has been established that the variability of the wool fibre renders it difficult to classify wool on the basis of its subsequent manufacturing performance. A formula has been found which would seem to be the basis of wool classification and involves measurements of crimp, fibre length, fibre thickness, contour, and what has hitherto been neglected, fibre constitution. The variability of sulphur content with its subsequent influence upon fibre structure is of the greatest importance. Already results are being applied in a practical manner to actual sheep breeding. During the past year the Board has published a monograph entitled "Wool—a study of the Fibre" by Dr. S. G. Barker, Director of Research to the British Research Association for the Woollen and Worsted Industries,

* E.M.B. 21.

Sheep Breeding and Biology of Wool.

Grant: *Animal Breeding Research Department, University of Edinburgh.* £3,000 capital and £800 p.a. for 5 years.

At Edinburgh, work is in progress consisting of a study of the biology of the fleece, including studies on the physiology of wool at the Department, and "field work" on selected flocks of Scotch Blackface sheep throughout the country. A large number of sheep breeders in Scotland have agreed to collaborate with the Department in a study of the inheritance of kemp and black-spotting in the fleece, and it is expected that the results of this investigation will show whether elimination of kemp from the fleece, the main disadvantage of Blackface wool, is possible without prejudicing other qualities. Some 160 rams are under observation in various parts of the country, and the inheritance of face-colour and black spotting is to be traced in their progeny this spring. These results should be of immediate interest in Scotland, where there are 3½-million Blackface sheep, since breeders believe that face-colour is an indication of efficiency in sheep. They should also be of considerable importance as a contribution to genetical knowledge. Work is also being done on brown Shetland sheep which are believed to be immune to blowfly. Considerable interest is being taken in these sheep by Australian and Tanganyika workers. Economically the colour of the fleece makes this of limited value, but the colour is recessive to white and they are being crossed on Cheviots to see whether their blowfly resistance can be inherited. A special study has been made of the influence of the thyroid gland on fleece. When the thyroid is removed, growth of wool becomes irregular and the fibres become etiolated, weak and inelastic. Iodine is the active principle of the thyroid gland, and this may link up with feeding experiments elsewhere. Tests have been made of Voronoff's theory that an old ram may be restored to full vigour by the grafting of the testis of an active ram, and that an increase of growth and wool production in an immature ram may be induced by grafts from a mature animal. Experiments seem to indicate that a temporary stimulus may result from the operation, but that when this ends there is no permanent increase in growth or fleece.

Survey of Empire Wools.

Grant : *British Research Association for the Woollen and Worsted Industries.* £2,000 p.a. for 2 years.

Dr. J. E. Nichols, an officer of the British Research Association for the Woollen and Worsted Industries, started in August, 1928, a tour of the wool producing countries of the Empire to carry out a detailed study of the conditions of wool production and utilisation. He has visited Australia, New Zealand, South Africa, Kenya and Palestine and is now in Canada. Later, if time permits, he will visit the Irish Free State. A full report will be presented by Dr. Nichols on the completion of his tour.

Supply of Wool Packs for Trials in Australia, New Zealand and South Africa.

Grant : *British Research Association for the Woollen and Worsted Industries.* £175.

The British Research Association for the Woollen and Worsted Industries recently produced an all-paper wool pack which satisfied the test of the Wool Pack Committee of the Bradford Chamber of Commerce. Certain further experiments were suggested to demonstrate the durability of the pack and the Board in 1929 made a grant to the Association to meet the cost of making and sending 150 of these packs to the Dominions to test their durability under commercial conditions. These packs were filled with wool and returned to this country by the ordinary method of transport. Many have been shown to stand the journey and treatment quite well and the knowledge so gained is now being utilised for the production of a still better pack to meet various circumstances under actual Dominion conditions which had hitherto been unknown.

FLAX.

Development of Research into Problems of the Flax Industry.

Grant : *Linen Industry Research Association, Northern Ireland.* £2,250 and £16,500 spread over 5 years.

(£750 capital and £8,500 spread over 5 years provided by Government of Northern Ireland.)

The Board approved a grant in 1929 to the Linen Industry Research Association for the breeding of improved varieties of flax, and for research into mechanical methods of preparing the fibre.

If improved methods could be devised for drying the retted straw and at the same time strains of flax seed could be evolved specially suited to the various climatic conditions throughout the Dominions, it is hoped that the establishment of an industry for the production of flax fibre on a considerable scale within the Empire might become a practicable proposition.

Flax Development in Cyprus.

Grant : *Government of Cyprus.* £2,500 spread over 3 years.

(Similar sum provided by Government of Cyprus.)

The climate and conditions of Cyprus are stated to be favourable to the production of a good marketable flax of the type which Russia, before the War, supplied in large quantities. The scheme for the development of a flax industry in Cyprus, which the Board decided in 1929 to support, provides for local research, i.e., seed production, cultivation, manuring, irrigation, retting and preparation of the fibre ; the establishment of a local training centre for scutching, etc. ; and for the training of young Cypriots in Northern Ireland in flax-growing and as Mill Supervisors.

DAIRYING.

Study of Faults in Dairy Products.

Grant : *National Institute for Research in Dairying, Reading.* £3,150 capital and £3,900 spread over 2 years.

The Board's grant to the National Institute for Research in Dairying has enabled a special study to be made of two faults occurring in dairy products, namely, " Red Spot " in Cheese and " Fishiness " in Butter. The Institute has succeeded in isolating the organism (*B. rudensis*) responsible for the appearance of " Red Spot " and an effort is now being made to trace the primary source of infection. Work so far carried out seems to indicate that the appearance of the colour depends upon a variety of factors, such as temperature, humidity, oxygen tension and acidity and the exact influence of each is still under investigation.

The source of "fishiness" in butter has been traced.

A scientific description of the work on "Red Spot" in Cheese is given in the "Journal of Dairy Research," Vol. 1, No. 1, and an article entitled "The cause of fishiness in dairy products" appeared in "Nature" (1928, Vol. 121, p. 324).

Investigations into Nutritive Value of Milk and enquiry into the Utilisation of Milk Residues.

Grants : (a) *Department of Agriculture for Scotland, Department of Health for Scotland and Ministry of Home Affairs, Northern Ireland.* £8,260. (b) *Department of Health for Scotland.* £5,000.

At the charges of the Board an investigation was carried out in 1927 and 1928 by a Committee appointed by the Board of Health for Scotland to determine the nutritive value of milk to school-children. The tests were carried out amongst children attending elementary schools in seven cities and towns in Scotland and in Belfast and receiving the varied and changing diet of the ordinary working-class household ; and the results strongly confirmed previous conclusions in demonstrating the great value of an additional milk ration to school-children of all ages. Reports on these investigations were published in the "Lancet" of the 23th January, 1928, and the 5th January, 1929.

With the aid of another grant from the Board further milk feeding investigations are now proceeding in Scotland on a community basis with a view to testing the previous findings by extending the scheme to a large number of children in industrial areas. At the same time the present tests will aim at determining the relative nutritive values of Grade A (Tuberculin Tested) milk and Pasteurised milk and for this purpose half the number of children will receive $\frac{1}{2}$ -pint a day of Grade A (T.T.) milk and the other half $\frac{1}{2}$ -pint a day of the same milk pasteurised.

A report on "Surplus Milk and Milk Residues" prepared by Mr. A. Macneillage has been published by the Hannah Dairy Research Institute in Scotland (Bulletin No. 1). This dealt mainly with two aspects of the problem, namely, the extent of the surplus and residues in Scotland and the general methods by which these residues might be manufactured into marketable products. It was, therefore,

limited to the economic and engineering aspects, but a detailed and exhaustive search of the relevant literature on the complementary aspects, namely, the chemical and physical, bacteriological and nutritional problems involved is now being carried out by the Hannah Dairy Research Institute.

Journal of Dairy Research.

Grant : £1,000.

By means of a grant from the Empire Marketing Fund it has been possible to carry out the recommendation of the Imperial Agricultural Research Conference of 1927 in favour of the publication of a Journal of Dairy Research. The first number of the Journal was published last December on behalf of the Dairy Research Committee of the Empire Marketing Board by the Cambridge University Press and future issues will appear every half year. Its object is to afford mutual assistance to workers in the Empire in the sphere of dairy science, and it is designed to include three classes of material, namely, monographs by specialists reviewing the existing state of knowledge in different aspects of dairying ; original contributions to dairy science, by workers within the Empire ; and reviews and abstracts of current literature. The Journal is edited by Professor R. Stenhouse Williams, Director of the National Institute for Research in Dairying, Reading, and Chairman of the Board's Dairy Research Committee, and he is assisted by official correspondents in various Empire countries.

Research on Cheese Ripening.

Grant : *University of British Columbia.* £1,100 spread over 2 years.

(Similar sum being provided by University of British Columbia.)

This grant was made in 1928 to enable researches into cheese ripening processes to be pursued at the University of British Columbia.

Work has been carried out on the method of ripening Kingston Cheese which was evolved by Professor Alec Todd and Professor Wilfred Sadler in 1911. Pasteurised milk has been used for the last six years. A particular feature of this variety of cheese is that it ripens rapidly and is ready for consumption when it is only three weeks old.

Bacteriological research which was in progress before the Board's grant was made has been intensified and extended. There are now strong indications that liquefying bacteria found in the udder play little or no part in the process of ripening. Indications have been strengthened that starter organisms, particularly streptococcus cremoris and streptococcus lactis play a major rôle in the ripening process. This confirms the recent work of Barthel and is in accordance with the enzyme theory of Orla-Jensen and the work of Barthel and Sadler on "casein splitting" properties of starters. A study of some 600 cultures is in progress.

The biochemical work is throwing light on the sequences of bacterial action and the classic methods of Orla-Jensen and Barthel are being followed for protein decomposition studies. Methods hitherto applied only to enzymatic hydrolysis of pure proteins are also being followed. The work is full of promise and information otherwise unobtainable on protein decomposition is emerging both in the study of pure cultures of bacteria and in the breaking down of the proteins in cheese itself.

The high percentage of "water soluble" nitrogen in newly made cheese is significant and may be specific; it is possible that the percentage of soluble nitrogen may be related not only to the progress of ripening as now accepted, but to the character, texture and quality of cheese as determined by a good cheese judge. It is becoming increasingly evident that it is important to regard the bacteriological and biochemical work and the study of the making process as a complementary whole.

The investigation is being greatly assisted by a newly erected cheese ripening room with automatic temperature and humidity control; and the whole study is providing a contribution to systematic knowledge which already has produced results of considerable importance to the dairy industry.

POULTRY.

Research on Poultry Nutrition Problems.

Grant: *Rowett Research Institution, Aberdeen, and the Hillsborough Experimental Station, Northern Ireland.* £7,000 capital and £2,500 per annum for 5 years.

Feeding experiments in regard to growth of chickens and egg-laying have shown that the rate of growth and egg production are increased

by balancing up cereal rations with minerals and vegetable proteins. The proper adjustment of the ration with regard to these two ingredients also affects the size of eggs. The past three years' work on mineral and protein adjustment have been largely empirical, every nutrient which might be deficient having been added.

Further work is in progress to determine the amount of each of the different mineral nutrients required, and also the right protein ratio. A paper has been published on the use of separated milk, which has been shown to be of exceptional value for growth. It has been found that, with a proper adjustment of the ration with minerals and protein, it is possible to obtain a rate of growth equal to that given by separated milk. The rations which produce a maximum amount of growth have given a lower mortality of chicks than control rations.

In addition, fundamental research is being conducted to find to what extent the onset of laying and moulting can be correlated with chemical or histological changes in the ductless glands, bones and blood. It has been found that before the onset of laying there is a storing up of calcium, the element most deficient in ordinary rations. Certain other changes have been noted in the ductless glands, and it is hoped that this fundamental work will yield information to serve as a guide to further practical experiments.

Scientific Feeding of Poultry.

Grant: *Animal Nutrition Institute, University of Cambridge.*
£890 capital and £1,870 spread over 5 years.

This grant provides for continuing at Cambridge research directed towards establishing a scientific feeding standard for poultry; on the digestibility of the commoner poultry feeding stuffs, with particular reference to feeding stuffs of Empire origin; and into the physiological conditions concerned in the production of fat in the bird. This latter investigation is directed towards establishing the conditions of feeding best adapted for the economical production of table poultry.

The Mottram chemical method for estimating fats in biological material has been investigated and a modification suitable for use with poultry products has been successfully evolved. The fatty acids in the liver of the laying bird are definitely higher than those in the non-laying bird.

Digestibility determinations on milling offals have also been carried out in the period under review. The Poultry Nutrition Section of the Animal Nutrition Institute is willing to undertake digestibility determinations of grain products, and would welcome enquiries from Dominions and Colonies anxious for such digestibility determinations to be undertaken.

Production and Marketing of Table Poultry, Eggs, etc.

Grant: *National Institute of Poultry Husbandry, Harper Adams Agricultural College, Newport, Salop.* £5,000 capital and £8,492 spread over 5 years.

The National Institute of Poultry Husbandry is concerned with commercial experiments in Poultry husbandry as distinct from poultry nutrition problems which are dealt with at Cambridge. The grant made by the Board to this Institute in 1928 will enable extended investigations of interest to many Empire countries to be conducted into the production and marketing of table poultry and eggs, and into duck, goose, and turkey production.

Quality in Eggs and the effect of Dietary Factors on Hatching Capacity.

Grant: *Ontario Agricultural College, Guelph, Canada.* £350 capital and £670 per annum for 5 years.

(Similar sum provided by Ontario Department of Agriculture.)

At Guelph a study is being made of quality in eggs and the effect of dietary factors on the hatching capacity of eggs.

It has been found that the addition of 2 per cent. of cod liver oil to animal proteins in the laying rations of poultry increases the hatching power of eggs laid during the months of February and March where milk or beef scrap is used. It has so far failed to increase the hatch where fish meal is used singly. Milk used in combination with either beef scrap or fish meal with the addition of cod liver oil gives very good results. Hens confined in ordinary poultry houses appear to require cod liver oil in the diet where there is less than 150 hours of sunshine per month. About 40 per cent. of the fully formed "dead in shell" are abnormal in position only. Data are being compiled on monsters, anæmic embryos, malpositions and periodicity of

embryonic mortality. Where there is less than 150 hours of sunlight per month the kind of animal protein with or without cod liver oil has considerable effect on the hatchability of the eggs. Various chemical analyses have been made of these protein supplements and of eggs from hens on carefully controlled diets varying only in the source of protein. The results, while showing interesting differences, offer no definite explanation of the difference in the physiological action of these materials nor of the differences in the hatchability of the eggs.

ANIMAL ECOLOGY.

Research on Fluctuations in the Numbers of Wild Rodents.

Grant: *Department of Zoology and Comparative Anatomy, University of Oxford.* £3,010 spread over 3 years.

Wild animals, particularly wild rodents, are subject to great fluctuations in numbers from year to year. Wild mice, voles, squirrels, hares, rabbits, muskrats, etc., afford striking examples of this phenomenon. The importance of these cycles in numbers is increased by their world-wide occurrence, and by the serious economic problems which they present in certain cases. Rats, for instance, are carriers of bubonic plague and voles do a great deal of damage to young trees, while the question of cycles in fur-bearing animals affects the fur trade of Canada.

The first year of research has enabled the cycles in numbers of certain wild rodents to be defined with some approach to precision, and there is a possibility of creating a forecasting system for certain types of rodent damage. The importance of such forecasting to the conservation of wild life and to the framing of trapping laws has led the National Parks Branch of the Canadian Department of the Interior to co-operate in the enquiry. In the British Isles a system of several hundred correspondents who reply to questionnaires on the abundance, behaviour, etc. of mice, voles, and rabbits has been built up. The Forestry Commission has taken an interest in forecasts of mouse cycles in Scotland which may be of definite value in determining times for the planting of seedlings; and the general methods which the investigators are developing are being taken up by plague research stations in various parts of the world, notably in South Africa.

AGRICULTURAL METEOROLOGY.

Empire Meteorological Conference.

Grant : *Ministry of Agriculture and Fisheries.* £500.

The Board made a grant to meet the cost of printing and publishing the proceedings of the Agricultural Meteorological Section of the Empire Meteorological Conference held in London in August 1929.

The Conference enabled closer contact to be established between specialists in meteorology and those concerned with the meteorological aspect of agriculture. The chief conclusions of the Conference were embodied in a series of resolutions to be brought to the notice of the Imperial Agricultural Research Conference in 1932.

OENOLOGY.

Preliminary investigation into problems of the Maturation of Wine.

Grant : £1,250.

On the advice of a small committee of distinguished scientists the Board has made a moderate grant for a preliminary investigation of the factors influencing the process of maturation of wine, with special reference to the action of glass as a potential source of alkali. Australia and South Africa are supplying samples of wine and the experiments will be carried out under the supervision of the committee of experts specially appointed for the purpose. Australian, South African and French wines will be bottled in three different types of bottle and it is hoped that some promising lines of research may be indicated and followed up by the interests concerned.

GEOPHYSICS.

Comparative trial of Geophysical Methods of Survey.

Grant : *Imperial Geophysical Survey Committee.* £16,000.

(Similar sum provided by Commonwealth Government of Australia.)

The Imperial Geophysical Experimental Survey, which was formed two years ago, has now completed in Australia its trial of the various methods of geophysical surveying. It has been agreed by the Geophysical Executive in Australia that the Report of the Survey shall be published in England some time during the present year.

MISCELLANEOUS.

Co-operative Organisation of Producers.

Grant : *Horace Plunkett Foundation.* £1,500 p.a. for 5 years.
(Similar sum being provided by Horace Plunkett Foundation.)

During the past year the Secretary of the Horace Plunkett Foundation has visited the British West Indies and his Report has been communicated to the Colonial Governments concerned. The Foundation have also produced its Year Book dealing with Agricultural Co-operation in the Empire.

Jamaica Producers' Association.

Grant : £1,200 p.a. for 3 years.

The Board decided in 1929 to continue its assistance to the Jamaica Producers' Association for a third year for the purpose of developing the co-operative marketing of citrus fruit.

With the aid of the Board's grants in previous years the Association has successfully launched a co-operative organisation for the marketing of bananas called the Jamaica Banana Producers' Association. A direct line of four ships has been started with the aid of a guarantee from the Government of Jamaica for the carriage of bananas and other fruit to the markets of the United Kingdom. From April to November 1929 the total numbers of stems of bananas shipped was 4,745,202 and the estimated average price realised per payable bunch from all markets was 3s.

With the aid of the third year's grant from the Board the parent body has recently created a similar organisation for citrus fruits and results in the Canadian markets are promising. Small regular shipments are being made to the Association's Marketing Company in London with a view to testing the market in the United Kingdom.

Commodity organisations for other products are being formed and the Association will, it is hoped, soon become self-supporting by means of the contributions which these organisations will make to it.

Comparative Study of Methods of Soil Analysis.

Grant : *University College of North Wales.* £430.

The international method for mechanical analysis of soils has been found unsuitable in various parts of the Empire and the Imperial Bureau of Soil Science has found itself unable to advise oversea workers as to the method most suitable without further investigation.

The conclusion has been reached that investigations are required at a central institute involving the examination of samples of soils for which the present method of mechanical analysis appears unsuitable.

Such investigations are being carried out at the University College of North Wales under a grant made by the Board during the past year.

Milling and Baking Tests of Pusa Wheats.

Grant : £170.

Arrangements have been made at the request of the Imperial Economic Botanist of the Agricultural Research Institute, Pusa, for the Flour Millers' Research Association to undertake milling and baking tests on sixteen samples of Pusa wheat.

TRAVELLERS.

Reference has been made in other parts of this section of the present Report to the visits of officers from Kew to South and East Africa, Somaliland, the British Solomon Islands, British Guiana, and the West African Colonies in connection with botanical matters; to Dr. Nichols' visits to Australia, New Zealand, South Africa, Kenya and Palestine in connection with wool production; and to Dr. Huntsman's visit to the United Kingdom to discuss with experts co-operation in schemes of fish research. In addition, Professor Crew of the Animal Breeding Research Department of the University of Edinburgh has visited Canada where he attended at Winnipeg a conference on live stock matters under the auspices of the Canadian Society of Technical Agriculturalists and the Animal Production Association of Canada; Mr. C. E. Douglas has visited British Guiana to report fully on the rice situation; Mr. I. Tribolet, late Chief Horticulturist to the Department of Agriculture in the Union of South Africa has visited Nyasaland and reported on the economic and

horticultural aspects of nut cultivation; and Mr. D. A. Gill, a Veterinary Officer from New Zealand, has visited this country where he has studied in selected laboratories. Major Walter Elliot, a member of the Board, in company with a member of the Board's staff, attended the Pan African Agricultural and Veterinary Conference at Pretoria in August of last year and paid official visits to Northern Rhodesia, Tanganyika and Kenya. Mr. Wilson, the Canadian representative on the Board, and Mr. Lindsay, the Indian representative, paid visits respectively to Canada and India in the course of which they were able to discuss the purposes and work of the Board with the authorities in those countries. Mr. John Webb, General Manager of the South African Citrus Exchange, has visited the United Kingdom and made an intensive study of the marketing organisation of the produce in which he is interested.

II. ECONOMIC INVESTIGATION AND MARKETING ENQUIRIES.

Marketing of Home Agricultural Produce.

The work being carried out by the Ministry of Agriculture and Fisheries with an annual grant from the Empire Marketing Board of £40,000 for five years has been actively pursued. The Ministry's programme falls roughly into four stages:—

- (1) Investigation and report.
- (2) Practical demonstration.
- (3) Demonstrations under commercial conditions.
- (4) The application of reforms to the ordinary operations of trade.

1. Progress continues to be made in the compilation of reports on various commodities. Twenty-three reports in this series have been published, total sales being now over 76,000 copies. Further marketing leaflets have been issued. Sub-grants have also been made to research institutes in aid of particular enquiries.

2. Demonstrations have been held at agricultural shows in London, Birmingham, Banbury, Swindon, Southampton, Ely, Gloucester, Bungay, Witham, Stafford, Leicester, King's Lynn, Sleaford, Peterborough, Harrogate, Folkestone, Alloa, Blackburn, Cardiff, Waddesdon Manor, Loughborough, Whitchurch, Spalding, Doncaster and Stoke.

3. Sub-grants have been made to co-operative and other commercial organisations to enable them to conduct certain marketing experiments, or to serve as demonstration centres.

4. The increasing strength of the "National Mark" as a factor in the sale of home produce has been perhaps the most striking feature of the efforts made by the Ministry. The following table indicates the progress made in the application of the "National Mark" to various agricultural commodities.

<i>Commodity.</i>	<i>Scheme Introduced.</i>	<i>Results.</i>
Apples and Pears ..	September, 1928 ..	70 growers and packers authorised; 400,000 labels issued.
Eggs.. ..	February, 1929 ..	150 packing stations authorised; 1,000,000 box labels and 2,000,000 carton labels issued.
Broccoli	March, 1929 ..	Trial consignments successfully exported to Germany and Belgium.
Tomatoes and Cucumbers.	April, 1929 ..	76 tomato packers and 23 cucumber packers authorised; 500,000 tomato and cucumber labels issued.
Wheat-Flour ..	October, 1929 ..	168 millers and packers authorised; 400,000 sack labels and 1,250,000 small packet labels issued.
Beef.. ..	November, 1929 ..	At present limited to London and Birmingham. 3,500 sides graded and marked weekly.
Malt Products ..	January, 1930 ..	35 firms authorised; 250,000 labels issued.

The general activities recorded under this section of the last Annual Report have been continued and extended.

A further annual grant of £12,000 for 3 years to the Ministry of Agriculture and Fisheries has been made from the Empire Marketing Fund for investigations into problems of marketing organisation.

Several grants have been made to the Department of Agriculture for Scotland for marketing purposes. A consolidated grant of £7,200 for the financial year 1930 has now been approved from the Board's fund and is being devoted to egg marketing, beef grading, Scottish National Mark labels, exhibits, economic enquiries and miscellaneous activities.

The Scottish National Mark has now been applied to the following products: Eggs, ware potatoes, malt products and beef (in the latter case the scheme is on an experimental basis).

So far 45 packing stations have been approved for eggs and the number of national mark labels issued to packers is 68,330, representing, approximately, a quantity of 1,622 thousand dozens of graded eggs produced in Scotland.

The number of potato growers and merchants who have been authorised under the national mark in connection with graded ware potatoes is 30 and 22,000 labels have been issued.

Twelve manufacturing firms are using the Scottish national mark in connection with malt extracts and malt flours manufactured wholly from home grown barley.

The experiment in grading and marking Scottish Beef with a national mark was arranged in co-operation with the Ministry of Agriculture and Fisheries, so that it should apply chiefly to beef consigned from Scotland to London. Accordingly certain districts in Aberdeenshire and Banffshire were selected for the experiment because they formed a compact unit and most of the Scottish beef for London is consigned from there. During the first few weeks of the experiment in November a weekly average of 797 sides of beef were graded and marked. By March of 1930 this figure had risen to considerably over 2,000 sides per week.

The additional funds made available by the Board during 1930 will enable the Department of Agriculture for Scotland to extend in a more adequate degree their activities in connection with the marketing of home agricultural produce. It will enable them not only to develop schemes for the application of the national mark to graded products but also to participate effectively at the various important exhibitions recognised by the Empire Marketing Board.

The investigations being pursued by the Scottish Department with the aid of a grant from the Empire Marketing Fund, into the improvement of pork and bacon production in Scotland have made satisfactory progress.

Two grants have been made from the Board's fund to the Government of Northern Ireland. The first, of £900 per annum for three years, is being devoted to investigations into the marketing of Northern Ireland agricultural produce. A general survey of the marketing organisation for the disposal of farm produce in Northern Ireland has been carried out, while a number of special enquiries have been made regarding the methods of marketing specific commodities—turkeys, whole milk, fat lambs and wool. A retail butter

survey, similar to that carried out in Great Britain, has been made in Belfast and in certain other towns of Northern Ireland. The second grant of £600 per annum for three years is in connexion with the economics of small holdings, and half the cost of this enquiry is being defrayed by the Government of Northern Ireland. Financial records are being kept in respect of seventy farms and this number will subsequently be increased, while economic surveys are being carried out in some of the poorer and more backward areas where there are groups of small 15 to 30 acres farms suitable for intensive study.

A special enquiry was carried out at the request of the Government of Northern Ireland into transport conditions of butter from Northern Ireland.

Statistics and Market Intelligence.

(1) The "Weekly Fruit Intelligence Notes" have now entered their fourth year of publication. They enjoy a circulation among fruit growers and merchants at home and in the Empire overseas amounting to slightly over 2,000 weekly, but their effective circulation is very much larger than these figures suggest, as the information is extensively reproduced in fruit trade journals in this country and overseas. One representative body of fruit retailers issues to all its members a weekly market news service based upon the information given in the Board's "Notes."

The scope of "Weekly Fruit Intelligence Notes" embraces imports, week by week, of each fruit in the 25 chief ports in Great Britain; arrivals and prospective arrivals from all the main producing countries, including complete lists of fruit cargoes afloat from eighteen different countries; reports on fruit crop prospects in every country in the world in which this information is likely to be of interest to Empire fruit growers, as affecting supplies to the United Kingdom markets; and special articles on fruit production and trade dealing with various aspects of the industry.

(2) The "Weekly Dairy Produce Notes" have been issued for rather more than a year, and circulate among some 3,000 producers and traders in the Empire. In general form they resemble closely the "Fruit Notes," the subject matter including lists of shipments of butter, cheese and eggs afloat from the various countries exporting to the United Kingdom; tables of weekly imports into the chief

ports in Great Britain ; gradings and stocks in the dairying Dominions; and reports on conditions in British and foreign producing countries. Current prices are quoted week by week, and special articles are included surveying various aspects of the dairy produce trade.

With the approval of the provision trade, and the ready co-operation of proprietors of cold stores throughout the country, the Board has recently started the collection of statistics of butter held in cold stores in Great Britain. The figures are furnished voluntarily at fortnightly intervals by cold storage companies, and aggregates are published in "Weekly Dairy Produce Notes." The number of important firms refusing to supply information is very small. The returns obtained are estimated to represent fully 90 per cent. of the stocks of butter held in cold storage in the whole country, and thus serve as a reliable index of changes in stocks held in cold store.

Following a recommendation in the Twelfth Report of the Imperial Economic Committee, the "Weekly Dairy Produce Notes" have been enlarged to include, from the beginning of April this year, information regarding bacon, ham and other pig products, similar to that in respect of dairy produce.

(3) "Dried Fruit Notes," surveying the statistical position of the raisin and currant trade, have been compiled for more than three years. These Notes include import statistics, stocks and sales of fruit in this country, and information regarding crop prospects and yields in the major producing countries. The surveys are prepared, primarily, for the service of the official representatives of Australian and South African producers.

Periodically, the statistical position of dried fruits other than raisins and currants is also reviewed in these "Notes."

(4) The statistical survey of the world position as regards the production and consumption of oranges, to which reference was made in last year's report, has been followed by a similar survey of cocoa. (See E.M.B. 27, Appendix 2.)

Further surveys of this nature, relating to wool and beef, are now being undertaken, and it is proposed to continue the series for other commodities about which information is particularly desired by Empire producers.

Wastage in Imported Fruit.

During the past year, the systematic survey of the wastage occurring in imported Empire fruits has been continued. The work was primarily undertaken in connection with the Board's economic studies of marketing, but, in addition, it has been of value in indicating lines of research of commercial importance and has served as a useful supplement to the laboratory study of wastage carried out at the Low Temperature Research Station of the Department of Scientific and Industrial Research. Throughout the investigations, special attention has been directed towards methods of controlling wastage under commercial conditions.

A Report on wastage in Canadian fruit (apples, pears, plums and peaches), has recently been published. Reports on Palestine oranges and on Australian and New Zealand apples and on the causes of slackness in barrels of Canadian apples will shortly be issued.

Experimental Consignments and Trade Enquiries.

(a) The Board has co-operated with Oversea Governments in exploring the possibilities of developing a trade in fruits and other products, not previously exported from Empire countries. Experiments have been carried out designed to investigate the technical and marketing problems involved.

A series of reports and leaflets describing the results of the more important experiments has been issued. These include shipments of grapes, oranges, pineapples, plums, apricots, pomelos, mangosteens, figs, prunes, almonds, tomato purée and various fruit pulps.

(b) In response to requests received from overseas, a number of smaller enquiries has been carried out in regard to the marketing of various food products in the United Kingdom. Information has been collected dealing with the extent and nature of competitive supplies, and with market requirements in regard to quality, grading and packing. Reports on the following commodities have been prepared:—tomatoes, grapefruit, citrus juice, pawpaws, melons, onions, sultanas, raisins, candied peel, broad beans, fruit syrups and crushed fruits, "locoum" (Cyprus), and mosphilo jelly.

Retail Surveys.

A series of retail market surveys has been carried out. Information is collected, in the course of these investigations, on retail policy, the distribution of Empire and competitive supplies, trends of consumption and market preferences. The data thus obtained are of practical value to the oversea producer in enabling him to adjust production and marketing methods to existing conditions and to anticipate changes in demand.

Experimental surveys of this kind were carried out in certain Midland towns and in London on the retail demand for butter. As experience was gained, the scope of the enquiries was widened and surveys of the retail marketing of canned fruits and of butter have been undertaken on a national scale. In addition, reports on the demand for cheese in London (*See E.M.B. 22, Appendix II*) on the retail marketing of South African oranges in Liverpool and on the demand for certain food products in the Newcastle area have been issued. Similar investigations on honey in London, apples in Liverpool and on cheese and other commodities in Glasgow, are in progress.

III. PUBLICITY.*

1. *Newspaper Advertisements.*

A series of advertisements under the general heading of " Empire Buying " was inserted during the year in a wide range of newspapers circulating throughout the United Kingdom and in the appropriate trade papers. This series drew attention, in their turn, to the following Empire commodities :—

- Home Fish.
- Home Potatoes.
- Scottish Oats.
- Canadian Apples.
- Australian Dried Fruits.
- New Zealand Apples.
- South African Citrus Fruits.
- Irish Free State Dairy Produce.
- Indian Rice.
- Southern Rhodesian Tobacco and Cigarettes.
- East African Coffee.
- Empire Eggs.

* Provision was made in the estimates for 1929-30 for an expenditure on publicity of £360,000.

A second advertising campaign throughout the national press was launched in April and is still in progress, setting forth the reasons why Empire buying is a duty that no citizen of the United Kingdom can afford to neglect.

Advertisements were also issued throughout England and Wales on the subject of the Home National Mark and of National Mark tomatoes and cucumbers, while localised newspaper advertising was undertaken for National Mark beef and flour.

Advertisements were inserted in the areas concerned with the numerous Exhibitions and Shopping Weeks in which the Board have assisted and a number of special advertisements were published in trade and other papers.

2. Posters.

(A) *Displays on the Board's own Poster Frames.*—The Board have now 1,780 poster frames in 450 towns in the United Kingdom. Specimen frames have also been erected in Australia, New Zealand, South Africa, and the British West Indies. 18 sets of posters were displayed during the year on the following subjects :—

- Empire Vines, Furs and Fish.
- Growth of Canadian Trade.
- Empire Tobacco.
- Irish Free State Dairy Produce.
- Growth of Australian Trade.
- Home Agriculture.
- Growth of New Zealand Trade.
- Empire Animals advertising various products.
- Some Empire Islands (Falklands, Channel Islands, Cyprus, Mauritius, Fiji).
- The British West Indies.
- The Empire Stands for Peace.
- One year in Australia.
- Home National Mark Beef (London and Birmingham only).
- Palestine.
- Statistics of Empire Trade.
- Buy Empire Goods from Home and Overseas (letterpress).
- Canadian Fish, Tobacco and Timber.
- Agricultural Maps of the British Isles.

(B) *Displays on the Commercial Hoardings.*—The Board made displays of posters on the commercial hoardings in the North-East Coast area, in Plymouth and in Hull in connection with exhibitions in these areas.

(C) *Poster Reproductions for Schools.*—Reproductions of 13 of the Board's posters were issued to schools—21,000 schools in the United Kingdom have applied to the Board to receive these poster reproductions as issued.

(D) *Shop Display Material.*—48 new bills, cards and window strips were designed and issued for display in shops to advertise various Empire products. Reprints of a number of earlier designs were also called for. Reproductions in cigarette-card size of the Board's Empire Animal Series of shop window bills were also issued.

At the request of the Office of the Irrigation Commission for New South Wales and of the National Federation of Women Institute the Board designed labels for their canned fruits and bottled jam and fruits respectively.

(E) *Contract Posters.*—A fresh edition was designed for the series of "contract" posters for use in factories where orders are being executed for the Empire overseas. 11,000 copies of the posters were issued to 900 firms. 53,000 reproductions of the posters were also issued for sending overseas to the customers and representatives of the firms concerned.

A special series of cards has also been issued for display in the works of motor car manufacturers.

3. *Leaflets.*

New leaflets were issued on the following subjects :—

- New Zealand Apples (with recipes).
- East African Coffee (with recipes).
- Australian Dried Fruits (with recipes).
- South African Oranges (with recipes).
- Home Fish (with recipes).
- St. Vincent Arrowroot (with recipes).
- Empire recipes for economical meals.
- Indian Rice (with recipes).

- Canadian Apples (with recipes).
- Home Potatoes (with recipes).
- Canadian Canned Salmon (with recipes).
- Empire canned and bottled fruits (with recipes).
- Herring cooking recipes.
- 7 leaflets giving Empire recipes from Broadcast talks.
- The National Mark.
- Home Fruit.
- The E.M.B. and Scotland.
- The importance of the Root System of Fruit Trees.
- Leaf Scorch of Fruit Trees.
- Herring Fishing.
- British Bulbs.
- A contrast in Cities.
- Cyprus.
- British West Indies.
- Irish Free State Creameries.
- Speed in the Empire.

For Fruit Growers.

For Schools.

Reprints of the following leaflets were also called for :—

- The Empire Marketing Board.
- Why should we buy from the Empire ?
- The Empire Marketing Board and the Home Producer.
- List of Empire Tobaccos.
- Fruit and Vegetables of Empire.

The total number of copies of these leaflets distributed during the year was close on two million.

4. Lectures.

2,400 Empire Lectures were given under the Board's auspices to audiences totalling over 500,000. Of these lectures, half dealt directly with Empire Marketing and the work of the Board and half were on subjects of general Empire interest.

5. Broadcasting.

In co-operation with the British Broadcasting Company, 22 fortnightly bulletins of Empire produce in season were broadcast. A series of 14 talks giving selected recipes were also given, as a result

of which 20,700 members of the public applied to the Board for copies of the recipes with the Empire sources of supply of the ingredients. A further series of talks to housewives on different Empire Products was begun in February, 1930.

Talks were broadcast from the local station in connection with the opening of the displays of the various Empire countries at the North East Coast Exhibition at Newcastle.

6. *Exhibitions and Shopping Weeks.*

(A) The Board participated in the following exhibitions :—

Date.

1929.

9-20 April.—Belfast Grocers' Exhibition (information bureau only).

1-11 May.—Scottish Grocers' Exhibition, Edinburgh.

14 May-25 October.—North East Coast Exhibition, Newcastle-on-Tyne.

3-6 July.—Aldershot Command Horse Show (information bureau only).

15-20 July.—Plymouth Empire Exhibition.

21-27 September.—International Grocers' Exhibition, London.

2-10 October.—Bristol Grocers' Exhibition.

10-16 October.—Hull Empire Exhibition.

25 October-2 November.—Imperial Fruit Show, Birmingham.

20-30 November.—Edinburgh Workers Exhibition.

1930.

31 December-8 January.—Schoolboy's Own Exhibition, London.

14-25 January.—Birmingham Grocers' Exhibition.

17-28 February.—British Industries Fair, London.

4-15 March.—Scottish Grocers' Exhibition, Glasgow.

26 March-5 April.—Portsmouth Grocers' Exhibition.

(B) The Board assisted in Empire Shopping Weeks in the following centres :—

London.

Plymouth.

Southampton.

Walton-on-Thames.

Staines.

Bromley (Kent).

Port Talbot.

Belfast.

Hull.

Aldershot.

Clapham.

Chingford.

Abertillery.

Mexborough.

(C) The Board inaugurated a new type of Exhibition by opening in January a shop in Glasgow which they are placing over a 6 months' period at the disposal of the various Empire countries in turn for a fortnight each, to make displays and sell samples of their products.

7. Trade Meetings.

Members of the Trade Branch have addressed meetings of Business Men, Distributive Traders and Producers at the undermentioned places during the last twelve months :—

Aldgate, Belfast, Birmingham (4), Bristol, Caerphilly, Chelsea, Clapham, Colwyn Bay (2), Edinburgh, Glasgow (4), Hendon, Hull, Islington (2), Liverpool, Malvern, Manchester (2), Mexborough, Middlesbro', Newcastle (4), Northampton, Oxted, Pitlochry (4), Plymouth (4), Pontefract, Port Talbot, Portsmouth, Walsall, Westminster, Wisbech.

8. Cinema.

(A) *Film produced under the Board's supervision and released for commercial distribution.*

Drifters—illustrating the Home Herring Industry.

(B) *Films completed from existing material for non-commercial use.*

(a) A series of one-reel films on the following subjects :—

Canadian Apples.
Holidays of Empire.
Highways of Empire.
Sheep Dipping.
Home Herring Industry.
Clean Milk.
South African Fruit.

(b) A series of short advertising films on the following subjects :—

The Port of London.
Gold Coast Cocoa.
Burma Teak.
Home Herrings.
Home Poultry.
New Zealand Dairying.
Canadian Apples.
Empire communications.

(c) A series of maps in cartoon form for use as prefaces to films.

(C) *Cinema Displays to the Public and to Schools.*

(a) *North East Coast Exhibition, Newcastle-on-Tyne.*—The Board built a cinema theatre in their Pavilion at the North East Coast Exhibition and the daily performances of Empire films were very well attended throughout the 6 months period of the Exhibition. Special displays were given to organised parties of over 40,000 schoolchildren.

(b) *Daylight Cinema at the British Industries Fair.*—The Board installed a daylight cinema projector of a new type as a central feature of their Pavilion at the British Industries Fair, and showed a series of short advertising films on various Empire subjects. The experiment proved a marked success.

(c) *Displays to Schoolchildren in Newcastle and Gateshead.*—With the co-operation of the local Education Authorities in conjunction with British Instructional Films, Ltd., and the Cinematograph Exhibitors' Association, the Board arranged for special displays of Empire films to be given in school hours in the local cinemas to some 46,000 schoolchildren in Newcastle and Gateshead, prior to the opening of the North East Coast Exhibition.

(d) *Empire Marketing Board Cinema at the Imperial Institute.*—The Board continued the grant to the Imperial Institute for the maintenance of a cinema in which Empire films are shown daily. During the year, 290,000 persons visited this cinema, including 76,000 schoolchildren in organised parties. These figures show an increase of about 30 per cent. over the attendances in the previous year.

(e) *Loan of Films.*—The Board have arranged for the loan of suitable films for displays to the public and to schoolchildren in connection with Empire Exhibitions and Shopping Weeks and for exhibition in schools equipped with cinema projectors.

APPENDIX I.

(1) THE EMPIRE MARKETING BOARD.

- The Secretary of State for Dominion Affairs and for the Colonies.
(The Rt. Hon. LORD PASSFIELD) (*Chairman*).
- The Parliamentary Under-Secretary of State for Dominion Affairs.
(Mr. W. LUNN, M.P.) (*Vice-Chairman*).
- The Financial Secretary to the Treasury.
(Mr. F. W. PETHICK LAWRENCE, M.P.)
- The Parliamentary Secretary to the Ministry of Agriculture and Fisheries.
(The Rt. Hon. C. ADDISON, M.D., M.P.)
- The Parliamentary Under-Secretary of State for Scotland.
(Mr. T. JOHNSTON, M.P.)
- The Parliamentary Under-Secretary of State for the Colonies.
(Dr. T. DRUMMOND SHIELS, M.C., M.P.)
- The Rt. Hon. L. S. AMERY, M.P.
- Sir ARCHIBALD SINCLAIR, Bart., C.M.G., M.P.
- Sir EDWARD CROWE, K.C.M.G.
(Comptroller-General of the Department of Overseas Trade).
- Sir THOMAS ALLEN (United Kingdom).
- Sir WILLIAM CRAWFORD, K.B.E. (United Kingdom).
- Mr. W. A. WILSON (Canada).
- Mr. F. L. McDUGALL, C.M.G. (Australia).
- Mr. R. S. FORSYTH (New Zealand).
- Mr. J. DIMOND (Union of South Africa).
- Mr. J. W. DULANTY, C.B., C.B.E. (Irish Free State).
- Mr. H. A. F. LINDSAY, C.I.E., C.B.E., I.C.S. (India).
- Sir FRANCIS NEWTON, K.C.M.G., C.V.O. (Southern Rhodesia).
- Sir EDWARD DAVSON, Bart. (Colonies and Protectorates).

Mr. S. G. TALLENTS, C.B., C.M.G., C.B.E. (*Secretary*).

Mr. E. M. H. LLOYD (*Assistant Secretary*).

(2) THE RESEARCH GRANTS COMMITTEE.

Dr. T. DRUMMOND SHIELS, M.C., M.P.
(Parliamentary Under-Secretary of State for the Colonies) (*Chairman*).
Mr. W. LUNN, M.P.
(Parliamentary Under-Secretary of State for Dominion Affairs).
The Rt. Hon. C. ADDISON, M.D., M.P.
(Parliamentary Secretary to the Ministry of Agriculture and Fisheries.)
Mr. W. A. WILSON.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
Mr. F. L. McDUGALL, C.M.G.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
Mr. H. A. F. LINDSAY, C.I.E., C.B.E.
(Member of the Empire Marketing Board.)
Sir EDWARD DAVSON, Bart.
(Member of the Empire Marketing Board.)
Sir BASIL P. BLACKETT, K.C.B., K.C.S.I.
(Chairman of the Colonial Development Advisory Committee.)
Major WALTER E. ELLIOT, M.C., M.P., M.B., D.Sc.
The Rt. Hon. W. G. A. ORMSBY-GORE, M.P.
Mr. F. W. PETHICK-LAWRENCE, M.P.
(Financial Secretary to the Treasury.)

Mr. E. M. H. LLOYD (*Secretary*).

(3) THE MARKETING COMMITTEE.

Mr. T. JOHNSTON, M.P.
(Parliamentary Under-Secretary of State for Scotland) (*Chairman*).
The Rt. Hon. C. ADDISON, M.D., M.P.
(Parliamentary Secretary to the Ministry of Agriculture and Fisheries.)
Sir THOMAS ALLEN.
(Member of the Empire Marketing Board.)
Sir WILLIAM CRAWFORD, K.B.E.
(Member of the Empire Marketing Board.)
Mr. R. S. FORSYTH.
(Member of the Empire Marketing Board.)
Mr. J. DIMOND.
(Member of the Empire Marketing Board.)
Mr. J. W. DULANTY, C.B., C.B.E.
(Member of the Empire Marketing Board.)
Mr. T. W. KING, C.B.E.
Mrs. MURIEL E. W. NICHOL.

Mr. LACHLAN MACLEAN, O.B.E. (*Secretary*).

(4) THE PUBLICITY COMMITTEE.

- Mr. W. LUNN, M.P.
(Parliamentary Under-Secretary of State for Dominion Affairs) (*Chairman*).
- Sir WILLIAM CRAWFORD, K.B.E.
(Member of the Empire Marketing Board, Governing Director of Messrs. W. S. Crawford, Ltd.) (*Vice-Chairman*).
- The Rt. Hon. C. ADDISON, M.D., M.P.
(Parliamentary Secretary to the Ministry of Agriculture and Fisheries).
- Sir THOMAS ALLEN.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
- The Rt. Hon. L. S. AMERY, M.P.
(Member of the Empire Marketing Board).
- Sir WOODMAN BURBIDGE, Bart., C.B.E.
(Chairman and Managing Director of Messrs. Harrods, Ltd.)
- The Viscount BURNHAM, G.C.M.G., C.H.
(President of the Empire Press Union).
- Sir EDWARD CROWE, K.C.M.G.
(Comptroller-General of the Department of Overseas Trade.)
- Mrs. COTTRELL.
(Director of the Co-operative Wholesale Society, Ltd.)
- Mr. J. W. DULANTY, C.B., C.B.E.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
- Lieut.-Gen. Sir WILLIAM FURSE, K.C.B., D.S.O.
(Director of the Imperial Institute.)
- Mr. D. G. GERAHTY.
(Director of Publicity for Canada in the United Kingdom.)
- Mr. T. JOHNSTON, M.P.
(Parliamentary Under-Secretary of State for Scotland.)
- Mr. H. A. F. LINDSAY, C.I.E., C.B.E., I.C.S.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
- Mr. F. L. McDUGALL, C.M.G.
(Member of the Empire Marketing Board and the Imperial Economic Committee.)
- Sir WILLIAM FERRING, J.P.
(Representing National Chamber of Trade.)
- Mr. F. W. PETHICK LAWRENCE, M.P.
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- Mr. F. PICK.
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Farham House Laboratory.

[Frontispiece.]

E.M.B. 29.

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THE BIOLOGICAL CONTROL OF INSECT AND PLANT PESTS

A Report on the Organisation and Progress of the Work of
Farnham House Laboratory

BY

W. R. THOMPSON, Ph.D., D.Sc.

Assistant Director, Imperial Bureau of Entomology, and Superintendent,
Farnham House Laboratory.



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PREFACE.

FARNHAM HOUSE LABORATORY was founded by the Imperial Bureau of Entomology in 1927, by means of a grant from the Empire Marketing Board with, as its principal object, the furtherance of the control of the insect pests of agriculture and forestry, by what is known as the biological method, that is, by means of beneficial parasites and predators. A fifteen-roomed house at Farnham Royal, Bucks, situated about two and a half miles from the town of Slough, on the Great Western Railway, and about 25 miles from London, was purchased in February, 1927, and work begun there in June of the same year, on the parasites and predators of a number of pests of primary importance in various parts of the British Empire, under the control of Dr. S. A. Neave, who was succeeded a year later by Dr. W. R. Thompson, the present Superintendent.

That the creation of the Laboratory met a real need in Imperial Entomology, the response of the Dominion and Colonial entomologists to offers of assistance has amply proved. Requests for help were received even before the Laboratory had been opened for work, and since that time, the list of injurious insects and plants we have been asked to investigate in the hope of finding parasites or predators, which can be utilised in their control, has increased very rapidly, until it now comprises some 70 species. The programme of work originally covered only the natural enemies of injurious insects, but in 1929, at the request of the Government of the Dominion of New Zealand, the laboratory took over the conduct of the European investigations and practical operations on the insect enemies of certain weeds, which had hitherto been carried out under the supervision of Dr. A. D. Imms of Rothamsted and Professor J. W. H. Harrison of the University of Leeds.

In 1928, after visiting the Laboratory and inspecting its facilities, Dr. R. J. Tillyard, the Chief of the Federal Entomological Service of Australia, requested us to undertake the supervision of the work of three members of his staff, who had been assigned to the investigation of certain important entomological problems in Europe. Mr. J. W. Evans spent a year at the Laboratory, studying methods for the mass production of the egg-parasite, *Trichogramma*, with the object of utilising it against the Codling Moth in Australia. He completed his

I

investigations and returned to Australia early in June, 1929. Dr. F. G. Holdaway spent the winter of 1928 to 1929, studying the problem of the Sheep Blowfly, and is now continuing these investigations in Southern France, with the help of an assistant, Mr. A. C. Evans, specially appointed for this purpose. Mr. S. G. Garthside began in the autumn of 1928 his study of the insects attacking St. John's Wort (*Hypericum perforatum*), assisted by Mr. T. D. Boyd, and this work is still going on.

The rapid progress of the Laboratory and the heavy pressure of work which has thereby resulted, have made it, hitherto, impossible to prepare an account of the work which has been and is being carried out. It seems, however, desirable that the entomologists of the Empire should be made acquainted with the work undertaken by the Laboratory and the facilities it offers. This report has been designed to meet this need. It comprises a general account of the object and methods of work on biological control, a description of the organisation and facilities that the Laboratory now possesses for dealing with problems of this kind, and a brief summary of the investigations and practical work undertaken up to the present time.

GUY A. K. MARSHALL,

*Director,
Imperial Bureau of Entomology.*

CONTENTS.

	Page
LIST OF ILLUSTRATIONS	5
I. INTRODUCTION	6
II. THE PRINCIPLES AND ORGANISATION OF WORK ON BIOLOGICAL CONTROL	7
1. The Principles of Biological Control	7
2. Preparatory Work	12
3. Preliminary Field Survey	14
4. Examination of Sample Collections	18
5. Choice of Beneficial Species	24
6. Large Scale Collections and Shipments	29
7. Methods of Treatment on Reception	46
8. Study of the Progress of Introduced Parasites in the Field	53
9. The Results of Experiments in Biological Control	55
10. Summary	71
III. FARNHAM HOUSE LABORATORY: ITS RESOURCES, EQUIP- MENT AND STAFF	73
1. Finance	73
2. Grounds, Buildings and Equipment	73
3. Staff	78
4. Summary	79
IV. PRACTICAL WORK	81
1. Parasites of Deciduous Fruit Insects	82
2. Parasites of Forest Insects	93
3. Parasites of Cereal and Forage Crop Insects	98
4. Parasites of Vegetable Crop and Small Fruit Insects	101
5. Parasites of Tropical Field Crops	104
6. Parasites of Citrus Fruit Insects	105
7. Parasites of Greenhouse Insects	106
8. Parasites of Insects affecting Man and Domestic Animals	106
9. Investigations in the West Indies	109
10. Insects destructive to Noxious Plants	110
11. General Investigations	113
12. Summary of Projects submitted to the Laboratory	113
V. BIBLIOGRAPHY	117

LIST OF ILLUSTRATIONS.

Plate		Facing page
I.	Farnham House Laboratory	Frontispiece.
II.	Diagnostic characters of entomophagous parasites	20
III.	1. Shipping Box with Mailing Case	34
	2. Cylindrical Glass Parasite Cage	34
IV.	1. Double Compartment Cage	35
	2. Standard Cage	35
V.	Plan of Grounds, Farnham House Laboratory	74
VI.	1. General Insectary	75
	2. Small Teak Insectaries	75
VII.	1. Oviposition Cage for Codling Moths	84
	2. Fiske Tray	84
VIII.	1. Rearing of <i>Aphelinus mali</i>	85
	2. Collection of <i>Sirex</i> Parasites	85

I. INTRODUCTION.

THE present report contains a general account of the work on Biological Control carried on at Farnham House Laboratory, which, having regard to its field of activity, resources and programme, can fairly claim to be the most important centre for work of this type now existing in the Empire.

A few words of explanation in regard to the rather unusual form of the report are perhaps necessary. Since it is the first published report it has been designed with the object of giving a comprehensive idea of the policy, organisation, resources, and practical efforts of the Laboratory. The second part is devoted to a general account of the problems encountered in operations in biological control with special reference to the organisation and conduct of practical work. A certain number of purely theoretical considerations have been included because of their value in indicating lines of research in the Laboratory and in the field ; but the great majority of the statements and suggestions are the fruit of some twenty years' experience in work in this field and have been repeatedly tested in practice. An attempt has been made to arrange them so that they constitute, as it were, a rough sketch of the technique of this branch of economic entomology. So far as the writer is aware no account of this kind has yet been published.

The third part of the report deals with the history, organisation, and equipment of the Laboratory, in order to show what resources it possesses to cope with the problems encountered in practical work. The fourth part gives a summary of the results obtained up to the present date together with a list of the projects which have been submitted to the Laboratory. A bibliography, including the papers most useful to workers in this field, has been appended.

The writer wishes to express his sincere appreciation of the encouragement and support received during the course of the work from Dr. G. A. K. Marshall, Director of the Bureau, Dr. S. A. Neave, Assistant Director, and the Staff of the Laboratory, all of whom have contributed in various ways to the progress of the work and assisted in the production of this report.

As has been stated elsewhere, the foundation of the Laboratory was made possible by grants from the Empire Marketing Board, and the officials of that Board have been most helpful and sympathetic in every way. Further we are indebted to them for the publication of this account of the work.

II. THE PRINCIPLES AND ORGANISATION OF WORK IN BIOLOGICAL CONTROL.

In this section it is proposed to give a general account of the way in which work on biological control is planned and executed at the Laboratory, in order to give some idea of the principles underlying it and of the technique used in practical work. This outline is divided into sections which follow the entomologist, so to speak, step by step in the investigations and practical efforts which he is ordinarily obliged to make in undertaking work on the biological control of the average insect pest. To those acquainted with the subject, some of the remarks and recommendations may seem superfluous. However, experience shows that they are sometimes necessary, and they are included for the sake of making the account as complete as possible.

1. *The Principles of Biological Control.*

The practice of biological control owes its origin to the fact that a great many injurious insects and plants are attacked by parasitic and predacious species, belonging to the same group. These beneficial insects play an important part in the natural control of many destructive forms. Furthermore, many plants injurious to agriculture and forestry have also their insect enemies, which seem in some cases to exert an important effect in limiting their increase and dispersion. When insect pests are accidentally transported to new countries, leaving their habitual parasites and predators behind, they frequently become extremely numerous and cause immense damage; for as experience has repeatedly shown, they are generally attacked to only a negligible extent by the beneficial species existing in their new homes. Of the 183 worst insect pests existing in North America almost half have been introduced from foreign countries, and of these, a large proportion came in from Europe (Smith '29). The Hessian Fly alone destroys each year a proportion of the wheat crop, valued at approximately £800,000. The control of the Gipsy Moth, accidentally introduced into America about 60 years ago, costs the United States about £50,000 per annum. The European Corn Borer, which reached America about 15 years ago, has done so much damage that appropriations of from £50,000 to £150,000 are being made annually in order to fight it, and in 1927 the sum of £2,000,000 was expended in order to arrest its spread. The insect now constitutes a

serious problem for Canada ; in 1925, an area of at least 400 square miles of excellent maize country in Ontario suffered a complete loss owing to its ravages. The Oriental Peach Moth, the Japanese Beetle and the Mediterranean Fruit Fly are also extremely serious(*).

In former times no regulations designed to prevent the importation of insect and plant pests existed, but as transport was very slow and no means of preserving foodstuffs existed, opportunities for the migration of injurious insects were not really very numerous. The modern development of rapid transport and of methods of food preservation, particularly cold storage, allows of the exchange of fresh or living food products between far distant parts. This development of a world trade has permitted and fostered cosmopolitan tastes and requirements, which in turn further stimulate commerce between the various points of the globe.

Now these modern developments of trade and transport permit injurious organisms to traverse, with relative ease, geographical barriers that formerly constituted impassable obstacles, under conditions which are exactly what they require. The rapid methods of locomotion bring them to new food supplies before the material in which they are being carried is exhausted, the cold storage facilities enable them to make the journey in a dormant state so as to issue in an active and healthy condition in their new home.

The increase in the development of world trade has thus, as a necessary consequence, caused an increase in the rapidity of the dispersion of pests. The more we foster trade within the Empire, the more opportunity we give to the injurious insects and plants to move from one part of the Empire to another. It is thus safe to predict that unless special measures are taken to prevent it, losses resulting from the introduction of pests from other regions will increase from year to year in all parts of the Empire. Strict laws concerning the inspection and quarantine of imported materials, if enforced by sufficiently large and competent technical services, will do much to arrest the movement, but they will never check it completely. Several of the most injurious insects existing in the United States were introduced in recent years in spite of the inspection services.

(*) The sums which the United States Government has been obliged to expend to date in order to combat the Gipsy Moth, the European Corn Borer, the Japanese Beetle, the Mexican Bean Beetle, and the Oriental Peach Moth amount in the aggregate to over £12,000,000.

Once an injurious animal or plant is well established, it can seldom be exterminated. Measures designed to reduce as far as possible the damage which it occasions must, therefore, be adopted. Methods of mechanical control, such as spraying, fumigation, and so on, will usually reduce damage sufficiently to enable the farmer to produce a reasonably satisfactory crop; but they increase the cost of production, and thus throw a heavy burden on either the producer or the consumer, and are, at best, mere palliatives. Such methods must, practically always, be repeated year after year. They do not bring the population level of the pests low enough to prevent a recurrence or even an increase of damage in the following year. In certain parts of the world, the amount of arsenic now used during the ordinary treatment against the Codling Moth in apples, is so great that the arsenical residue on the fruit at the time that it is gathered is dangerously large and has to be removed by special processes. There is some reason to suppose that the arsenical compounds washed down into the soil may, after a certain length of time, prove injurious to vegetation. Furthermore, in some cases at least, there is definite evidence that certain species of injurious insects are becoming immune to some of the poisonous substances ordinarily used, such as hydrocyanic acid gas and lime sulphur wash.

In view of the disadvantages of mechanical methods of control, entomologists are now attempting to utilise the parasitic and predacious enemies which attack injurious insects in nature. Many pests are attacked by one or more species of parasitic or predacious insects, which, in combination with other factors, often prevent them from multiplying excessively in their native homes. As we have already stated, it appears to be the escape from the parasites and predators, resulting from the transport of the injurious species to a new country, which is in many cases mainly responsible for its undue increase. Since organisms increase in geometrical progression, the survival in each generation of even two or three females above the number necessary to maintain the population at an even level, may produce in a relatively short time, disastrous results. For example, one female of a species with a three-fold increase per generation will have in the twentieth generation almost 8,000,000 descendants. This explains the phenomenal spread and catastrophic destructive power of certain introduced insects.

It is obvious that the attempt to keep pace with insect invasions of this type by the use of the mechanical methods of control may be extremely costly or even ruinous.

Under such circumstances, an attempt to deal with the pest by introducing its habitual parasites and predators is always advisable. Abundance of the host insect is one of the most important factors favouring their increase. Unless for some reason the new environment is unfavourable to them, they increase rapidly in numbers at the expense of the pest, and sometimes eliminate it as a practical factor in agriculture, or, at all events, reduce its power of multiplication so that its importance is very greatly lessened.

During the period between the colonisation of the parasite and the time when control is effected, it retards, but of course does not arrest completely the multiplication of a pest which is increasing and spreading. During this intermediate period mechanical measures of control must, therefore, be adopted. It does not appear, however, that these measures will increase the time required for control unless they eliminate a larger proportion of the parasite than of the pest.

The process of biological control is thus one which may require a considerable period of time, during which developments should be carefully followed, so that additional beneficial species can be introduced if this is necessary. This slight disadvantage is, however, altogether outweighed by the fact that in successful cases, what is practically permanent relief is obtained for an absolutely trifling cost. Once biological control is established and the beneficial insects introduced are distributed over the whole of the infested area, any outbreaks that may occur owing to conditions momentarily disadvantageous to the parasites, due either to their own action or to that of environmental factors, are ordinarily brought under control automatically owing to the increased facilities for the reproduction of the parasites produced by a more abundant host population.

The successes obtained with the method of biological control in relation to a number of serious insect pests have been so striking that all the important entomological services now include it in the programmes of investigations concerning introduced pests. The Hawaiian Sugar Planters' Association have for many years past employed a special staff of entomologists to deal with the insects of sugar cane along these lines, and recognise that biological control has, in fact, saved the Hawaiian sugar cane plantations from complete destruction. The United States Bureau of Entomology maintains special investigators in all parts of the world to study and collect the insect enemies of introduced pests. The funds allotted to the laboratory

dealing with the European phase of the Corn Borer work alone have amounted for several years past to about £5,000, and sums almost equally large are expended on many other projects. The total sum set aside each year by the United States Government for work on biological control exceeds £100,000. The State of California has an independent organisation for the purpose, enthusiastically supported by the horticulturists of the State, because of the practical help they receive from it. One of the important projects carried on by this organisation, under the capable direction of Professor H. S. Smith, is the breeding of the *Cryptolaemus* ladybird to control the citrophilus mealy-bug, an extremely dangerous insect which is bound to become of considerable importance to the British Empire. On this project alone the sum of £40,000 is expended annually; but the work is far cheaper than any known method of mechanical control and is a complete success. The Canadian Entomological Service maintains at Belleville, Ontario, a parasite laboratory, mainly concerned with the Corn Borer and Peach Moth problems, but which will certainly extend its activities in the future, especially if we are able to provide it with the material it requires. Parasites introduced from England against a very serious insect of larch, the Larch Sawfly, have proved highly successful, and according to the Dominion Forest Entomologist, are rapidly bringing this pest under control. The Cawthron Institute in New Zealand, and, more particularly, the new Federal Entomological Service of Australia, have made experiments in biological control the most important department in their work, while efforts along the same line are being made in South Africa, India, and a large number of the British Colonies and Dependencies, as well as in foreign countries.

Within the British Empire, work on biological control has not, until quite recently, been as actively pursued as in some other countries, principally because of the inadequate character of the entomological services, due in turn to the insufficient appreciation of the tremendous losses incurred through the attacks of injurious insects. At present, however, attempts to introduce and utilise beneficial insects are becoming rapidly more numerous in all parts of the Empire. The effort to bring injurious plants under control by the use of phytophagous insects, initiated in Hawaii by Perkins and Koebele against Lantana, and in Australia against the Prickly Pear, is now being carried out on a more comprehensive scale in Australia and New Zealand, than in any other part of the world.

The use of the parasitic and predacious enemies of insect and plant pests constitutes, of course, as has already been pointed out, merely one of the methods of economic entomology. To describe it as a method destined in the near or even distant future to replace all other methods is quite unjustifiable. There are many cases in which it is inapplicable, either because the pests to be combated have no specific natural enemies, or because those which do attack them are of no practical importance, or, finally, because, though their work is sometimes effective, there is at present no way in which they can be utilised in practical work. Nevertheless, in spite of the fact that the application of the method of biological control is limited, the practical achievements in this field are economically of great importance,* and its possibilities are as yet far from being exhausted.

2. Preparatory Work.

The first step the entomologist must take when asked to utilise the methods of biological control in order to prevent damage by any pest is to diagnose accurately the cause of injury. Unless the plant or insect which is the cause of the damage has been accurately identified, it is impossible to find in the vast mass of entomological literature which now exists, the information which previous workers on the subject have accumulated. The first essential for the economic entomologist is thus the opportunity to consult with experienced systematists, having access to adequate collections and well stocked libraries. The inability of the authorities to appreciate this fundamental fact has rendered the task of the economic entomologist everywhere difficult, and has most seriously impeded the progress of the practical work in control.

When the injurious insect has been identified, the next step is to consult the works of other entomologists who have dealt with the subject. This is in itself an extremely difficult task. The literature on economic entomology is now enormous and the information in regard to important pests is scattered through a great mass of papers published in all parts of the world. If the entomologist has not at his disposal a fairly complete reference library, it is extremely difficult for him to collect, read and digest all the published works dealing with his subject. The fundamental necessities in work on

* One of the most remarkable successes in recent years is the elimination of the Coconut Moth by Dr. J. D. Tothill and his associates in the Fiji Islands. A detailed account of this work is now in course of publication.

biological control as in all other phases of economic entomology are thus facility of identification and a summary of the current literature. In order to meet these needs the Imperial Bureau of Entomology was founded in 1912, having as its principal function the collection and co-ordination of all information bearing on injurious or useful insects, and the organisation of a system for securing the authoritative identification, with reasonable promptitude, of all insects of economic importance, submitted by officials connected with Departments of Agriculture or Public Health throughout the Empire, together with the preparation of a card index to the whole literature of the subject and the compilation of a journal, intended to give an up-to-date epitome of the current literature. The Imperial Bureau of Entomology is now so well known, and its identification service and its Review of Applied Entomology so familiar to entomologists, that they need no description. They have, however, been mentioned in order to bring out the fact that the work on biological control inaugurated at the Laboratory, is being carried on within an organisation already possessing comprehensive resources in regard to identification and a bibliographical service unequalled anywhere in the world, which renders possible an extremely rapid and efficient survey of any problem.

Through the courtesy of Dr. S. A. Neave, Assistant Director of the Bureau, the Laboratory has obtained the part time service of Miss R. N. Davenport, an expert bibliographer, who has prepared in the form of a card catalogue, a complete bibliography of all the projects undertaken by the Laboratory. This bibliography is based, for the most part, on the Review of Applied Entomology and enormously facilitates the preliminary work on our problems.

As the work of the Laboratory is, at present, almost exclusively in the field of biological control, the information regarding any insect pest which is most important to us, is, of course, that which concerns its parasites and predators. In order that this information may be obtained in any given case, without delay, the bibliographer has prepared a card catalogue of the parasites and predators of all the insects mentioned in the Review of Applied Entomology as having natural enemies, and cross-reference cards giving the recorded hosts of all the parasitic and predacious species mentioned, and the titles of the articles in which the records are given. This catalogue now includes over 10,000 cards, though it is not yet by any means completed. A list of parasitic Nematodes has recently been included in it.

A list of all the projects submitted to the Laboratory by the entomologists of the Empire is kept on cards in a special file, on which the most important information concerning the species studied is tabulated. As soon as it has been decided to take up the investigation of one of these projects, the member of the staff detailed to the work consults the bibliography of the species and prepares a digest of the most important information, with special regard to the distribution and relative abundance of the species in various parts of its range. He then draws up from the Host and Parasite Catalogue a list of the parasites and predators recorded for the pest, making a special note of any point likely to be useful in the collection of parasitised material. A careful summary of these data is made and copies supplied to the field agents of the Laboratory for their information and guidance.

3. The Preliminary Field Survey.

When the data mentioned in the preceding paragraph have been gathered together they very often give a very good general idea of the main facts concerning the biological control of the injurious species. However, our information in regard to the parasites and predators of most injurious insects is still so incomplete, and our knowledge of the possibilities of the method so vague and uncertain that we can seldom make a decision in any given case without a careful investigation. As is well known, the published lists of the parasites and predators of injurious insects contain a great deal of erroneous information, owing to the fact that proper precautions are not taken in determining the relations between the parasitic and predacious species and the form they are supposed to attack. On the other hand, the natural enemies of a great many injurious species are still practically unknown even in Europe. For example, in 1919, only a single parasite, and that one wrongly determined, was known from the European Corn Borer. A careful investigation showed, however, that over twenty parasites belonging to several groups attack this pest. For this reason it is almost always necessary to make a careful field survey of the parasitic and predacious fauna of any injurious insect. In planning this survey it must be remembered that the parasites and predators attacking a pest very often differ in different parts of its range. Sometimes this variation depends on the fact that in different parts of the area in which it exists, it feeds on host plants belonging to different species. In other cases, although the host plant remains the same, the parasitic and predacious fauna

differ in composition in different bio-climatic regions. Furthermore, even when the same species of parasites attack the same pest in several different regions, it may happen that one of them is consistently abundant in one region and consistently rare in another. It follows that even when we are dealing with a single species of insect it is impossible to study and collect its parasites and predators in a single one of the districts it inhabits, while if the parasites and predators of a large number of species have to be investigated, the examination of a great number of different areas is absolutely essential.

It is obviously impossible for the staff of a small laboratory to carry out exploratory work of this kind. The field investigator must be able to move from part to part about the country with considerable rapidity in order to cover as much ground as possible during the period when the material containing the parasites or predators is available. It is not practicable for him to carry about with him the apparatus and equipment necessary for dealing adequately with the material he collects. On the other hand, the members of the laboratory staff cannot possibly suffice for the work they have to do if they are obliged to spend any large part of their time in the field. In order to work efficiently a parasite laboratory must, therefore, have a staff divided into a body of workers who remain at headquarters and a body of field investigators or scouts. In the opinion of the present writer the possession of an efficient field staff is absolutely essential for success in work of this kind.

With very few exceptions, as has already been pointed out, we know very little about the parasites and predators of even the major pests and hardly anything about their distribution in relation to their hosts, and in any event the precise manner in which the parasitic and predacious fauna of a given pest varies in composition in relation to habitat is usually unknown. It is, therefore, impossible to lay down any rules for the organisation of the field work equally suitable for all projects. However, as in all other aspects of the work, it seems, on the whole, better to organise investigations on some rational principle, even though this may be inadequate in certain cases, than to proceed simply by empirical or hit-or-miss methods. An effort is, therefore, being made to sub-divide the European area in which most of the work is done into the principal bio-climatic zones, differing in climatic, agricultural, and other features. It is hoped that eventually it will be possible to establish an agent of the Laboratory in a sub-station in each of these areas. The staffs of sub-stations working

continuously in a relatively restricted field in a given country rapidly acquire a very thorough knowledge of local conditions and customs, and through their acquaintance with the inhabitants of the district are able to carry out a survey of any kind with great rapidity and accuracy.

The first effort of the present Superintendent was, therefore, to bring together the nucleus of a field service. It has not, of course, been possible up to the present, because of the relatively limited resources of the Laboratory, to cover even in Europe, anything but a small proportion of the area in which collectors should be located. We have now, however, three field agents; one located in England, a second in Northern France, and a third in the Mediterranean coastal regions.

To map out the bio-climatic areas, even very roughly, is not by any means an easy matter. Most papers on bio-geography, even in Europe, are either much too broad in scope to be of any use in work of this kind, or else treat of areas which are very limited in extent. No satisfactory treatise on the bio-climatic areas of Europe apparently exists. The entomologist is, therefore, obliged to utilise the information obtained from topographical maps, rainfall maps, and temperature charts, and draw up a plan of survey based upon the data given by these maps, and the available information concerning the distribution of the host plant of the species on which he is working.

The system of installing special agents in each locality to be investigated may appear at first sight to involve unnecessary expense, which could be avoided by obtaining the co-operation of scientific individuals or organisations in the various parts of the world. The fact is, however, that efforts to carry on any prolonged and difficult investigation in this way are very seldom successful, not because the average scientist is unresponsive to requests for assistance, or fails to appreciate the interest or importance of the problem in which he is asked to co-operate, but simply because he cannot find time from his own duties to undertake the detailed investigations which are necessary. Furthermore, if the data collected from various regions are to be of any value they must be gathered according to some definite and uniform plan, and it is very difficult to impose any plan of this kind upon individuals who give their services freely, and whom the organiser of the work is consequently not free to criticise. Much useful information can often be obtained from scientific workers or

agricultural officials in the region studied, but unless they can actually be employed by the organisation it is impossible to rely upon them for any continuous and detailed study or collections. A field organisation under the control of the staff at headquarters is therefore necessary.

After it has been decided in what region the preliminary collections shall be made, the next step is to pick out points within the region likely to give a representative idea of conditions as a whole. It is, of course, impossible to decide in advance what localities are really most suitable for the work. The best practical rule is to select points which are at once accessible and significant, in that they represent, within the bioclimatic area studied, a number of different sub-types, characterised by topographical, agricultural, or other features. In order that work of this type may be planned to the best advantage, it is desirable to have at headquarters a collection of the most important works dealing with the climatic, agricultural, and biological characters of the principal areas in which the work is to be done. An effort is being made to gather together a library of this kind. Another very important part of the equipment necessary for the work is a collection of detailed and accurate maps, including a series on as large a scale as possible, for the regions in which collections are made. One set of these maps is kept at headquarters, the other in the possession of the agents in the field, who send with their material, indications as to the precise points at which their collections are made. In this way it is possible, as the work progresses, to obtain exact information as to the ecological conditions in each locality, which can then be correlated with the data obtained from the examination of the material.

*The work of the field agent will not give results corresponding to the efforts expended, unless reasonably full and accurate data concerning the conditions under which the material was collected are obtained. In order to ensure this the most convenient method is to supply the agent with printed forms, on which the data desired by the entomologists in charge of the work are indicated and which can be filled in at the time the collections are made. The printed forms are bound up for convenience in booklets provided with a heavy cardboard cover, and filed as they are received.

The equipment of the field agent need not be very elaborate since the detailed investigation of the material sent in is carried on at headquarters. He is, however, provided with a field kit consisting of

a hand lens or folding microscope, and the usual entomological equipment, together with a supply of mailing boxes. The design of the mailing boxes is of considerable importance. The type used at the Laboratory (Pl. III, Fig. 1) is the one originally developed at the Corn Borer Laboratory of the United States Department of Agriculture, for the shipment of the larvæ of the Corn Borer. It is a cylindrical brass box, with large openings covered by copper gauze in the sides, so as to give a certain amount of ventilation. These boxes are sent in heavy cardboard postal boxes of the same size, with a cover attached by tapes. They are not too heavy to send through the mails and are yet strong enough to resist injury. They are therefore used in all cases where the material collected is not too bulky to be sent in this way.

As is well known, the various stages of insects and plants are attacked by different pests or natural enemies. An effort is therefore made to obtain in the preliminary collections material of each stage. This necessitates making one round of visits about the end of the period of oviposition, and another about the middle of the period of pupation. It is obvious that when several projects are being carried out by the same agent his itinerary and the organisation of his work must be very carefully planned.

It is hardly necessary to give any details as to the precise methods of collection, since these differ in regard to every insect studied. The regions in which collections are made are for the most part at a relatively short distance from headquarters, so that the collections are posted on the same day that they are made. There is thus usually little mortality during transport. The field agent is, of course, notified of any mistakes made during the process of collecting and packing as soon as the material has been examined.

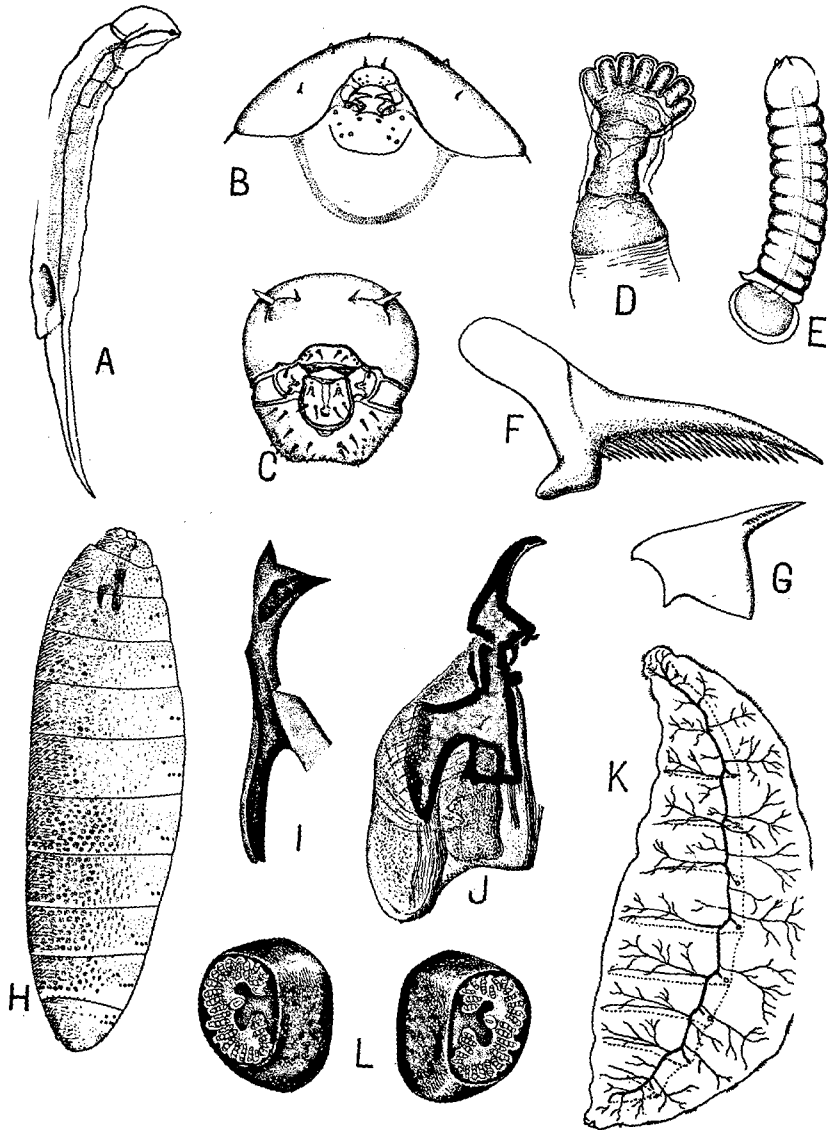
4. Examination of the Material.

It is an unfortunate fact that the technique employed by many entomologists in studying the parasites and predators of insect pests in the past has been in some ways seriously defective. A method very frequently used is to take the material and place it without any careful examination in large cages, where it is supplied with food, after which the adult pests and parasites which emerge from it are collected from time to time. This procedure has been in the past, and still is, the cause of a great many serious errors, which could

easily have been avoided. The methods employed during this phase of the work must be such as to give absolutely accurate and definite information as to the relation of any parasites or predators obtained to the host which is being studied ; or, in other words, they must be such as to demonstrate beyond any possibility of doubt that the parasites or predators obtained have actually been feeding upon the insect with which they are associated in the rearing cages.

The first step in the examination of the collection is, therefore, to pick it over very carefully, examining, if possible, every individual specimen, in order to make certain that nothing but the species studied is being introduced into the rearing cages. If two or more allied genera or species are being collected these should, as far as possible, be separated before the material is studied. In many cases the preliminary collections contain cocoons, larvæ or puparia of parasites, and larvæ or adults of predators, considered by the field agent to be associated with the pest under consideration. A very careful investigation must be made before it can be decided that these insects are really parasitic or predacious on the pest studied. In the case of larvæ, cocoons, or puparia of parasitic insects, a careful search must be made for the remains of the host, which can generally be found in close proximity to the parasite at the time of collection. Any remains of this kind, such as larval skins or pupal shells, are prepared and examined microscopically, and compared with known specimens of the host insect in the same stage. Unless this precaution is taken, very serious mistakes can easily be made. Thus, during the work on the parasites of the Corn Borer, undertaken by the writer, a considerable number of cocoons of Tryphonine Ichneumonids were found in the tunnels of the hibernating caterpillars, and these were at first considered to be parasitic on the Corn Borer, but later investigations showed that they really had emerged from the larvæ of certain sawflies which entered the tunnels of the Lepidopteron in order to pupate. Their true host relations were eventually determined by an examination of the empty host skins found in close proximity to the cocoons.

Furthermore, it must be remembered that the parasites or predators which issue from cocoons or puparia associated with the host, do not always belong to the species which produce the cocoons or puparia in question, but may be secondary parasites, or parasites which are for the most part primary but become secondary parasites under certain special circumstances. For this reason, unless the



and eight abdominal segments ; without a definite head capsule, the cephalic region greatly reduced, unpigmented, retractile, bearing only some microscopic sensoria ; mouth parts consisting of a single median hook or a pair of parallel non-opposable lateral hooks having a dorso-ventral movement in the median plane and which are posteriorly articulated to or fused with a highly chitinised and pigmented skeletal structure in the wall of the pharynx, which is U-shaped in section and provided with muscles so as to form a pharyngeal pump ; tracheal system apneustic, metapneustic, or amphipneustic ; the anterior spiracles, when present, usually digitate and situated near the posterior border of the first segment, the posterior spiracles usually much larger than the anterior spiracles, situated side by side on the flattened posterior face of the last segment ; cuticle unpigmented, excepting in the first stage larvæ of certain groups, but bands of pigmented spines usually present : almost always three larval stages : usually contracting a respiratory relation with the external air ; parasitic forms endophagous ; pupa formed within the hardened larval skin, constituting a puparium.

Diptera Cyclorrhapha (Pipunculidae, Phoridae, Muscidae sens. lat.).

Group II.—Larvæ legless, but not usually maggot like, cylindrical in form though sometimes with a spherical or conical tail ; three thoracic and ten abdominal segments in most forms, though various exceptions exist ; mouthparts consisting of a pair of opposable mandibles, articulating with the tentorium at the sides of the mouth opening ; maxillary and labial appendages sometimes present or represented by definitely circumscribed sensorial areas, but often absent ; with a definite head-capsule, often pigmented, the cephalic region not notably reduced, often large, not retractile, bearing microscopic sensoria or setae ; pharyngeal wall without a definite chitinised skeleton ; tracheal system apneustic, metapneustic, or peripneustic, with spiracles approximately equal in size and similar in form ; cuticle unpigmented excepting in the early stages of certain Chalcids (Perilampidae, Eucharidae) ; setae often present but usually feebly or not pigmented ; bands of highly pigmented spines not usually present ; four or five larval stages ; usually lying freely within the body-cavity of the host without contracting a respiratory relation with the external air ; parasitic forms ectophagous or endophagous.

Hymenoptera Parasitica.

A. Maxillary and labial appendages present or sensoria arranged in definitely circumscribed maxillary and labial areas, at least in the later stages of development ; cocoons usually formed.

(a) An accessory longitudinal tracheal commissure lying in the thoracic segments ventra of the tracheal trunk, toward the ventral part of the body ; tracheal system apneustic or peripneustic ; nine pairs of functional spiracles usually present in the later stages ; a conical tail often present in the endophagous species ; mandibles usually simple ; three thoracic and ten abdominal segments ; ectophagous or endophagous ; usually solitary or feebly gregarious.

Ichneumonidae.

(b) No accessory longitudinal commissure ; tracheal system apneustic or peripneustic ; nine pairs of spiracles in the later stages ; a globular tail or caudal vesicle often present in the endophagous forms though a trifurcate tail is sometimes present ; mandibles sometimes simple but often toothed or pectinate ; three thoracic and ten abdominal segments ; ectophagous or endophagous ; often gregarious, seldom solitary.

Braconidae.

B. Maxillary and labial areas not differentiated ; the sensoria below the mouth opening not grouped on definitely circumscribed regions ; mandibles usually simple, no accessory longitudinal tracheal commissure in the thorax ; apneustic, metapneustic or peripneustic, spiracles variable in number and arrangement ; endophagous forms sometimes with a tail ; cuticle usually colourless, but highly pigmented in the first stage larvæ of the Eucharidae and Perilampidae ; setae present or absent ; three thoracic and ten abdominal segments usually present ; ectophagous or endophagous ; usually gregarious, seldom solitary ; except in the case of certain parasites of Coccids, or the eggs of Lepidoptera, not contracting a respiratory relation with the atmospheric air ; cocoons seldom formed.

Chalcididae.

This key will help to identify the parasites most commonly encountered in dissections, but does not include the members of several minor or little known groups. Of these, the most important are the heterogeneous family Proctotrypidae, including a number of parasites of economic insects such as leaf-hoppers, gall-gnats, wire-worms, etc., and the parasitic forms of the family Cynipidae, of which

a number are parasitic in the larvæ of root-maggots, blow-flies, etc. Extensive further researches are necessary before a summary of the larval characters of these groups can be given.

The most thorough treatment of the larvæ of any group of the parasites of insects is that published in 1924 by H. L. Parker on the larvæ of the Chalcididae. A general account of the larval biology of the Ichneumonidae, with numerous figures, was given by Cushman in 1926; while valuable descriptions of Braconid larvæ have been published by Keilin, de la Baume Pluvinel, Crossman, Genieys, and others. Proctotrypid larvæ have been described by Ayers, Marchal, Keilin and Thompson, Haviland and Eastham, and Cynipids by James, Keilin and Haviland. Descriptions of numerous species of Tachinid larvæ will be found in the papers by Green, Nielsen and Thompson listed in the bibliography.

An effort is being made to gather together at the Laboratory, for the reference of the staff, as complete a collection as possible of the larval forms of the various parasitic groups, together with a complete set of all the existing papers dealing with the subject. The collection of Tachinid larvæ includes over 100 species of this group belonging mostly to the European fauna.

An important point concerning the examination of the material collected concerns the keeping of records. An effort has been made to devise a system of notes as simple and practical as possible, but capable of extension in the case of projects requiring long and extensive investigations. The note cards are kept in loose-leaf notebooks and are filed at the conclusion of an investigation. Each lot of material received from the field and each experiment started on the subject is given a separate number or sub-number, and all material placed in rearing cages, or preserved in any way is labelled with this number. At the conclusion of each experiment the data is filed under its respective number, and under the name of the species concerned. Provision is made on the note slips for the utilisation of a numerical system for the classification of data, analogous to that proposed some years ago by Hinds and Bishopp for the work on the Cotton Boll Weevil.

From the preliminary collections and dissections it is generally possible to select one or more of the best localities in which to make collections on a large scale. Before this work is begun, it is, of course, necessary to investigate more fully the biology and inter-relations of the various species concerned. In order that this work may be pushed

forward as rapidly as possible, it is sometimes desirable to accelerate the development of the parasites. A portion of the material collected is, therefore, placed in an incubator acting at a constant and relatively high temperature, and in this way the adults of the parasite or predator can often be obtained many months before they would normally emerge in the field, and any information contained in the literature in regard to their biology can be readily secured. This sometimes makes it possible to carry out the whole work from the preliminary collections to the large scale shipment within a single year.

5. The Choice of the Species to be utilised.

It is now well known that the great majority of pests are attacked by several species of parasites and predators, which affect them at different stages of development. The various species differ in habits and in relative efficiency, so it is necessary to devote some thought to the question of their relative usefulness, or, in other words, to the selection of species likely to be suitable for the control of the pest in the country into which it has been introduced. This subject has been carefully discussed by several entomologists. Trouvelot (1925) considers that the choice of parasites depends, in the first place, on the characteristics of the biology of the host insect. If the host is a species of which the population remains approximately constant from year to year, as in cases where energetic destructive measures are not periodically employed, the most valuable parasites will probably be those with markedly specific host relations, producing an abundance of offspring and having a developmental cycle more rapid than that of the host. Beneficial species of this type will thus be especially valuable against insects destructive to perennial cultures, such as fruit or ornamental trees, forests or grasslands.

If, on the contrary, the host is a species which fluctuates violently in numbers owing to remedial measures or the action of climatic factors, polyphagous parasites will be desirable, especially if the host becomes very rare at periodical intervals. Such parasites will be able to maintain themselves by breeding on the other hosts to which they are ordinarily attracted and will thus be already present in the field in appreciable numbers when the population of the host species begins to increase. A specific parasite would in such circumstances become extremely rare owing to the lack of hosts. Furthermore, while the food material of the host (or pest) is maintained by agriculture at a constant high level, so that it can increase rapidly and easily if other conditions are favourable, it will be some time before

the parasite can profit by this increase. It will recover less rapidly than the host because its food material has been reduced and rendered less accessible by the measures of control taken.

Among the parasites attacking only one particular stage of a pest with separate and distinct generations, such as the Gipsy Moth, the Codling Moth in the northern part of its range, the Pine Shoot Moth, etc., it seems best to select species of which the development synchronises with that of the host. If, in such a case the parasite passed through several additional generations in other hosts, it might not be able to maintain itself at a sufficiently high population level with regard to the pest against which it is being utilised, owing to the occasional absence or rarity of some of its intermediate hosts.

On the other hand, for beneficial insects attacking various stages of their hosts, and for those attacking hosts with overlapping generations, an asynchronous development is often desirable since it permits of very rapid multiplication.

Other important points to be considered are the parasitic activity of the species considered (effective reproductive rate, power of searching for the host, etc.), the tendency to superparasitism (deposition of an excessive number of eggs in a single host), tendency to hyperparasitism (habit of attacking other primary parasites), and, finally, the rapidity of dispersion of the beneficial species as compared to that of the host.

According to H. S. Smith (1919), the points of greatest importance concerning the habits of the available beneficial forms are the comparative reproductive capacity of the host and the available entomophagous insects; the powers of locomotion both of the pests and their natural enemies, and the sequence of available entomophagous insects.

It does not appear, however, that up to the present the majority of entomologists engaged in practical work in biological control have made any serious effort to conform to these rules. The most important factor governing the conduct of most of the practical operations which have been undertaken has probably been of the financial order. Generally speaking if sufficient funds have been available, the practice of entomologists has been to import all the parasites and predators found attacking the pest without very much regard to their possible or probable interactions or their effect on species other than the pest considered. This, for example, has been the method followed in the long series of experiments in the Hawaiian

Islands, and in the operations carried out by the U.S. Bureau of Entomology in relation to the Gipsy Moth, the Brown Tail Moth, the Alfalfa Leaf Weevil, the European Corn Borer and the Japanese Beetle.

In recent years, as a result, more particularly, of the work of Pemberton, Willard and Bissell in Hawaii, there has grown up a belief that the practice of miscellaneous introductions may be, in some cases, very injurious. According to these authors certain of the parasites of the Mediterranean Fruit Fly introduced into Hawaii have interacted in such a way that a parasite able alone to control the host insect was greatly reduced in efficiency through the action of another parasite of much less value as a controlling agent. From this some entomologists have concluded that, in general, it is inadvisable to introduce parasites which may come into conflict in some way. Such conflict is, of course, a matter of fairly frequent occurrence. Furthermore, a few parasites are known, which, though they are of considerable importance in the role of primaries, may, on occasion, develop as hyperparasites of other species. The whole subject has recently been discussed in a detailed and comprehensive way by the well known American authority on biological control, H. S. Smith (1929), who maintains that it is probably never disadvantageous to introduce conflicting species no matter in what way the conflict may come about. He shows fairly conclusively that the data given by the Hawaiian authors really does not constitute a valid proof of their contention, and his treatment of the whole subject is in every way so far superior to that of the upholders of the opposite view, that the hypothesis of multiple introduction must be considered, at present, to hold the field.

It may, however, be shown mathematically that in certain special cases, during the period when both the host and the parasite are increasing, a parasite, which by itself is unable to overtake the host, may yet be able to check the increase of another parasite capable alone of exterminating the host. Certain results obtained by V. Volterra in his mathematical studies also seem to suggest that if a parasite and its host have reached a condition of equilibrium, the addition of a second parasite might produce perturbations from which the host would ultimately emerge at the same average level. It seems, therefore, that the whole subject merits further discussion, even from a theoretical standpoint. One point which may, however, be borne in mind, is that a successful introduction may be retarded but cannot be annulled. Once a parasite has

become established in a new country, it is impossible to exterminate it, and if any harmful effect does result it will continue for an indefinite period. It seems, therefore, in view of the complex way in which parasites act upon each other and upon their environment that it would be as well, on general grounds, to proceed with considerable prudence. It may be, as some maintain, that even when a host insect has reached a condition of stability a single species of parasite is unable to bring it under control in the economic sense, either because it is unable to attack the host over the whole area in which it exists, or else because the gradual rarefaction of the host population produced by the action of the parasite begins to interfere with the activity of the latter before it has reduced the host to a point below the level of economic damage. Again, the action of a parasite or predator is not usually equally intense over the whole area of distribution of the host, from which we may infer that a parasitic fauna, including several species, is generally likely to be necessary. Nevertheless, the most satisfactory method of ensuring the establishment of a parasitic or predacious fauna capable of producing the desired results, seems to be to introduce the parasitic or predacious species singly, and observe their progress and the effect which they exert upon the host when they have reached their maximum development, after which other species can, if necessary, be brought in with a definite knowledge of the needs of the situation. If there is the slightest risk of producing ill-effects which will endure until the end of the time, by the promiscuous and simultaneous introduction of all the available parasites and predators, this method may legitimately be rejected, even though some loss of time may thereby be entailed. The presence of a large number of species of natural enemies greatly complicates the task of the entomologist who is studying the effect of the introduction, and probably will not, in many cases, very greatly accelerate the process of control.

We therefore prefer, for the present, to introduce one species of natural enemy at a time, and to wait until this species has begun to exert its effect before proceeding further. This method of work is not only, on general grounds, justifiable but is also the most practicable procedure in the case of an institution like Farnham House Laboratory, where the amount of money available for any one project is distinctly limited. On the other hand, if only a single parasite is collected for export, it must be chosen with some care. The simplest and most satisfactory principle on which to make the collection is to choose the species which is the most efficient in the

region studied. If in two different parts of the area in which collections are made, there are two species equally efficient, the choice will fall on one from a region which is similar in its general characteristics to the one into which the parasite is to be introduced. There are, of course, difficult cases, as when an important parasite, primary in one species may be secondary in relation to some other important pest in the infested area. Such cases are dealt with as they arise.

The idea of parasite "efficiency" needs some explanation. As used in ordinary practical work, it generally designates the species which is most frequently found associated with the host and consistently destroys a large proportion of its population, this proportion being calculated, however, not in relation to the total number of offspring produced, but in relation to the population at the time of collection, i.e., the number of individuals in the developmental stage collected. Such values are, of course, not comparable either as between parasites attacking different stages in the same zone, or between parasites attacking the same stage in different zones or different seasons, because they do not indicate the fraction of the total population destroyed by the various species. This is serious enough, but what is more so is that they have relatively little value as indicators of the real significance of the parasites as controlling factors, because they give us no indication as to the fraction of the total population for the destruction of which they are indispensable, nor of its potential value as a controlling agent.*

On the other hand these figures do give us some idea as to the relative value of species attacking the same stage in the same zone and in the same season, and in view of the ease with which they can be obtained and the enormously greater difficulty of obtaining the true values, we are obliged, at present, to use them as rough indicators of parasite efficiency.

In view of the difficulty of predicting the behaviour of an organism after it enters an environment in which it has not previously been observed, the formulation and adoption of more complicated rules seems, at present, impossible.

* It appears from the studies of Volterra that if s is the coefficient of decrease of the parasite in the absence of the host and γ the coefficient of its "parasitic activity" (ability to detect and attack the host), then the *average level* of the host population, and, consequently, the average level of economic damage, will depend on the value of the relation $\frac{s}{\gamma}$, which could therefore be considered, from the economic standpoint, as the coefficient of parasitic efficiency.

6. *Large Scale Collection and Shipment.*

Although the introduction of the natural enemies of an introduced pest is now very generally practised, some considerable interval of time usually occurs between the moment when the pest is first observed and the moment in which the parasite is introduced. Furthermore, a considerable period usually elapses before an introduced pest is discovered. The data available on this subject seem to indicate that during the initial period following its introduction the pest usually spreads as it increases in such a way as to cover a very large area, in which it is present for a fairly long time in numbers so small that it escapes detection, after which it suddenly appears in a large number of points, where it rapidly becomes abundant.

Since the host insect is usually present in large numbers and distributed over a large area, it is obvious that whenever possible it is best to introduce a parasite or predator in as large numbers as possible at a number of points over the infested area. In this way we are more likely to secure the establishment of the beneficial species and the control of the pest within a reasonable time. The provision of parasitic or predacious species in large numbers thus constitutes a very important problem in work on biological control. The supply of a large number of individuals of a parasitic or predacious species can be arranged in two ways. The first is the breeding of the species from a small stock collected in the field; the second is the direct collection in its native home of large numbers of the parasite or predator. Each of these methods has its special advantages and disadvantages.

The advantages of the system of breeding the parasite in large numbers from a small stock is that it very greatly reduces the expense and effort necessary in the field. As we have already pointed out, the various parasites and predators which attack a pest are not uniformly distributed over the whole area in which it exists, and though they may be extremely abundant at certain points they may be very rare in others. The points in which they are abundant are, furthermore, not necessarily the same from year to year, so that in order to be sure of obtaining a large number by field collections in any given season a great deal of scouting work is sometimes necessary. All this can be avoided by breeding the species in the laboratory, and, as will be shown later, the cost of this operation, if properly organised is, in some cases, much less than that of making collections directly in the field. Another advantage of the method of breeding in the

laboratory is that the danger of introducing hyperparasites or other undesirable insects is practically eliminated, since all the material eventually introduced descends from a small number of specimens, which have been identified with certainty. Finally, in a good many cases the breeding work can be arranged in such a way that the adults are ready for liberation at the time when the hosts are in the condition most suitable for attack, whereas when the material is collected from the field it may be necessary to keep it in cold storage and ship it over long distances, so that it arrives at a time when the host has disappeared from the field.

The disadvantage of this method lies principally in the fact that it requires a very considerable amount of technical knowledge and equipment in order to carry it on successfully, and, at least at the beginning, a staff of trained assistants who must usually be kept on the pay-roll all the year round. Furthermore, there are certain parasites of which the host insects are extremely difficult to rear in captivity. The rearing of the parasite in large numbers depends, of course, on the rearing of the host. In really difficult cases the loss of material due to the mortality in rearing the host may very greatly increase the cost of production.

The advantages of the method of field collection on a large scale are, in the first place, that a rapid extension of the effort is possible with considerable ease because the method of collection can be readily taught to ordinary labourers, who might never acquire the necessary technical skill for carrying on the breeding work. Nothing but the most inexpensive and simple equipment is usually necessary. In the second place, the technical organisation necessary in order that secondary parasites and unwanted species of the other insects may be eliminated and the equipment required to ensure this, is much less elaborate than that which is needed for breeding work. In cases where it is desirable to introduce a number of species of parasites, several of these can usually be obtained at the same time, whereas several quite different methods and sets of equipment may be necessary if a number of species are to be bred in captivity. When species are collected directly in the field in large numbers, the establishment of the parasite can often be brought about immediately, whereas a long time may elapse before material can be obtained in sufficient quantities for the liberation of a large colony by breeding. Finally, after the work of rearing and liberation, which takes relatively a short time, the entomologist who is being supplied with material

collected in the field need give little further attention to the project, whereas continuous and often very time-consuming work is required for the breeding of the parasite.

The disadvantages of field collections are, in the first place, the greatly increased expense at the collection centre and in the transportation of the material collected, the danger of introducing hyperparasites or unwanted species of various kinds when the entomological staff at the receiving end is inadequate, and, finally, the difficulty of getting material to the point where it is to be liberated at the correct moment. This is especially serious in cases where material is transferred from the Northern to the Southern Hemisphere, or vice versa.

It will be clear from what has preceded that whether we are to choose the method of large field collections or that of breeding in the laboratory depends, on the one hand, upon the habits of the species concerned and, on the other, upon the nature of the organisations collecting and receiving the material. Certain species mate readily in captivity but can only with the greatest difficulty be induced to oviposit; others oviposit freely when they are collected in the field, producing offspring of both sexes, but cannot be induced to mate, and, if reared in the laboratory from larvæ produce only male offspring. Others exhibit in captivity unfortunate habits which make it very difficult to rear them in large numbers; for example, *Pimpla instigator*, when supplied with chrysalids, oviposits freely in them, but if it is allowed to do so, bites holes in them, even after oviposition, and drinks the blood of the chrysalids, so that both the host and the progeny of the parasite ultimately perish. In other cases the parasites are easy to handle, but the breeding work is rendered difficult by the problem of obtaining and rearing the host in large numbers. This is especially true in the case of insects like stem-borers, leaf-miners, or gall-makers, which live within the tissues of green and living plants. In such cases, as has already been mentioned, the loss through mortality and the expenditure of time and money necessary to collect host material, renders breeding work quite unprofitable.

The practice we have adopted is, therefore, to restrict our breeding work to species which reproduce freely in captivity and of which the hosts can be either bred or collected with ease and rapidity. In other cases we rely on large collections in the field. The existence of trained staffs in the laboratory and in the field enables us to change our method

of attack according to circumstances. Thus, the method of breeding on a large scale in the laboratory is used in the case of *Alysia manducator*, the parasite of the Sheep Blowfly, *Ascogaster carpocapsae* the parasite of the Codling Moth, and certain other parasites of this species, *Aphelinus mali*, the parasite of the Woolly Aphis, and *Blastothrix sericea*, the parasite of *Lecanium coryli*, of which the two latter species are bred in the insectaries. On the other hand, our consignments of the parasites of the Earwig, the Pear Slug, the Pine Shoot Moth, and the Sirex Wood Wasps, have been collected exclusively in the field.

The general subject of the breeding of the insect parasites and predators is much too difficult and technical to be treated within the compass of this paper, especially since the methods to be adopted vary a great deal in the case of different species. A few general suggestions may, however, be useful.

Not very many years ago the general impression among entomologists was that the best results could probably be obtained by providing the parasites with conditions resembling, as closely as possible, those existing in their natural environment. Parasites were, therefore, placed with the hosts in large cages, where they were able to fly about freely, and in which the hosts were feeding on plants arranged, as nearly as possible, in a natural manner. As work on breeding progressed, however, it was found that arrangements of this kind were, in many cases, not merely unnecessary but positively injurious. Thus, during the work in the Gipsy Moth Parasite Laboratory, the first attempts to breed the Dipterous parasites were made in large cages resembling outdoor insectaries, but it was found later that the loss through mortality before the parasite had reproduced in cages of this type was much greater than when various small cylindrical glass cages were used. Similarly, a number of years ago, when the writer first attempted to breed *Microbracon brevicornis*, the braconid parasite of the European Corn Borer, he thought it necessary to supply the parasite with live Corn Borer larvæ, lying in their tunnels in portions of the green Corn plant; but it was soon found that much better results could be obtained by placing the parasite in small tubes with unprotected larvæ of the Corn Borer, and a method of rearing the species along these lines on a very large scale was ultimately developed. Finally, in the breeding work on *Trichogramma*, the egg parasite of the Codling Moth and other Lepidoptera, this process of eliminating all but the conditions essential for life and reproduction in the most

efficient possible manner has been carried to its maximum. The parasite in question ordinarily attacks the egg of various butterflies and moths, which it finds on living plants in nature. As a result of a careful series of experiments for which Mr. S. Flanders, now of the University of California, is largely responsible, it has been found that this species can be bred in colossal numbers by utilising the eggs of certain insects attacking stored products, as for example, *Sitotroga cerealella* and *Ephestia kuehniella*. These moths are reared in cages of a special type on flour, rolled oats, or grain, and their eggs obtained in large numbers by an ingenious mechanical method. The eggs are then spread in fairly large numbers on sheets of paper in petri dishes with a number of the parasites, judged sufficient to produce practically complete parasitism of all the material supplied. In this way, by a careful adjustment of external conditions and a careful attention to the minute details of the process, the breeding work has been developed to such an extent that, under favourable conditions, a million parasites a day can be produced, though, as will be clear from the description, the conditions are very different from those the parasite meets in its natural habitat.

After some experience in this line of work, the writer has, indeed, become convinced that natural conditions are, in general, far less favourable to the development of large populations than those which can be supplied in the laboratory. By a careful study of the biology and physiology of the parasite and its host it is usually possible to determine, with a fair amount of precision, the conditions under which its development will proceed in the most rapid and normal manner. Conditions of this kind can then be supplied continuously, whereas in nature it is certain that they obtain only at infrequent intervals. For purposes of breeding, therefore, it seems that artificial conditions, in general, are likely to give more satisfactory results than in so-called natural conditions, and the practical results obtained up to the present support this theoretical conclusion.

As has already been stated, the process of breeding a parasite successfully in the laboratory depends essentially upon a careful study of its biology and habits. This does not mean that it is necessary in all cases to carry on a prolonged and detailed investigation into all phases of the physiology of the insect. If such work were necessary progress would be extremely slow. As a matter of fact, the number of points which need be investigated is relatively few. All that is necessary in regard to the phase concerned is to determine with

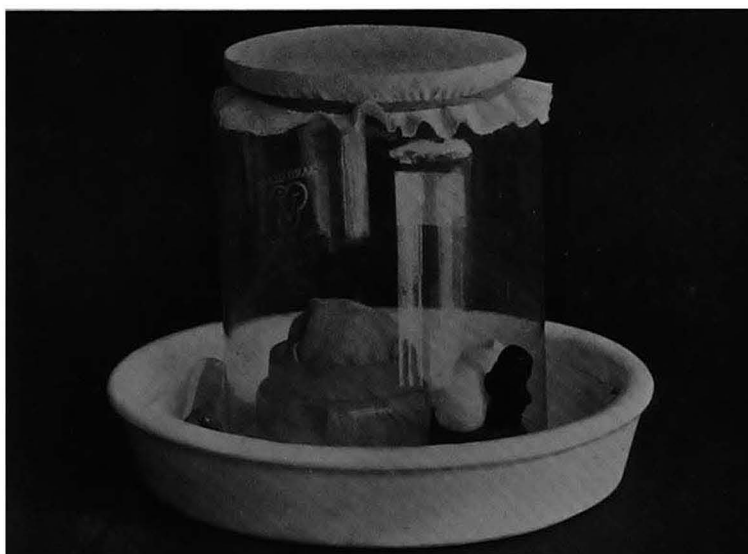
reasonable accuracy, under what conditions the reproductive process goes on with the greatest rapidity and in the most normal manner, so that large numbers of healthy offspring are produced.

In general, the receptacles in which the parasites are confined, should be large enough for them to move about comfortably, without being so spacious that they can take refuge in some corner at a considerable distance from the host or attain high speed in flight. In order to obtain satisfactory results, the parasite must, of course, be supplied with food. Failure to do this may very greatly reduce the length of life and the rate of reproduction. The nature of the food supplied varies somewhat in the cases of different species, but in practice the most useful types of food seem to be honey, or sugar-water, supplied in such a way that the danger of honey entangling the parasites is reduced to a minimum. A very useful food, first suggested by Dr. J. G. Myers of the Farnham House Laboratory, is raisins. In many cases very satisfactory results have been obtained by supplying the parasite simply with a number of raisins attached to a piece of cork, and a supply of water provided by a damp pad consisting of a piece of cloth covering a wad of cotton wool, dipping into a small, deep petri-dish, full of water. The raisins remain moist for a considerable period and certain parasites feed upon them with avidity.

If they are properly cared for many parasites will, contrary to the general belief of many entomologists, live for long periods in the laboratory. Individuals of some species have been kept alive by the writer and other workers for periods of many months. Nevertheless, although most parasites are fairly easy to keep alive in captivity, it is not always an easy matter to induce them to mate and reproduce. The conditions governing mating in these insects are not by any means clearly understood at present. In some cases better results can be obtained if the males and females are kept separate for a considerable period and then placed in cages together, being separated after mating has occurred. In other cases even this method does not give satisfactory results. Thus, during the work on *Eulimneria crassifemur*, Thoms., Dr. H. L. Parker and the writer found it impossible to induce this species to mate in small cages, though it had been observed to do so as soon as the species was liberated for colonisation, in which case mating occurred immediately, in close proximity to the point where the liberation was made. After various



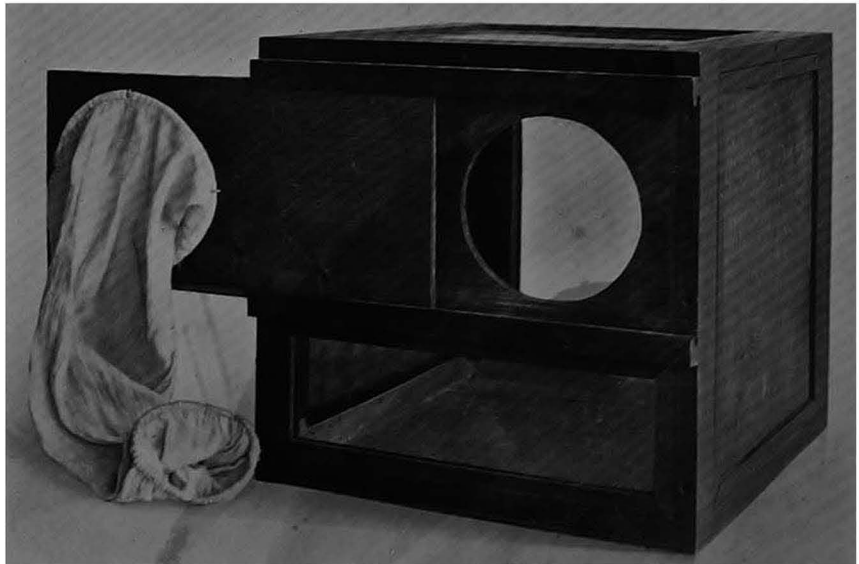
1. Shipping box (right) with its Mailing Case (left).



2. Cylindrical glass parasite cage, with water jar, raisins, and lump sugar.



1. Double compartment cage in teak with emergence tubes ; front and top with sliding doors, behind which are glass panels.



2. Standard cage in teak with wire gauze sides, vita-glass front and top (removable) and sliding panel with sleeve in back.

artifices had been tried without success, some males and females were liberated in a large outdoor cage, to which the sun and air had free access, and mating occurred at once.

Certain other parasites can be induced to mate with a fair amount of ease, but cannot be induced to oviposit in captivity. In the case of some species studied by the writer, efforts continued over a period of many months have altogether failed to produce any satisfactory results. It appears that conditions of a very special kind, which it requires prolonged investigation to discover, may be necessary in order to secure reproduction. Thus, in working with the parasites of the Earwig, it was found that the most satisfactory results were obtained when the parasites, which belong to the group of the Tachinidae, was supplied with flowers of certain umbelliferous plants. Another point which must be borne in mind in the case of the Dipterous parasites is that a rather long period sometimes precedes oviposition, because development to the larval stage takes place in the uterus within the body of the mother, whereas in the case of the Hymenopterous parasite the egg is deposited in an undeveloped condition, and the parasite is sometimes ready to oviposit almost as soon as it has emerged from the pupal skin. Dipterous parasites, therefore, require a great deal of care, especially when they are active, and when kept in cages frequently reduce themselves to a very abnormal condition before they are ready to oviposit.

Furthermore, though it is sometimes fairly easy to induce a parasite to reproduce in captivity, it is not possible to rely upon its judgment for the proper distribution of its progeny. My experience, both in the field and in the laboratory, has shown fairly conclusively that the majority of parasites, if given the opportunity, will continue to deposit eggs and larvæ in individuals of the host until the number of parasites it contains far surpasses its capacity for supplying food, with the result that all of the progeny as well as the host perish prematurely. In order to avoid the consequences of reckless oviposition special arrangements are usually necessary. With some species all that is required is to remove the parasitised host and supply new ones at intervals, the length of which can be determined by a few careful experiments. In other cases the most satisfactory method is to allow the parasite to oviposit freely and distribute its eggs artificially upon a series of hosts in a suitable condition. This method was devised a number of years ago by the writer in rearing *Exeristes*

roborator, the parasite of the European Corn Borer. Experiments showed that this species oviposited freely in larvæ of the Corn Borer placed in sections of maize pith in which a small chamber had been hollowed out and which was covered with a thin sheet of pith or perforated paper. In order to prevent the host larva from escaping from the chamber, its head was crushed with a pair of forceps. Within the course of twenty-four hours the parasite stung the larva and deposited upon it a number of eggs much greater than it could possibly nourish. The eggs were, therefore, removed with a fine camel hair brush and placed one at a time upon caterpillars of the Corn Borer, which had been killed by a very short immersion in hot water. Although it was usually necessary to renew the caterpillars during the course of the development of the parasites, the method proved, on the whole, very satisfactory. When the supply of host larvæ became difficult to obtain an attempt was made to circumvent the difficulty by substituting the larvæ of a large ant (*Camponotus* sp.), which was fairly abundant in the region where the work was being carried on, and it was found that a fair proportion of the larvæ could be quite satisfactorily reared upon this host.

This method is, of course, only suitable in the case of parasites which deposit their eggs externally. It has not so far been found possible to utilise it with species which place their eggs within the body of the host. It is, however, quite suitable for species like some of the Dipterous parasites which deposit their eggs or larvæ in the vicinity of the host. Thus, the Tachinid, *Sturmia scutellata*, which is an important parasite of the Gipsy Moth, deposits its eggs on leaves, and when it has been induced to lay a few eggs, will usually continue to oviposit in captivity for a long time and will continue to deposit a great number of eggs on leaves in the absence of any host. These eggs can then be placed separately on leaves and fed to caterpillars. The same method was used by Altson in the case of one of the Dipterous parasites of the Earwig, and proved very successful. Similar methods can be adopted in the case of the parasitic flies of the same group which deposit their larvæ on leaves, and were utilised by Dr. Parker and the writer in rearing two of the Dipterous parasites of the Corn Borer, which have somewhat similar habits. In the case of the Dipterous parasites, it is possible to carry the artificial distributions of the progeny one step further. A number of years ago the writer carried out a few experiments in which larvæ of certain of the parasites of the Corn Borer, still undeposited, were removed from the uterus of

the mother, placed in saline, and then distributed by means of a small camel hair brush on larvæ of the Corn Borer in a suitable condition, or injected into the body cavity of the chrysalids of this species. The results of these experiments were very encouraging, and the procedure has now been utilised on a large scale by some of the entomologists working on the Dipterous parasites of the Japanese Beetle. It is obvious that these methods are capable of extension in various ways, and that we are, as yet, only in the initial stages of work of this kind.

To sum up the discussion of this phase of the problem, it may be said that by careful attention to details and consistent efforts to supply both parasites and hosts with an environment which approaches as closely as possible to the optimum, the process of breeding parasites can often be carried on in the laboratory or the insectary on an extremely large scale. The initial stages of work of this kind require, in every case, a careful investigation by trained entomologists, but when the details of the process have been worked out it can often be passed to relatively untrained assistants. There is no reason why the work of producing parasites in quantity cannot be carried out on as large a scale as any other industrial process, such as the production of machinery of various kinds. The initial expenditure is considerable, but once the work is under way it can be continued at relatively little cost, and may, in many cases, give results far superior to those which can be obtained by any other method. The work of Professor H. S. Smith in breeding *Cryptolaemus* in order to combat the *Citrophilus* Mealy Bug in California, to which we have already referred in the introduction, is an excellent example of what can be done in this way. In some cases, work of this kind can probably be carried out with fair success by the individual agriculturist, but usually it is more satisfactory to establish a centre in which the requisite facilities will always be available, supported by bodies of fruit-growers, farmers and co-operative organisations. That stations of this kind may be commercially profitable the experience of the Hawaiian Sugar Planters' Association has amply proved.

When the requisite supply of parasites or predators cannot be obtained by breeding the species in the laboratory—and, as we have already pointed out, this is often a task for which the entomologists in many parts of the Empire have, at present, neither the resources nor the equipment—it is necessary to rely on the collection of the material in large quantities in the field. The problem of collecting a

sufficient quantity of material in condition suitable for transport, of preparing it so as to reduce the likelihood of loss in a journey which may occupy a considerable period, and of moving it to its destination as rapidly as possible and under the most hygienic conditions is extremely important.

The collection of a large quantity of material is always desirable and often essential to success. The mortality due to careless handling during collection, to unsuitable methods of packing, unfavourable conditions during shipment, and accidents during rearing and liberation, is often considerable. In reading the history of attempts to introduce beneficial insects, one repeatedly meets with cases where collections of parasites or predators, obtained at great expense from far distant points, were completely lost before they could be utilised owing to the high death rate on the one hand, and the ridiculously small number of individuals collected on the other. The collection of large amounts of material adds, as a rule, relatively little to the cost of such undertakings and enormously increases the chances of success. Every effort should, therefore, be made to secure a large number of individuals of the species it is desired to introduce. In some cases, if collectors are to be maintained in the region considered, the collections need not be excessively large, but if they are merely visiting the district and have come from a considerable distance, they ought certainly to secure enough specimens so that a colony of several thousand individuals will be available for liberation at each point at which it has been decided to introduce the parasite or predator. As has already been pointed out, a liberation of a thousand individuals means the collection of a very much greater number owing to the unavoidable mortality which always occurs during the process of collection, rearing, and shipment.

The methods to be followed in locating an area where large collections can be made have already been described. When such an area has been found, the task of the collector is to obtain the amount of material desired within the time available for the work. The general character of the organisation necessary for this depends chiefly upon the amount of time available for the collection. If the insects to be collected are rather uncommon and are present in a condition where they can be obtained only during a brief period, as is often the case with parasites which go through the whole of their development during the summer months, then it is necessary to employ a large staff of collectors and push forward the work with great energy. If the

developmental stages of the host containing parasites or the parasites themselves, can be secured during the period of hibernation, whether facultative, as during a cold or dry season, or obligatory, as in many insects which have phases of dormancy more or less independent of external influences, the organisation need consist only of a few collectors. A highly trained personnel is not necessary for work of this kind. Since the collectors have to deal only with a very few insects they soon acquire knowledge sufficient for the work, which is not intrinsically more difficult than the collection of agricultural products, such as fruit or vegetables, or than many phases of industrial work. The collectors employed for prolonged periods must, of course, be chosen with greater care than those employed for short periods, since they may have to work more or less independently, and may have to deal with several different types of material. The most suitable personnel for collecting work of this kind is usually found among the native agricultural population of the district in which the work is done. Workers of this kind have, as a rule, some acquaintance with the material to be collected and are accustomed to labour of a closely allied type. Country schoolboys can sometimes be employed successfully.

The method and amount of payment to workers employed for large field collections demands careful consideration, in order that the greatest possible returns may be obtained for the funds available, which are sometimes unavoidably small. As a general rule the rate of payment should not exceed that which is usual for the class of labour in the region where the work is done. Higher rates of pay may facilitate matters at the outset, but are likely to give rise to difficulties later, either with the employers of the region or because the labourers themselves are apt to conclude that unlimited funds are available and that any demand, however unreasonable, will be met. The fact that payment is made for the collection of material considered by the labourers themselves to be quite useless makes it all the more necessary to conduct the whole operation on strictly business lines. The only case in which payment in excess of the customary rate can be granted is when the work to be carried on is of a particularly difficult or disagreeable nature, as for example, the collection of caterpillars with poisonous hairs, of larvæ living in offal or excrement, and so forth.

Whether payment should be made on a time or on a piece-work basis must be carefully considered in every given case. Each of these systems has its advantages and disadvantages. If collectors are paid

by the day or by the hour, careful record should be kept of the amount of material turned in by each worker so that unsatisfactory employees can be eliminated. If the workers are paid by the piece, some experiments must be made to find out how much material can be obtained in a given period when a reasonable effort is made, and the rate of pay should then be fixed in such a way that any effort above the average is justly compensated. When the collectors have acquired some experience their daily wages may, on the basis chosen, rise considerably above the current wages for the region, but as they can then be considered as specialised workers, there is no objection to this. However, when this mode of payment is adopted the material collected must be carefully inspected, otherwise a great deal of damage may be done to the collections by careless handling, which results from the attempts to work more rapidly than is consistent with the skill of the labourer. When direct surveillance of the labourers is necessary it is best to follow the industrial custom and appoint a foreman in each locality where collections are made. The foreman is then responsible for the conduct of the work, and is paid at a higher rate than his subordinates. This procedure greatly facilitates matters, especially in foreign countries and leaves the entomologist in charge free to devote himself to technical problems. Furthermore, as anyone who has travelled in foreign countries realises, it is much more easy to carry on an intelligible conversation with one person, to whose vocabulary and accent one has become accustomed than to make oneself understood by a large number of individuals. Again, the foreman can be a very useful intermediary with the agriculturists of the district in whose properties the material must be collected, or the work carried on. The employment of such locally known intermediaries is on general grounds highly desirable. Since they are locally known they can penetrate into regions or into properties where a foreign entomologist would be regarded with suspicion.

Agriculturists are usually quite willing to allow collectors to visit their properties and examine their fields or orchards during the process of preliminary collection. On the other hand, when large scale collections are made, matters usually take on a somewhat different complexion. In the case of some insects the work of collection necessitates the removal of a considerable amount of plant material from the fields or orchards. Sometimes this material is removed after the crop has been harvested and has very little value, as, for example, stubble, dried maize stalks, decomposing fruit, and so forth.

In other cases, the work necessitates the collection of fruit or portions of the plant, which are actually utilised by the agriculturist, even though they are more or less damaged in condition. In any event, whether the material is utilised or not, the fact that it is desired in large quantities, and that an obviously considerable sum is being spent upon its collection and examination, somewhat enhances its value. The collector must, therefore, expect to have to pay for the material he wishes even though its value upon the agricultural market is very small.

In all such cases the field agent must exercise great care in negotiating with the agriculturist, otherwise he will not only very greatly increase the cost of the particular project in which he is dealing, but will also prejudice the cost of any future operations in the district. When the material collected has obviously a marketable value, as in the case of fruits, which, although they are infested by insects, can, nevertheless, command a fair price, or of green crops used as forage, of which a certain proportion contains the egg or young stages of certain insects, the price offered must be usually more than that which the product commands in the open market. When the material utilised is in itself of relatively little value, the fixing of a price is a good deal more difficult. It is, however, desirable to fix a price which allows the farmer disposing of the material, reasonable and rather attractive profit, especially if it is desired to continue the work during several years, because the knowledge that stuff hitherto regarded as worthless, can be sold, will spread rapidly in the countryside, and the collector will find that eventually he is able to obtain delivery of large amounts of material, without any effort on his part, and without having to spend time in travelling over large areas of the district.

The actual process of collection and the treatment of the material immediately after collection need very careful study in every given case. It is usually possible, having regard to the situation of the organism to be collected, to divide the work into several different phases, which can then be taken up separately, with better results than if the collection is carried on in a haphazard manner. Thus, in working on the parasites of the insects attacking certain forage crops, the most satisfactory method is first to cut and harvest the entire field and then to turn over the material to a band of workers under the direction of a foreman, who examine it piece by piece and

separate the infested plants. These are then handed over to a second and more highly trained band of workers, who remove the eggs or larvæ of parasites and pack them for shipment.

In the case of leaf-feeding insects, sweeping with a net or beating with a sheet or umbrella are often very rapid and efficient methods of collection. In some cases mechanical apparatus will probably prove very useful. Thus, according to Johnson, one of his correspondents obtained from the apparatus used in shelling peas in the Southern United States, about twenty-five bushels of Syrphid larvæ, chiefly *Allograpta obliqua*; Metcalf (1916) estimates that this collection could scarcely represent less than 3,000,000 individuals. As this large quantity was obtained during the course of a few days' work the value of the method is obvious.

The separation of parasitised and unparasitised material can sometimes be effected mechanically. For example, the workers at the Gipsy Moth Parasite Laboratory of the United States Department of Agriculture, have devised a special machine for the separation of the parasitised and unparasitised eggs of the Gipsy Moth. The eggs of this moth are covered, during oviposition, by the female moth, with a thick pad of hairs, and after a collection has been made, the first operation consists in the removal of these hairs. According to Crossman, this was originally done by rubbing the egg-clusters with the bare hands or with a pad over a piece of cotton cloth, drawn tightly over a tray, until the hairs had been rubbed off; but for this method a mechanical plan has now been submitted. The machine used in this work consists of two discs about two feet in diameter, the lower one of which is stationary, while the upper one above it revolves, the power being furnished by a small motor. The inner surface of each disc is padded with felt covered with canvas. The upper disc works on a spindle and can be adjusted so as not to injure the eggs. The egg-clusters are broken up and fed into the machine through a box-like opening in the upper disc. As the disc revolves the eggs are gently rubbed between the two inner surfaces. As the eggs are worked to the circumference of the disc they become separated, cleaned and drop off, assembling in a jar below. The hairs that are rubbed from the egg-clusters are removed by means of a blower attached to the centre of the apparatus, and thus no ill effects result to the workers engaged in the process. After the eggs have been cleaned they are separated

into parasitised and unparasitised eggs. Formerly, the eggs were placed in trays, in the top of which were numerous one-inch holes. In each tray on top of the layer of eggs were placed one or two thicknesses of close mosquito netting, through which the small caterpillars had to crawl on leaving the tray. When the eggs and netting were in place, each tray was entirely covered with black paper and placed on a rack in a large room to allow the non-parasitised eggs to hatch. Before it was time for the non-parasitised eggs to hatch, the paper was broken over the hole in the front of each tray and glass vials were inserted, into which the caterpillars crawled. When hatching began, the entire attention of several men for nearly two weeks was required to remove the larvæ from the glass tubes. This was accomplished by clearing out each tube with a camel's hair brush, and placing the caterpillars in paraffin. After the process of hatching was complete the eggs were removed, and placed in a machine, so constructed that as the parasitised eggs, dead eggs, and egg-shells ran down a chute, the dead eggs and egg shells were drawn off by suction; the parasitised eggs, which are heavier than the other material, assembled in a glass tube at the bottom of the apparatus. This method of allowing the non-parasitised eggs to hatch, so that the parasitised eggs could be separated from the rest of the material was a long and tedious process, and has now been discontinued. A little apparatus called a "bouncing machine" is now used for this work. The eggs are allowed to run down a wooden chute, at the bottom of which is a small piece of tin placed at right angles to the inclined surface. This piece of tin is termed the "take-off." When the eggs hit it, they bounce into the compartments of a box beneath. The eggs containing the parasite maggots do not have the same capacity for bouncing as the healthy Gipsy Moth eggs, and therefore fall into the first and second compartments, while the other eggs bounce farther and drop into the compartments beyond. The non-parasitised eggs are then destroyed. The eggs containing parasites are then put into small manilla envelopes in lots of about one thousand parasites each, for colonisation in the spring. These parasitised eggs are not actually counted but are measured in a small glass tube, so graduated that each colony will contain about one thousand eggs. The application of the method is, of course, strictly limited, but it has been described in detail since it is a very interesting example of the way in which work of this kind can be standardised so as to be carried on with a minimum of effort along the lines used in other industrial processes.

After the material has been collected it must be packed in a condition suitable for transport. The method employed will depend, of course, mainly upon the stage in which the material is collected and its physiological condition at the time of collection. In the case of parasite cocoons or puparia, eggs with hard shells, chrysalids, or hibernating larvæ, the method used is, in general, relatively simple, and the main points to be kept in mind are the provision of an environment neither too humid nor too dry. It must be remembered that organisms, such as hibernating caterpillars, or even parasitic cocoons, if packed together in large numbers in closed containers and left there during a considerable period will sometimes give off a considerable amount of moisture, which in turn will cause either overheating or the development of mould, and consequently a very high mortality during the process of shipment.

High mortality from the absence of moisture arises rather less frequently, possibly owing to the fact that under ordinary conditions prevailing in the shipping boxes, very little loss of the moisture content ordinarily occurs. Whenever excessive evaporation is likely to occur measures should, of course, be taken to provide humidity. A very successful method devised by Dr. J. G. Myers in the shipment of the larvæ of *Sirex*, consisted in putting the larvæ of this parasite in large gelatin capsules filled with sawdust. In other cases the material may be packed between layers of clean living sphagnum moss, which provides a supply of moisture without any danger of the development of mould.

The possibility of the interaction between individuals of the species shipped must be considered. Cocoons or puparia collected in the field are not infrequently infested by secondary parasites, such as *Dibrachys*, and unless the shipment is kept during the whole course of the voyage at a low temperature, individuals of these secondary species may emerge and attack the healthy parasites, so that when the material reaches its destination all the primary parasites have been destroyed. In order to avoid accidents of this kind it is best, whenever possible, to isolate the cocoons or puparia in individual tubes or gelatin capsules. The capsules are usually quite satisfactory unless the surroundings are exceptionally humid, when glass tubes must be used.

If the material collected is in a condition of obligatory dormancy, then it can be shipped during the winter months and no special arrangements need be made for preventing its development, though

on general grounds it is preferable to send it under such conditions that high temperatures are avoided. In many species, exposure to high temperatures in the condition of obligatory dormancy does not perceptibly accelerate development, but it may cause a rather serious mortality. If parasites or hosts are shipped in a condition in which the development is accelerated by high temperatures, arrangements must be made for shipment in cold storage. A temperature of from 40° to 45° Fah., is very suitable for shipments of this kind, and this temperature can practically always be obtained in the vegetable chill room of most sea-going vessels. In some cases it happens that material has to be collected during the summer months, and stored for some considerable time before it can be shipped, and must then be carried to the port of entry from a point so far distant that the journey takes from 24 to 48 hours. In this case, arrangements must be made for storing the material at the place of collection in small household ice-chests, and it must be carried to the port at which it is shipped in a portable refrigerator. A very convenient refrigerator of this type was developed by the entomologists of the United States Department of Agriculture, and consists of a steel valise, lined with a layer of thick felt, and containing three zinc boxes, of which the two end ones are about half the width of the middle one, and are packed with ice, while the middle compartment contains the specimens to be shipped. It is found in practice that once this box has been chilled down, it can be carried for a considerable time without a very great rise in temperature. A somewhat similar box for the same purpose is constructed by Chas. Hearson & Co., Ltd., of London. In making shipments of material, the development of which is notably accelerated by high temperatures, it is necessary to provide cold storage facilities, not only during collection and shipment, but on reception.

An important point concerning the shipment of insects whose development must be retarded artificially by refrigerators is that the effect of low temperatures on the various phases of development may be very different. Cocoons or puparia which have almost completed the process of development are extremely difficult to carry through cold storage. The adults sometimes emerge, in spite of the low temperatures to which they are subjected, and die before the material reaches its destination. Sometimes it is necessary to ship adult parasites, though few attempts to develop methods suitable for this purpose have as yet been made. The requisites appear to be a

combination of some satisfactory feeding method with moderately low temperatures, so that the parasites will remain active enough to feed, without exhausting themselves en route. Some very successful shipments of the adults of *Blastothrix sericea*, the parasite of *Lecanium coryli*, have been made from Farnham Royal Laboratory by placing the adults of this parasite, which is a very minute Chalcid, in glass tubes, simply provided with raisins attached to the inside of the cork. Several lots containing fairly large numbers of individuals were sent to the Dominion Parasite Laboratory at Chatham, Ontario, and trans-shipped from there to Vancouver, with a mortality averaging rather less than 10 per cent. The shipment of adult parasites is, in general, most likely to be successful with robust and hardy species. The Canadian Parasite Laboratory has however used it successfully with *Digonochaeta setipennis*, the Tachinid parasite of the Earwig, a relatively fragile insect, but which Mr. A. B. Baird of the Canadian Laboratory sent successfully from the region of the Great Lakes to the West Coast.

Whatever the material shipped, and whatever the method of shipment, all cases or boxes utilised should be solidly constructed and capable of being hermetically sealed, so that there is no chance that any undesirable insect will escape en route, or that any of the parasites shipped can find their way out of the boxes before the material reaches its destination. When glass containers of any kind are employed, plenty of packing should be used and the dimensions of the packing boxes should be sufficient to allow ample provision for this.

All shipments should be preceded or accompanied by a letter stating the names and numbers of the parasites shipped, the time and conditions of shipment and any information which is of interest concerning the methods of handling the material. If possible there should be included with the shipment, a set of pinned and identified specimens of the species sent. In this way the entomologist at the receiving end can proceed at once to separate and identify the material, and liberate the desired species of parasites or predators immediately.

7. *Methods of Treatment on Reception.*

The first step that the entomologist at the receiving end must take when he is advised of the arrival of a lot of parasitic material is to ensure its rapid conveyance, under the most favourable conditions, to the laboratory where it is to be dealt with. Very frequently, after the material is taken from the vessel it has to be sent to its

destination by rail. In such cases, if the distance from the port of entry to the ultimate destination is very great, the best method is to have the shipment conveyed by a special messenger, in cold storage, to the laboratory where the parasites are to be reared. In some parts of the world refrigerator cars exist on certain railway lines, but if these are not available the portable refrigerators must be used. In order that there may be no delay after the arrival of the material in the port of entry, the usual method is to advise the entomologist at the receiving end of the shipment by cable. It is then his duty to make arrangements with the authorities at the port of entry, or the shipping companies, so that he may be notified without delay, of the arrival of any packages of material. If the material has been transported in cold storage it should not be allowed to warm up too rapidly, as sudden changes in temperature may often cause mortality.

On the other hand, the treatment of the material after it has reached the laboratory at the receiving end, demands special attention. The points of greatest importance in this connection are that the consignments be dealt with as rapidly as possible, and that the packages be opened under such conditions that there is no likelihood of the escape of undesirable hyperparasites or other noxious insects. If through any unforeseen circumstance it is impossible for the staff of the laboratory to deal with the consignment immediately upon its arrival it should be placed in cold storage at once, but this must be avoided whenever possible. In order to prevent the escape of any undesirable insects, the packages containing the parasites should be opened only in rooms of which the windows are covered with fine wire gauze, or in insectaries specially built for the purpose and designed in such a way that the escape of any insects is impossible. Any adult parasites or predators which are found on opening the package, should at once be set aside and provided with food, and the remaining material separated into species and put aside for rearing.

In some of the large scale rearing experiments conducted in the past, as for example in the work on the parasites of the Gipsy Moth and the Brown Tail Moth, the material received was collected in various parts of the world by entomologists who had not previously carried out any investigations in regard to the habits of the parasites and predators sent. Consequently, before these could be utilised it was necessary, in many cases, to carry out extensive studies of their biology. It is now recognised that it is

much better and much safer to carry on studies of this type within the native home of the beneficial insects where information concerning their habits can be secured much more easily than in the country into which they are to be introduced. However, even though relatively full information in regard to the biology and habits of the various species has been obtained it is still necessary for the entomologist at the receiving end to take certain precautions, especially when the material received consists of parasite puparia and cocoons, which have been collected in the field and may have been attacked by secondary parasites. Furthermore, we know that there are certain parasites, which although they are secondary, actually attack the primary parasite while it is still within the body of the living host. Such for example are the Chalcids of the genus *Perilampus*, whose remarkable life-history was described a number of years ago by H. S. Smith. The possibility that parasites of this type may be present has some bearing on the methods of liberation and ought therefore to be mentioned.

The liberation of the parasites received may be accomplished in three ways. In the first place, the entomologist at the receiving end may liberate in the field the developing larvæ or caterpillars of the pest, of which a certain proportion is known to contain the younger stages of the parasite which it is desired to import. A sufficiently accurate idea of the number and specific identity of the species present can be obtained by dissection, and since the host insects are placed, as soon as they are received, in their natural environment, it has sometimes been considered that this method of liberation is, in the long run, the most satisfactory. However, as has already been stated in a previous section, it is very questionable as to whether the conditions which the average group of individuals of the species actually encounter in nature are really as suitable as those that can be provided in the laboratory. Unfavourable meteorological influences of various kinds and the activities of various predators, such as birds, beetles, etc., may very greatly reduce the population of larvæ or caterpillars liberated before the parasites have had time to complete their development. In view of this fact, it is usually preferable to keep parasitised caterpillars or larvæ in the laboratory, in an insectary, until the parasites they contain have emerged as adults. The rearing methods suitable will differ in the case of the different species studied, and need not be described in detail. They ought to be of such a nature

that individuals of the host which have pupated, or parasites which have emerged and have formed their puparia or spun their cocoons, can be removed from the breeding cages from day to day. One of the most useful pieces of apparatus yet devised for this purpose is the Fiske Tray, of which a photograph is given on Plate VII. This is simply a wooden framework, the bottom of which is closed by a sheet of cloth and in which a band of tanglefoot prevents the escape of the caterpillars. These trays have been used with success for the rearing of larvæ in very large numbers. They must be given attention during the rearing work as the caterpillars can very easily escape from them if a leaf or twig, introduced for food, happens to bridge the interval between the top of the tray and the inside. They require to be cleaned at fairly frequent intervals since the food, which is supplied in the form of freshly cut leaves or twigs is exposed freely to the air and dries up fairly rapidly. Their great advantage is, however, that all the material contained in the tray is easily accessible, and that parasite cocoons, larvæ, chrysalids, or puparia can be detected and removed with great ease. For larvæ which are too delicate to be transferred to fresh food at frequent intervals, and which will not move to the fresh food as the old food dries up, this kind of rearing tray is not suitable and cylindrical or cubical cages, which are large enough to contain growing plants or twigs in water, must be provided.

The moment when the parasite larva emerges from its host is, in the case of some species, very critical. Certain Tachinids, like *Sturmia scutellata* and *Pelatachina tibialis*, if allowed to emerge and pupate in trays or cages, generally die off in rather large numbers, particularly if they are left exposed to the air for any length of time. When such parasites are present, arrangements must be made so that when they emerge from their host they can descend directly into the earth. Many Hymenopterous parasites, if allowed to emerge from the body of the host on a perfectly flat surface or in a glass container, whose volume is much greater than that of their own bodies, are unable to form their cocoons and frequently perish after vain attempts to do so. The larvæ must, therefore, be removed immediately after their emergence and placed where they can obtain the right conditions for spinning.

Many parasites, after they have formed their puparia or spun their cocoons, remain in a condition of obligatory dormancy for many months, as, for example, during the winter season. With species of

this type it is often necessary to regulate the humidity conditions with some care, and the specimens must sometimes be buried in earth under outdoor conditions, if satisfactory emergences are to be obtained.

Finally, there are some species which pass the winter in a condition of obligatory dormancy, but which are, nevertheless, not completely indifferent to fluctuations in temperature; which are, in other words, in a condition of imperfect diapause. If such insects are kept in a warm room throughout the winter they will develop and emerge many months before the host is available in a stage suitable for attack. Care must, therefore, be taken to retard their development until such time as the host is available, either by placing them out-of-doors or by leaving them in a refrigerator during the winter months.

The rearing of parasites sent from Europe to the Southern Hemisphere or from the Southern to the Northern Hemisphere presents special problems. If the parasites are of the type which emerge in the same season as that in which their development began, it is usually rather difficult to retard them sufficiently to bring them from the point where they are collected to countries like Australia, South Africa, or New Zealand, and even if they arrive alive it may still be extremely difficult to induce them to survive until the host is available in the field. On the other hand, if the parasites are of the type which spend the succeeding winter in a condition of hibernation and emerge normally in the following spring, attempts to force them to develop in time to attack the early stages of the host in the country in which they have been introduced may not be successful, or, if emergence is obtained it may occur at a time when there are no longer any hosts available in the field. In such cases it is, therefore, necessary to leave the parasite or predator in cold storage till some three or four months after the moment of normal emergence, and this long exposure to abnormal conditions has, not infrequently, prejudicial results. Whenever it is possible to do so the correct method of procedure with such species is for the entomologist at the receiving end to rear the host continuously, so that individuals in all phases will be available at the time the shipment of parasites arrives. In this way he can obtain another generation which can be placed in cold storage until the host appears normally in the field.

The next step after the rearing of the parasites and predators in satisfactory numbers from the material received, will either be the building up of colonies large enough for liberation by breeding work

in the laboratory, or the liberation of the imported material directly in the field. The methods of breeding have been dealt with in a preceding section, and we need not return to them here. The question of colonising, however, merits a little further attention. The main points to be considered are the number of individuals to be liberated, the condition in which they should be when liberated, the time at which they should be liberated, and the choice of localities in which to colonise them. It is very difficult to make any satisfactory statements as to the number of individuals it is desirable to liberate. The main advantage of the method of biological control is generally held to be that it is self supporting, and if this view is taken, of course, all that is desired is the establishment of the species in the new home. However, in order that this may be brought about with certainty, and in order to avoid the disastrous results of climatic irregularities affecting any particular point in the new home, it is desirable to make the introduction in a number of different localities, which differ in agricultural, topographical, or climatic characters. In each of these localities a colony of as many individuals as possible ought to be liberated in a single spot. This spot should be one containing a population of the host as dense as possible, and in which no heavy mortality due to artificial or mechanical controlling factors is likely to occur for a fairly long time to come. If populated regions are used for the purpose of colonisation it is as well to make special arrangements in order that methods of mechanical control may be abandoned until such time as the establishment and dispersion of the parasites is demonstrated.

Whether it is proper to employ mechanical measures of control after the establishment of the introduced parasites or predators has been the subject of debate. Trouvelot considers that the effect of these measures is generally more prejudicial to the parasites than to their hosts, either because they cause such a diminution in the population of the pest that the parasite cannot find enough hosts for its progeny, or because they destroy a larger proportion of parasites than of hosts. Volterra in his important work on the variations and the fluctuations in the number of individuals in species of animals living together, maintains on mathematical grounds, that if we remove from their common environment the same proportion of two species, the first of which feeds upon a medium considered as omnipresent and inexhaustible, while the second feeds upon the first, the population of the predacious species will fall more rapidly than that of its prey,

owing to the increased difficulty it experiences in finding food. The results of these calculations are said to agree with the statistical studies made by d'Ancona of the Adriatic fisheries, where it was found that the interruption of fishing due to the war was followed by an increase in the proportion of the predacious forms. The present writer has, on the contrary, argued, also on mathematical grounds, that unless mechanical methods destroy a larger proportion of parasites than hosts, their effect will not be injurious. In expressing this view, he had, however, in mind cases in which the host population was still increasing, in which hypothesis mechanical control would not adversely affect the food supply of the parasite, unless it were so effective as to transform the increase of the host population into a decrease. In the case of pests of which the populations have become stable, it is quite conceivable that mechanical measures of control may considerably reduce the effective reproductive rate of the parasite, not only by destroying its progeny, but also by preventing it from producing its full quota of young owing to the rarefaction of the host population which it determines. The subject is, however, more complex than it appears on first sight, and requires further study, not merely from the theoretical but, more particularly, from the experimental standpoint. In any event, few entomologists will advise agriculturists to abandon mechanical control in order to favour the increase of parasites or predators, simply because mechanical methods produce in most cases a certain immediate benefit, while the benefits to be derived from favouring the increase of the parasite are, in most cases, somewhat problematical.

The moment at which parasitic and predacious species are to be liberated has given rise, in the past, to some controversy. Some entomologists, believing that the best method is essentially to place the parasitic or predacious species in its natural environment as soon as possible, and that in this environment its chance of survival is much greater than in the laboratory, have maintained that individuals ought to be liberated in the field as soon as they emerge and are completely formed. Others, on the contrary maintain that owing to the small size of the population the process of dispersion is likely to separate the males and females before they are ready to mate, so that the latter will perish without producing any progeny, or produce progeny which are only of the male sex. There are certain number of species, particularly in the group of the Diptera, in which there is an interval of many days or even

several weeks between fertilisation and oviposition. It has been claimed that with these parasites the best results will be obtained by keeping the females in captivity until they are ready to oviposit. The difficulties which have been encountered in the attempt to establish certain parasites seem to suggest that in some cases, at least, it is better to ensure the mating of the sexes before the liberation of the species, but we have, at present, no accurate information concerning the comparative rates of mortality of the adults in the laboratory and in the field. The provision of a perfectly suitable laboratory environment for active winged insects is, however, a problem more difficult than that of dealing satisfactorily with larval stages. The attempts made up to the present by the writer to rear Dipterous parasites in captivity have never given very satisfactory results, since by the time the individuals reared are ready to oviposit they are usually in an extremely damaged condition and far inferior to the specimens of the same age that one habitually collects in the field. They would obviously be unable to survive for any length of time if they were liberated. The utility of this method is, therefore, somewhat questionable.

During the work on the parasites of the Gipsy Moth carried on in 1908, C. H. T. Townsend attempted to solve the question of colonisation by inducing the Dipterous parasites which he was studying, to oviposit in captivity on young larvæ of their host which were then liberated directly in the field. The results of these liberations do not seem to have been very satisfactory, and so far as the writer is aware, no further attempts of this kind have been made.

The question of the moment when parasites should be liberated is relatively simple. Colonies of individuals ready to oviposit should be turned loose at a time when the host is available in the field in a state known to be attacked in the native home; or, if the parasite is liberated before the host is in this stage, it should itself be in a correspondingly earlier stage of development. Information concerning the stage in which the host is habitually attacked should, therefore, be obtained in the native home of the insect and supplied with the colony to the entomologist at the receiving end.

8. *The Study of the Progress of Introduced Parasites in the Field.*

As has already been said in a previous section, the chief advantage of the method of biological control is generally held to be that it is self supporting, and this view is perfectly justified in so far as the

individual agriculturist is concerned. It is, however, very desirable and sometimes necessary that the progress of an introduced species be followed by a technical expert, at least for a number of years after colonisation, in order to ensure, in the first place, that the species introduced has actually become established and, in the second place, that we may determine with accuracy exactly what effect it has in controlling the pest which is being studied. This work should be done as accurately as is possible with a view to obtaining precise quantitative data in regard to the increase of the parasite and its effect upon the host. Unless an attempt to provide data of this kind is made by the entomologists importing parasites it is very difficult for the students of biological control to arrive at any satisfactory conclusions regarding work that has been done. It has happened not infrequently in the past, that introduced parasites have been given the credit for the temporary rarity or disappearance of the host although this rarity or disappearance may have been due to factors of an altogether different order. It is therefore necessary to point out that it is quite insufficient for scientific purposes to state that after the introduction of a parasite a reduction in economic damage has occurred. It is absolutely necessary to demonstrate by a careful series of rearings and dissections that the reduction in damage is due to the parasite and that there is no reason to suspect that the changes produced have been caused by variations in any other factors.

During the first few years after the distribution of a parasitic or predacious species it is, of course, sometimes impossible to find the species in any numbers and attempts to demonstrate its presence by dissection require so much labour that they are often quite impracticable. In this stage of the work it is therefore quite sufficient to make large collections which are reared with care, preserving for identification any parasite which is obtained from them. An attempt should, however, be made to plan the observations in advance in some consistent and rational way. A number of points within the infested area should be selected and in each of these a large number of larvæ should be collected year after year, in such a way that it will be possible to obtain a fairly accurate idea as to the increase of the percentage of parasitism from generation to generation. The oviposition period of the parasite may extend over a period of several days or weeks. Collections of the host in a stage suitable for attack should therefore be made during the whole period in which these

are present in the field and the average percentage of parasitism should be calculated from these collections made over the whole of the region considered. An effort should also be made to collect as much data as possible in regard to the interaction of the introduced species with other parasites attacking the host in question and with other host insects normally present in the area. Each introduction of a beneficial parasite or predator is an experiment carried on in an extremely large scale in nature and unless the results of these experiments are carefully kept the progress of the study of biological control will necessarily be extremely slow.

9. *The Results of Experiments in Biological Control.*

In the preceding sections the practical methods employed in work on biological control have been discussed. We have now to consider the important question of the results which may be expected from experiments of this kind.

Although work on biological control has been going on for a relatively long period, our knowledge in regard to the subject has not advanced very rapidly. One reason for this is that the progress of the introduced parasites and predators and the results which have followed their establishment have not been studied with sufficient care. Another is that the practice of biological control presents peculiar difficulties, as compared, for example, to such methods as spraying, which can be conducted on orthodox experimental lines.

In the most common form of experiments in the field of biological control we introduce the beneficial insects attacking a noxious animal or plant into an environment in which they have never before been observed. It is, however, obvious, that the effectiveness of the introduced parasites or predators will depend not simply on the presence and abundance of the host insect, but on a precise and definite combination of the environmental factors. If we introduce a beneficial insect into two different regions inhabited by the same pest the results may be very different, as experiments have repeatedly shown. The introduction of a beneficial insect into a new country thus constitutes, in a certain sense, a new and unrepeatable experiment. For this reason it is very hard to draw any conclusions of absolutely general value from the work that has been done, especially since it is often a very long time before any experiment can be considered as concluded.

We are therefore obliged to supplement the results of our observations in practical cases by theoretical considerations, which are, of course, in large measure, of the mathematical order, since the problem is mainly one of numbers.* The procedure here is to begin with the more general facts of parasite and host interaction as it occurs in nature. These facts are then stated in mathematical language and can then, by mathematical artifices of various kinds, be examined from various aspects, so that all the deductions concerning the numerical relations involved in the hypothesis can be obtained, with much greater ease than by ordinary reasoning. There are two serious pitfalls in work of this type. The first is the attempt to extract more from the end of the mathematical operation than was put into it at the beginning, or, in other words, the attempt to apply conclusions valid only in certain special cases, to phenomena of a much more complex order and which differ radically in some way from the case taken as a basis for the work. The second is derived from the fact that the mathematical methods most useful in work of this type have been evolved by the physicists in work on problems of mechanics and consists on the reliance upon dangerous analogies with inorganic systems, in the framing of the basis hypothesis. The difficulty of avoiding these pitfalls is considerable, so that, not infrequently, we are obliged to retrace our steps and recast our fundamental assumptions. In spite of this, however, the combined efforts of the students on biological control have gradually clarified our ideas, so that the broad general outlines of the theory of the interaction of beneficial insects and their hosts are now fairly apparent.

As has been said in the first section of this part, the basic theory of operations on biological control rests on a few very obvious facts. The potential reproductive rate of organisms is such that if all the offspring of every individual of any species survived in every generation they would, in a relatively short time, occupy the entire

* Several mathematicians and biologists have contributed to this subject; but the most important work by far is that of the eminent Italian mathematician, Vito Volterra, published in 1926. By utilising the methods of the Calculus, Professor Volterra has succeeded in elaborating an absolutely general theory of biological associations; the fundamental importance of which is not yet generally realised by biologists, owing to the highly mathematical form in which it is presented. The deductions made by this author have been of great help in dealing with the matters discussed in this section.

area of the globe. Nevertheless, organisms do not increase uninterruptedly. On the contrary, their populations often remain relatively stable, or present oscillatory movements of which the periods and amplitudes vary with different species and under different conditions. In other words, we may say, in a general way, that the *normal* condition is *control*, while *outbreaks* are *abnormal*.

The fundamental explanation of this fact is, of course, that every organism has certain specific characteristics, which though they actually oscillate about a mean, may be considered for practical purposes as fixed. These specific characteristics imply and indeed include specific needs and specific powers, limited in certain particular ways. For example, in order to subsist, every organism requires a certain set of physical conditions, a certain type of food, and a place where the other organisms which prey upon it cannot attain it. Given an absolutely optimum environment, indefinite increase at a specific rate is possible. But the environmental conditions of the globe vary from point to point and are probably in no two places exactly alike.* From this it follows, that at a given moment in a given area, the precise environmental complex constituting the optimum for a given species will be found at relatively few points. When conditions in a locality inhabited by a given organism approach the optimum, the species automatically increases in numbers. This increase constitutes what we call technically an outbreak, but it is, of necessity, as we have already said, an abnormal phenomenon. The organism considered may increase in numbers for a considerable time but it obviously cannot go on increasing indefinitely. As it increases in numbers it necessarily spreads, both in space and time and during its spread it moves to points outside its optimum environment, when its rate of multiplication immediately diminishes. A progressively increasing number of individuals die without producing offspring. A progressively increasing number of the offspring which are produced, fail to survive. In other words, the effective rate of reproduction progressively diminishes, and the population ceases to increase; control has been re-established.

* The discontinuity and variability in habitats, produced by the physical factors, both in time and space, is undoubtedly the primary extrinsic factor of natural control. At every moment in its life history an organism requires a certain specific habitat. As these habitats are scattered about over the environment the organism is obliged at certain intervals to traverse zones which are more or less unsuited to it, and it is during these intervals that the highest mortality usually occurs. Competition for food does not seem to be of great importance, except in certain special cases.

If we examine the situation at a time when the population of the organism is stable, that is, when it is neither increasing or decreasing, we shall find that a large number of environmental factors combine to produce this result. In practice it is found that the qualitative and quantitative composition of the complex of environmental factors varies at different times and in different places. Nevertheless, as was long ago shown by Howard and Fiske, they can be broadly classified into several different groups, which act in different ways.

The first group of controlling factors comprises those agencies described by Howard and Fiske as the *catastrophic* factors, but which it would be better perhaps to describe as *independent* factors, since the effect which they produce is essentially independent of the number of individuals in the population upon which they are acting. This group is composed of the factors comprising the physical environment in the broad sense of the term. The mortality resulting from the action of meteorological causes, such as rainstorms, excessive heat or cold, excessive humidity or drought, and so on, is about the same, other things being equal, whether the population is large or small. Thus, in rearing insects under laboratory conditions, we find that whether the number handled is large or small, providing, of course, that sufficient assistance to deal with it adequately is available, approximately the same number of adults is secured. The proportion of eggs failing to hatch and the death-rate during a given stage and under given conditions, remains practically constant, whatever be the population handled. This does not mean, of course, that when the population in the field increases, the percentage of individuals destroyed by a given physical factor will necessarily remain constant. On the contrary, the proportion of individuals destroyed by this factor may quite possibly be considerably larger than before. But this would be due to the fact that in increasing and spreading, a larger proportion of the population has moved out of the optimum physical environment and consequently become accessible to the action of the physical factor. In such a case it would not be the numerical increase in itself which is the cause of the increased mortality, but the secondary effects produced by this increase. If the environmental conditions were homogeneous, the numerical increase of the population would not have brought a larger proportion of individuals into unsuitable physical conditions and the proportion destroyed by the independent factors would have remained the same.

The second group of controlling agencies comprises what may be called the *individualised* or *dependent* factors of control, so-called because the intensity of the effects which they exert is in some way directly dependent upon the number of individuals in the population of the organism on which they are acting. This group includes not only the various parasites, predators, and pathogenic organisms, which prey upon and develop at the expense of the species considered, but also the organism itself. The reasons why the intensity of the action of these factors is dependent upon the numerical value of the population on which they are acting is that they are *limited*, not only in space and time, but also in their destructive capacity. A parasite belonging to a given species can only deposit a certain limited number of eggs; a predator can only devour a certain limited number of its hosts. The larger the population of the organism upon which they are acting, the smaller the fraction of this population which each individual parasite or predator will destroy. On the other hand, the more numerous the host population the more completely the parasites and predators will be able to realise their potential powers of reproduction.

This group of factors can be further sub-divided in various ways. In the first place they can be classified according to the nature of the effect they exert upon the organism upon which they act. Thus the action of what we usually call natural enemies is *directly destructive*; they prey upon and destroy individuals of other species. Organisms inhabiting the same environment can, however, produce effects upon each other which are *indirectly destructive*. The reduction in numbers and in reproductive rate is brought about in this case by the occupation of habitats suitable for other individuals and by the alteration of the character of these habitats in such a way as to make them unsuitable for other species.

In the second place, we may classify these factors according to their degree of dependence upon the numbers of the organism they attack, that is, upon the way in which their intensity of their action varies with the variation in numbers of the organism on which they act. The rapidity of increase of parasitic and predacious insects with markedly specific host relations depends to a large extent on the density of the host population. There are, however, certain parasites and predators, whose rate of reproduction is relatively little affected by the variation in numbers of any one of the species they attack, either because they are able to utilise a large variety of organisms for food, or because relatively large increases

in the numbers of the species upon which they feed affect their rates of reproduction relatively little. Such are the vertebrate predators and many of the predacious insects, as well as the polyphagous parasites. Such are also the pathogenic organisms, which appear to increase only when certain exceptional physical conditions accompany the increase in the numbers of their host.

Without discussing any further the characteristics of all the factors enumerated, let us consider more particularly the effect of variations in the intensity of the independent, as compared to the most characteristic group of the dependent factors, that is, the specific parasites and predators whose multiplication and development depends in large measure upon the numerical variation in the populations of certain definite species of hosts.

Suppose we have a population of one hundred female individuals per unit of area living in a region where the physical conditions are such that of the six offspring each individual can produce only one pair survive in every generation. If the intensity of the physical factors suddenly decreases, so that all the six offspring survive in every generation, in four generations there will be 64,800 female individuals per unit of area. If then the physical factor returns to its former intensity so that as before, four out of six offspring are killed, the population will again become stable, but at a higher level than before. Similarly, if the population was depressed below the level of one hundred individuals per unit of area by an increase in the intensity of the physical factor, it would remain stabilised at the lower level in spite of the return to normal conditions.

The effect of variation in the intensity of the dependent factors, that is, the parasites and predators, is very different. If the host population has become stabilised at a definite value and a considerable fraction of the parasite population is accidentally killed off, the pest will begin to increase, unless some unfavourable condition intervenes; but this increase in the abundance of the host will be favourable for the parasite, by making it easier for it to find hosts, for although the *potential* power of the parasite of locating its prey is dependent upon its specific habits, its *effective* power depends mainly on environmental conditions, among which one of the most important is probably the relative density of the host population. The parasite will thus increase more rapidly than before and if the host population had been stabilised before this increase began, it will progressively reduce its numbers until the effects produced by its own multiplication, such as superparasitism, rarefaction of the host population, etc.,

begin to effect it adversely. It will thus automatically reduce the host population to something near its original level. A similar effect will be produced if the numbers of the host are accidentally increased through the temporary decrease in the intensity of some physical factor, and stabilised at a higher level.

Now, other things being equal, the economic significance of a pest depends upon what we may call, roughly, the number of individuals per unit of area, that is, upon its population level. The fact that they are able to reduce the population level of their hosts is, of course, the principal reason for the importance attributed to the parasites and predators of destructive insects.

When a pest is transported into a new environment without the natural enemies which habitually attack it in its native home, it will begin to increase and spread, provided food material in the proper stage of development is available and the physical factors acting in the new environment are not more adverse to the pest than they were in its native home. It is, of course, evident that this increase and spread cannot continue indefinitely, for the reasons given at the beginning of this section, even in the absence of the natural enemies. The entire biogeographical area suitable for the species must eventually be occupied and after this point a very large proportion of the offspring will continually overflow, both in space and in time, into unsuitable environments. Finally, in extreme cases there may be a serious diminution of the food supply, which further reduces the number of adults able to reproduce and offspring able to survive. However, when the population has reached this point, its level will in all probability be very considerably higher than in its native home, and consequently the importance of the species as a pest will be immensely greater. Occasional fluctuations in the severity of the physical factors may, from time to time, reduce the population level, but in this case the effect would, in all probability be only temporary, because one of the most important reasons why the pest has ceased to increase is assumed to be that all of the available suitable environments have been occupied.* The partial destruction

* This does not necessarily mean that all the food has been devoured, or all the suitable habitats occupied, but simply that, at a given moment, all of the offspring of the *average* individual that are able, *on the average*, to get to places where food, suitable physical conditions, and freedom from the attack of enemies *all* co-exist, have, so to speak, taken up their positions. There is almost always an abundance of food, but the organisms cannot get at it.

of the population would liberate a number of these environments and permit the effective reproductive rate of the pest to rise, so that it would soon regain its original level. It therefore seems logical to introduce the controlling factors, whose intensity varies in proportion to the numbers of the pest, that is to say, the parasites or predators which attack it in its native home.

The success of this introduction as a measure of control will depend, of course, in the first instance, on the effect which the new environment exerts upon the introduced species. If the physical factors affecting it are less favourable than in its native home it will either not be able to increase, or will only do so extremely slowly, in which case, although it multiplies at the expense of the host and will theoretically reduce its numbers, it probably will not produce any susceptible economic effect within any reasonable time. It is thus extremely important for the entomologist of the area into which the parasite has been introduced, to follow its progress carefully from year to year so as to determine with certainty whether it is increasing or not. Although the introduced species is able to increase for a considerable number of years it may in some instances cease to do so before it has produced any measurable economic effect, partly because the temporal and spatial relations of the host to the new environment differ in some way from those which exist in the native home. Suppose, for example, that a pest, which, in its original environment, lived upon or near the surface of the plant it attacks, adopted in its new home, a habit of burrowing more deeply; in that case a parasite which was able to attack a large proportion of this species in its native home would kill a smaller proportion in the new environment, and as has been shown elsewhere, the effect of this might be to arrest completely the progress of the parasite before it had produced any noticeable reduction in the numbers of the host, a proportion of the offspring perishing through super-parasitism and the remainder through the inability of the parent to find hosts.

Let us suppose, however, that conditions are relatively favourable to the parasite and it is able to increase in its new environment until its population becomes quantitatively equal to that of the host.

Even under these conditions the course of events may not present a very satisfactory appearance.

Perhaps the most important point to remember in this connection is that during the period which follows the introduction and establishment of a species, and the time when it has reached the highest population that it can attain in the area, there is an intermediate period during which the species increases slowly but steadily in numbers, but during which this increase may be masked by local irregularities of various kinds, so that in one locality the parasite may appear for a certain length of time to increase with extreme rapidity, while in another it exerts absolutely no effect, after which it may disappear from the first locality and become abundant in the second.

It is evident that, other things being equal, the phenomena which will follow the introduction of a parasite or predator depends, on the one hand, upon its rate of increase, and, on the other, upon the precise manner in which it spreads. Suppose, in the first place, that the rate of increase and the rate of spread are uniform, that is to say, that the species increases at the same rate over the whole area in which it is distributed, and that it also spreads at a uniform rate so that the population continues to be evenly distributed. In this case collections at any point in the area in which the parasite has become established will give very similar results. Nevertheless, even in this case the data obtained in regard to parasites belonging to different species may be very different. If the rate of spread is very slow in relation to the rate of increase the collections may indicate a perceptible rise in parasitism from year to year, but with a very localised distribution of the parasite. On the other hand, if the rate of dispersion is relatively rapid, as compared to the rate of increase, the collections made, even though they contain large numbers of the host, may completely fail to demonstrate the presence of the parasite, even for a considerable period. It is at present, hardly realised, even by entomologists, how enormous the population of an insect actually is and how tremendous is the disproportion between the populations of introduced beneficial insects and the population of the pest among which they are liberated. Even in moderate infestations several million individuals of the pest are often present in every acre of the infested territory. Supposing that the population of the pest is only one million per acre, then in a square mile of the crop attacked, there would be 640,000,000 individuals. If we liberate in such an area a colony of 1,000 female parasites, there will be only one parasite to 640,000 individuals of the pest. In such a case the rise in proportion of the parasitised hosts would necessarily be slow, unless the effective reproductive rate of the

parasite was very much greater than that of the host. Thus, suppose that the effective reproductive power of the parasite was twice as great as that of the host and that both host and parasite had only a single generation in a year. In that event, under conditions quite favourable for the progress of the parasite it would have to reproduce at the expense of the host for eighteen years before its population became equal to that of the host, *and in the fourteenth generation the percentage of parasitised hosts would actually be less than three per cent.* So far as can be determined from theoretical calculations, which are, as a matter of fact, in very fair agreement with the results obtained up to the present in practical work, the progress of events over the area considered as a whole, may usually be described by saying that the curve of the percentage of parasitism rises very slowly for a considerable time and then, when the end of the parasitic cycle is near, more and more rapidly until the work of extermination is complete, or the parasite has reached its numerical limit and ceased to increase. This means that during a number of years following the introduction of the parasite, its increase may be practically impossible to detect because of the local variations in numbers, even although its progress is, in fact, quite satisfactory. From this we may conclude that there is no reason to be discouraged, even though no perceptible results follow immediately on the introduction of a parasitic species or even for *many years afterwards*. In other words, experiments which are proceeding in a quite satisfactory manner and are, in fact, predestined to success, may present the appearance of failures. The method of biological control is not, in most cases, one which can be relied upon to give rapid results, at least in temperate climates. Its value, when it is successful, lies chiefly in the fact that it produces eventually, a permanent improvement in the agricultural situation with very little initial cost. Future generations will benefit from the results obtained, but they will also inherit the effect of any imprudent measures undertaken with a view of accelerating the process of control. Great care must, therefore, be taken to determine whether or not the results of an introduction are successful before taking any further steps.

The second case to be considered is one in which the rate of increase is uniform over the area considered as a whole, but the rate of dispersion is irregular, that is to say, in which the parasite remains confined to small areas scattered here and there throughout the district. In such a case the agriculturists in one locality may report results

that are almost incredibly satisfactory, while those from other areas report complete failures. Owing to the change in local climatic or other conditions, the conditions may be reversed in a few years time. The entomologist must, therefore, be as much on his guard against premature reports of success as against premature complaints of failures. Sometimes the localisation of the parasite in certain small areas may be a purely accidental phenomenon, so that after a few years the parasite spreads over the whole of the area. In other cases, however, its failure to spread may be due to the fact that its powers of locomotion are inadequate, and in this event it may be necessary to spread the parasite by artificial means, such as the United States Bureau of Entomology has found it necessary to use with *Anastatus bifasciatus*, one of the egg parasites of the Gipsy Moth.

In considering the effects of the introduction it must also be remembered, that at the time the beneficial species are liberated, the pest may not as yet have reached its limit in the new environment, but may still be on the increase, spreading year by year into new territories and producing greater and greater destruction in those it already inhabits. If the host population is increasing, the parasite will not overtake it unless its reproductive rate is equal to or greater than that of the pest, though, of course, it may do so after the host population has become stabilised. If the reproductive rate of the pest and its parasite are equal, the parasite will eventually overtake it, but the process will be very slow, the time required for control, other things being equal, being determined principally by the relation between the initial populations of the two species. If the reproductive rate of the parasite is greater than that of the host, the time required for control will be considerably lessened, a slight superiority in reproductive rate being a great advantage. Thus, a population of a thousand parasites, reproducing one and a half times as fast as the host, might under certain conditions overtake a population of a million individuals of the latter, in only fourteen generations. Under the conditions postulated, and supposing that all of the individuals of the host are accessible and attacked by the parasite introduced, the moment when the parasite overtakes the host will theoretically be marked by the total extermination of the latter followed by that of the parasite; or, in a practical case, by a very considerable reduction of the host population, after which the parasite population will also be decimated owing to the rarity of the host, the condition thus produced forming a point of departure of a new cycle of development.

However, in spite of the fact the host is ultimately almost exterminated by the parasite and that the percentage of hosts destroyed increases from generation to generation no reduction whatever in damage will be produced until the generation in which extermination occurs. On the contrary the pest will steadily increase in numbers and consequently in destructiveness. Although its rate of increase from generation to generation will gradually diminish, the general situation, considered from an economic standpoint, will steadily become not better, but worse and worse until the climax is reached.

If the host population has reached its maximum and become stable, and the introduced parasite or predator is capable of increasing in its new home then immediate benefit may be expected, provided the increase of the host has not been checked because its population is too large for the area, in which case, as has already been said, the loss through parasitism might, at least for a time, be counterbalanced by the increase in reproduction, due to the fact that localities suitable for the offspring can be more easily found; and provided also that the individuals destroyed will not naturally succumb, even in the absence of the parasite, through the action of other controlling factors, in which case the action of the parasite will have no effect until it becomes abundant enough to kill individuals which would otherwise survive. If the host is destroyed in the pre-destructive stage the diminution in the damage produced will naturally be more rapid than when it is killed at the end of the destructive stage in its life history, but in any event, under favourable conditions, the action of the introduced parasite or predator population should produce an immediate, if slight, reduction in economic damage.

As has already been said, the rapidity of the increase of the parasite at the expense of its host and consequently the length of the interval between the time the introduction is made and the time when an appreciable reduction in economic damage occurs, appears to depend principally upon the effective reproductive rate of the parasite and is relatively little affected by the rise of the initial population. It follows from this that attempts to produce rapid results by liberating an enormous population of the parasite, or by making repeated introductions of the same species year after year are not likely to give results commensurate with the expenditure involved, though these introductions are, of course, justifiable if designed to establish and spread the beneficial species.

As we have already said there is, theoretically, at least, a possibility that owing to the inaccessibility of a fixed proportion of the hosts, the parasite population might be unable to overtake the host during the period of its increase, destroying in each generation a high percentage of hosts, but remaining economically ineffective. This is probably a partial explanation of the curious case of the parasites of the Alfalfa Weevil, which have increased in the Western United States until they destroy, in many districts, over ninety per cent. of the Weevil larvæ, the adults of the parasites being actually more abundant than the Weevils themselves, and are, as yet, unable to prevent economic damage.

Let us now consider more particularly the events which are likely to follow after the parasite has reached the limit of its increase ; that is to say, has reduced the numbers of the host to such a point that the rarefaction in its population has prevented the beneficial species from increasing further.

As we have already said, this rarefaction may be abrupt and catastrophic in cases where both parasites and hosts are increasing, while if the host population becomes stable before the parasite overtakes it, the diminution in numbers is likely to be gradual, unless the beneficial insect has exceptionally rapid powers of increase.

It is highly probable that the level to which the population of the pest is reduced when the parasite overtakes it during a period of increase is much lower than that to which it will fall if it has become stabilised during the progress of its enemy. The chance that any given parasite will find a host may be considered to depend more or less directly on the density of the host population, so that if the number of parasites finding hosts be represented by p_0 , the number of hosts by h , the number of parasites present by p_1 , and the dimensions of the total area by A , the relation between these values could be very roughly expressed by the simple equation :—

$$p_0 = \frac{p_1 h}{A}$$

The fall of the curve represented by this equation for equal decrements of h is at first rapid, but becomes slower and slower as the value of h diminishes. This means that the effect of the increase of the parasite at the expense of the host will be to cause a rapid decrease in the number of hosts it finds, so that its rate of multiplication soon

slows down and the population eventually becomes stabilised at the point where its destructive capacity is balanced by the loss in progeny, or oscillates about this level.

When the parasite overtakes the host at the end of a period of increase the effect will be exactly the opposite. The increase in the density of the host will facilitate the attack of the parasite, and, as has been shown elsewhere, the loss through superparasitism may not be sufficient to prevent its advance. The result will be the simultaneous disappearance of the vast majority of the individuals of the host, after which the parasites, unless they are species capable of attacking other hosts will disappear in their turn, so that the population will fall far below the level it would reach in the first case studied, and an enormous reduction in damage will immediately ensue. In the last generation of its abundance, the vast majority of the host larvæ will produce, not adults of the host but parasites. These will emerge in vast numbers in the following generations, but the number of individuals of the host per unit of area will now have fallen far below the point where the average individual of the parasite is able to reproduce so that unless it is a polyphagous species, able to utilise other and perhaps less favoured hosts in times of scarcity, it will be decimated in its turn. In the generation of its maximum abundance, the parasite will, however, succeed in destroying a certain proportion of the remaining hosts because of the thoroughness with which the area is explored. But the number of parasites which issue in the following year will necessarily be very small. There will then occur a series of what the physicists call "damped oscillations," i.e., fluctuations in the numbers of the two species which are at first considerable, but gradually decrease in amplitude, with a gradual movement of the populations to a higher level.

The reason for this is that the hosts and parasites are widely scattered and, on the average, widely separated, so that a large proportion of the former will escape their enemies, the population of which will fall still further. The increase of the host will thus go on for a considerable period; but as it becomes more numerous, the parasites, having increased facilities for reproduction, will also become more numerous and will eventually catch up with the pest. However, the population level at which this will occur will evidently be much lower than at the end of the first cycle, because the numbers of host and parasite are much more nearly equal at the beginning. Furthermore, the numbers of the host will probably not fall to a level as

low as in the preceding case, because at the point when the parasite population becomes numerically equal to it, its density will be much less, which will diminish the chance of encounters and increase the amount of residual host population. Since the residual host population is fairly large, the parasite population will not fall so far. Without following the details of the process any further it is evident that from generation to generation the variations in numbers of both host and parasite will become less marked, while at the same time the level of their populations will rise until they finally come to oscillate regularly about the same level they would have reached if the parasite had been acting on a host population already stabilised in relation to the general environment. The course of events in the two cases is very different, but the ultimate result is the same.

If the level about which the population of the pest oscillates after the parasite has had time to exert its full effect, is still above the level of economic damage, as it may be in a great many cases, the introduction of additional species must be contemplated. As we have said in a preceding section, there is a great deal of controversy in regard to this important question. The theoretical study of the problem indicates several curious possibilities, which may be briefly indicated.

Let us suppose to begin with that after an introduced species, attacking some particular stage of the host, has reached its maximum development, so that the two species oscillate more or less regularly about a certain average figure, we introduce another parasite attacking another stage. To take a simple case, let us suppose the first species attacks the larva and the second the egg, and that the egg parasite is one like *Trichogramma*, which is able to develop on several hosts, so that its attack on any one particular species has relatively little repercussion on its own reproductive powers.

During the initial period of development, the egg parasite may have no very marked effect, even though it is increasing, because a large proportion of the eggs it destroys would be killed off in the normal course of events. Eventually, however, it will begin to eliminate individuals which would otherwise have survived and would have been attacked by the larval parasite. Let us suppose its population becomes relatively stable about this time. The number of individuals of the larval parasite which succeed in finding hosts will now diminish. The number of progeny produced by the average individual of the pest will, of course, remain the same, since the

larvæ lost by the larval parasite have been gained by the egg parasite. In the following generation the number of eggs of the host will therefore be the same as if the egg parasite had not been present ; greater or less than in the preceding generation according to whether the host population is rising or falling. The egg parasite, under the conditions stated, takes approximately the same *number* as before. Now if the host population is in the descending phase of the cycle, this will mean that a greater proportion of eggs are destroyed than in the preceding generation. This will greatly increase the difficulties of the larval parasite, of which more individuals will perish, so that it will fall much below its ordinary minimum level. As the egg parasite can maintain its abundance in spite of the rarefaction of the host population, it continues in every generation to destroy the same number of eggs, and, consequently, an increasing proportion of them. The level of the host population gradually sinks. Suppose now that a sudden climatic change decimates the population of the egg parasite or favours the host so that it begins to rise. The effect of the egg parasite will then become in every generation less and less marked since the number of eggs it destroys is constant and the proportion, in a rising population, decreasing. A severe outbreak will then occur, which neither the egg parasite nor the larval parasite can check, the former because in every generation a proportion of its population overflows or is dispersed among other hosts, the latter because its population level has been greatly reduced and its increase is still checked by the influence of the egg parasite.

The effect of the introduction of the new parasite would thus be to produce violent fluctuations in the abundance of the pest, or, in other words, a series of severe outbreaks. If the average level of the pest had primarily been only slightly above the level of economic damage, the new state of affairs would obviously be worse than the first.

By a similar line of reasoning it could be shown that if two parasites attacking the same stage and occupying the same ecological niches were introduced, the effects exerted by the two considered separately, could not be added together, because the parasite with the more efficient habits would ultimately displace the other from the environment.

Without going into any more complicated cases, it is evident that the question of multiple parasitism is obscure, and that there is at least something to be said for the policy of introducing beneficial

species singly. Although the theoretical or mathematical studies on the subject can be continued indefinitely and will doubtless produce many interesting results, the most urgent need at the present time is for an exact and detailed study of the results of practical experiments combined with carefully planned research in the laboratory on particular problems. The value of theoretical considerations depends essentially upon the fundamental assumptions on which they are built up, and here, as in all other fields of science, the ultimate test of such hypotheses is the careful observation of concrete events.

If after a number of years of very careful observations, it has been determined with certainty that the increase of the parasite over the whole area has ceased and that the population present is unable to bring about the control of the host and prevent economic damage, then further steps must be taken. Nevertheless, before any further parasites or predators are introduced a very careful effort should be made to determine exactly why the species already present is insufficient to produce control. Once this is known the task of selecting another of those species known to attack the pest in its native home is considerably facilitated. Although the danger of conflicts between species with allied habits may be inconsiderable, it seems on general grounds preferable to take as the object of the next introduction, species attacking some quite different stage of the host and consequently quite unlikely to interact in any prejudicial way with the first species introduced. For example, if the species introduced has been one attacking the larval stages of the host and emerging before the pupæ have formed, the next species should, if possible, be one attacking either egg stage or the pupal stage. It may, of course, happen that the parasites attacking the particular stages may be quite inefficient in the native home, but this does not actually prove that they will be equally inefficient in the new environment. This method should therefore be given a fair trial before the introduction of species attacking the same stages of development is attempted.

10. *Summary.*

We have now covered in a very rough and general way the main phases of a practical operation in biological control. The account given has no pretension to completeness, as the special methods necessary in the case of given species may differ very greatly. However, we hope to have succeeded in making clear that the

operation of biological control is a very well defined phase of economic entomology, necessitating special knowledge, special equipment, special resources, and special methods. It is on this account emphatically a branch of economic work, in which centralisation of effort is advantageous. The present organisation of work of this type in some parts of the world has hitherto been rather prejudicial to the progress of the subject, owing to the fact that enterprises of this nature are carried on in a disconnected and uncoordinated manner in entirely different sections of the entomological services of the country concerned. The creation by the Imperial Bureau of Entomology of a central organisation, equipped with a staff and resources necessary to carry on this type of work on behalf of the different parts of the British Empire is thus expected to result in a rapid improvement in the methods employed. On the other hand, the centralisation of the work will not bear its proper fruit unless there is complete cooperation between the members of the staff dealing with the various projects and the entomologists of the Empire, on behalf of whom they are working, nor unless the operations are organised according to some coherent and intelligent plan.

The duty of the entomologist who collects and studies the material is to obtain information as complete as possible, as to the biology, habits, and methods of rearing the parasite which he collects, so that the entomologist at the receiving end is supplied with the information he requires for dealing properly with the species he receives. The duty of the entomologist who distributes the material is to keep and supply to the central organisation a complete and accurate record as to the effect produced by the parasite which has been introduced. It is gratifying to say that a number of the entomologists to whom parasites and material have been sent from Farnham House Laboratory have made an effort to supply the Laboratory with careful and accurate reports as to the condition of the material received and the results which have followed liberation. Nevertheless, the surveys that have been made up to the present in most experiments on biological control are not yet by any means sufficiently accurate and detailed. Careful studies of the exact effect produced by the introduced beneficial species are of the very greatest importance in estimating the general value of experiments in biological control, and it is not too much to say that the future progress of this work as a phase of practical economic entomology will depend mainly on the accuracy and thoroughness with which these investigations are carried out.

III. FARNHAM HOUSE LABORATORY: ITS RESOURCES, BUILDINGS, EQUIPMENT AND STAFF.

1. *Finances.*

The foundation of Farnham House Laboratory was made possible by a grant from the Empire Marketing Board of £15,000 for capital expenditure, and £25,000 to cover maintenance expenditure during a period of five years. Owing to the rapid development of the work of the Laboratory, the sum allocated for maintenance expenditure proved inadequate. In 1929, after the matter had been thoroughly discussed between representatives of the Marketing Board and the Imperial Bureau, an application for a further £2,000 per annum for maintenance expenditure was made and granted as from 1st July, 1929. In 1929 at the request of the New Zealand Government, we took over the conduct of the European end of the work on the insect enemies of New Zealand weeds, and receive from the New Zealand Government a special grant of £1,000 per annum for this work. Several members of the Australian Federal Entomological Service have been given accommodation in the Laboratory at the request of the Commonwealth Council for Scientific and Industrial Research, and payment for this accommodation is being made on a cost-account basis. In addition, a special grant of £95, for the work carried out with the parasites of certain insect pests, was made to the Laboratory in 1929, by the New Zealand Government, while similar subsidies have been offered for other pieces of work by the Governments of New Zealand, Cyprus, etc.

2. *Grounds, Buildings and Equipment.*

The grounds of the Laboratory, which comprise about six and a half acres, run north and south, with the long frontage on the Beaconsfield Road, from which they are separated by high walls and hedges. The front of the property, in which is situated the main building, is surrounded by a small park containing lawns, trees, shrubs and flower borders, of which the utility in work of a general entomological character can hardly be overestimated, since they provide a supply of plants of all kinds, to which many insects of economic importance are attracted.

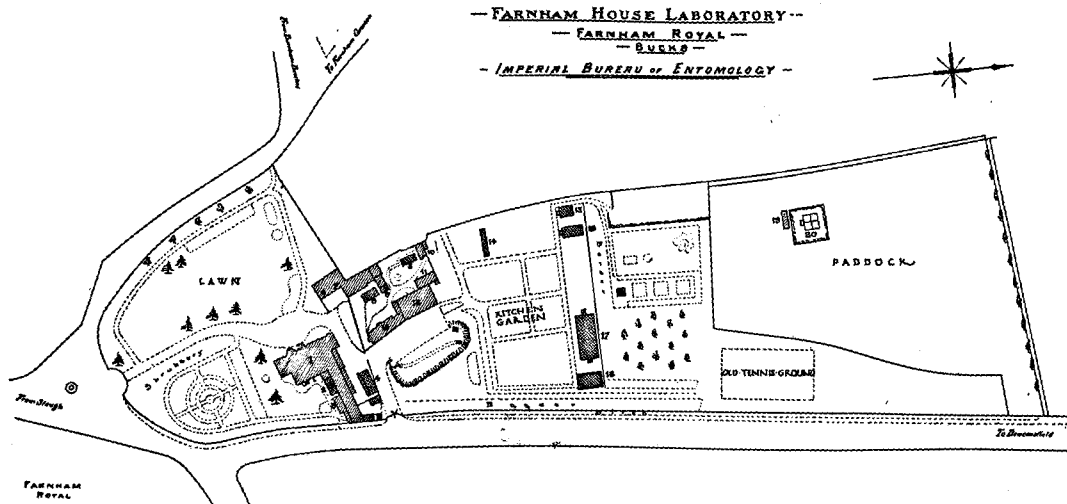
Behind the main buildings are the stables, now used as garages and store-rooms, a small greenhouse, and the cottage of the carpenter-mechanic and his wife, adjacent to which is the carpenter's shop and

a large barn. The remainder of the grounds comprises a vegetable garden of about two acres, planted with fruit trees, vegetable crops of various kinds and certain of the weeds under investigation, and in which are the four principal insectaries, situated on the south side of a high privet hedge. On the north side of this hedge is a sunken garden which contains a small pond, and is bordered on both sides by strips of uncultivated land. The extreme northern end of the grounds comprises a small grass paddock, in which animals can be kept, and an area of about two acres which was planted with forest trees of various kinds at the time the property was purchased. Adjacent to this are the filter beds and a special small insectary for work such as the breeding of Blowfly parasites, which it is not desirable to have near the main building.

The Laboratory proper is a country house, which has been admirably adapted for scientific purposes. It comprises a two-roomed cellar, an entrance hall and six rooms on the ground floor, and two upper floors, each with seven rooms. A narrow wing running from the main block to the wall separating the property from the Beaconsfield Road, contains five small additional rooms. Against the south wall of this wing are two small lean-to greenhouses.

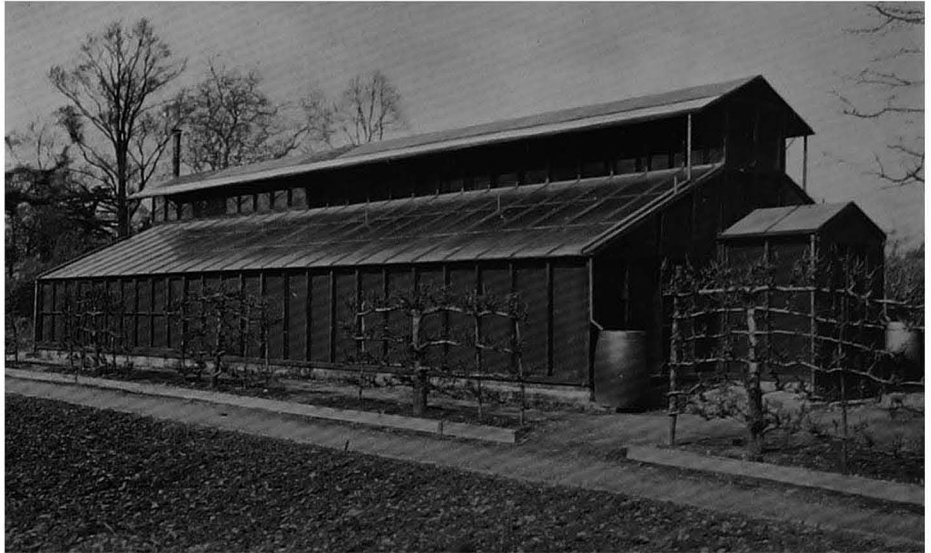
When the building was taken over it was found that the electric light cable had not sufficient capacity to supply the current required for laboratory work. A new cable was therefore laid. As commercial gas was not available, the house was fitted with a petrol gas plant. A central heating plant was installed and radiators were provided in the various rooms, hall, passages, etc. The telephone was put in, with connections to the Superintendent's room and the upper two floors, and the telegraphic address "Entburlab" registered at the Post Office for cables and telegrams.

The modification of the premises has gone on steadily since they were taken over and is now practically complete. One of the rooms in the basement has been provided with a "baffle-chamber," lined with cement, repainted with white enamel, and the hot-water pipes passing through it covered with non-conducting material. Three electric wall heaters, thermostatically controlled and a simple apparatus for the provision of atmospheric humidity, provided with an electric hygrostatic control, which actuates an electric fan, have been installed in this room, which thus functions as a constant humidity and temperature chamber, in which these factors as well



Plan of Grounds, Farnham House Laboratory.

1. Main Building; 2, 3, 4, 5. Greenhouses; 6, 7, 8. Garages and Stables; 9. Pump; 10. Carpenter's Shop; 11. Shed;
 12. Barn; 13. Cottage; 14. Pit Lights; 15. Single Insectary; 16. Double Insectary; 17. General Insectary; 18. Storage
 Insectary; 19. Top Insectary; 20. Filter Beds.



1. General Insectary in teak, with baffle chamber, ventilated central corridor and separate lateral compartments.



2. Small teak insectaries; that on the left with one, and that on the right with two compartments.

as light, can be regulated in a manner quite sufficiently accurate for practical work. Two rooms on the ground floor, three on the first floor, and four on the second floor, have been provided with teak-topped benches with drawers and sinks. Each bench is fitted with drawers, a triple laboratory tap, power and lighting plugs, necessary water supply, sealed waste-pipe and drains. Cupboards and bookshelves have been installed in all rooms. One of the large rooms on the ground floor has been fitted up as a library, two as offices for the Superintendent and the Secretary, two as store and temporary work rooms, and one as a stewards' room. In five of the rooms plate glass windows have been fitted to facilitate microscopic work.

On the first floor, one room, giving access to a convenient outdoor terrace above the library, has been fitted up as an indoor breeding room. A second has been transformed into a studio, the small window originally present having been removed, the opening enlarged to about eight feet square and a new steel-framed window, with quarter-inch plate glass inserted. The room adjacent to the studio was made into a dark-room and provided with shelves, and a very large lead-lined sink with a special photographer's tap.

In the wing running from the main building towards the Beaconsfield Road a refrigerator house was constructed by throwing the larder and dairy into one and raising the roof, inserting the necessary girder, and providing a new concrete granolithic floor. A new timber and corrugated iron enclosure was provided to accommodate the new petrol gas plant and the necessary steel gantry was erected in conjunction therewith. The heating apparatus of the leanto greenhouses was later found to be defective, and as one of these was needed for practical work, a system of electric heaters was installed.

Four insectaries were originally constructed (Plate VI). Three of these were built of teak, with phosphor-bronze or copper gauze sides; the other, which is chiefly used as a shelter or hibernating shed, of deal. One of the teak insectaries, situated in the upper part of the garden, has a wooden roof, the remaining two are roofed with "Vita" glass, which admits a high proportion of ultra-violet rays, in order to make the lighting as natural as possible. Of the two original teak insectaries, with "Vita" glass roofing, one has only a single long compartment, while the other is divided into two.

In view of the rapid development of the work, it was soon found that the insectary and greenhouse space was quite inadequate. In the early part of 1929, plans for a large insectary were therefore drawn up. This insectary (Plate VI) is constructed like most of the others, of teak, with sides of fine meshed copper gauze and a "Vita" glass roof. It consists of ten lateral compartments, opening by means of double doors into a central corridor, at the end of which is a baffle chamber. Above the central corridor is a ventilating chamber with gauze sides and overhanging eaves, constructed in order to prevent the development of excessive temperatures during the summer months. In order to permit of the breeding of tropical pests and beneficial insects, even under English winter conditions, the four compartments, situated at the end away from the door, the end of the corridor, and the end and sides of this part of the ventilating chamber, have been fitted up with detachable "Vita" glass sashes. Three rows of four inch pipes have been run round the inside of the compartments, which are heated by a greenhouse boiler, bricked into the end of the corridor. At present coke is used for heating, but as soon as a suitable oil burner is obtainable, this method of heating will be employed, since it can be used in connection with a thermostatic control, thus giving a constant temperature in the heated portion of the insectary.

Each of the compartments of the insectary is ten feet square, five feet high on the outside, and ten feet high on the side next to the corridor. In each compartment there is a cement trough two feet deep and two feet nine inches wide, surrounding a cement platform four feet by four feet nine inches with raised sides. This trough is filled with sand or sterilised soil, so that any plants or trees required can be grown under conditions as natural as possible.

The corridor and each of the compartments are provided with wall plugs and droplights, and in the four heated compartments, power plugs have also been installed. A power cable connects the insectary with the meter at the main building. A tap for water, connected with the main, has been provided in the end of the corridor.

In spite of this new building, the space provided for breeding work is still insufficient, and an additional small building may have to be erected for the breeding work on the Codling Moth parasites early this season.

An effort has been made to provide in the laboratory an equipment as efficient and up-to-date as possible.

Three automatic Hearson incubators, and an automatic Hearson refrigerator were purchased at an early date. Two special Wisconsin Cabinets constructed on the lines of those designed by Mr. R. H. Stoughton, of the Rothamsted Experiment Station, and permitting of a very accurate regulation of temperature, humidity and light, have been constructed by the Laboratory Carpenter, Mr. J. W. Smith, and fitted up with the necessary heaters, humidifiers and controls. A special apparatus for the regulation of humidity and temperature, in relation to small insects, was constructed for Mr. MacLagan in his work on *Smythurus*. Finally, some eighty-five cages, built of teak, with copper gauze sides, and, for the most part, "Vita" glass tops and doors, of most excellent construction, and in a great variety of sizes and designs, have also been built by Mr. Smith. A considerable number of thermographs, hygrothermographs, Livingston atmometers, and thermometers of various types, including a standardised instrument, have been purchased for use in connection with certain phases of the work.

Two excellent cameras, one of the most recent type, are available for outdoor work, and another for high-power work in the Laboratory. The optical equipment also includes two compound microscopes (Swift and Zeiss) and six Zeiss binocular microscopes. An autoclave, fitted for electric heating, has been installed for bacteriological work, and a Brunsviga Calculating machine and a Dictaphone have also been purchased.

In spite of the close proximity to London, and the unusual facilities available at the Publication Office of the Bureau, a well-stocked local library is essential to the proper conduct of the investigations carried on at the Laboratory, especially since, as will be clear from the remarks in the second part of this report, the reference works required necessarily cover a much wider field than is usual in entomological libraries. At present, the Laboratory library comprises more or less complete sets of about twelve periodicals, about 150 reference works, and a collection of about 2,000 separates, including a large number of the bulletins of the United States Bureau of Entomology, obtained through the kindness of Dr. L. O. Howard, as well as a number of duplicates transferred, with the kind permission of Dr. S. A. Neave, from the library of the Publication Office.

The present Superintendent wishes to take this opportunity of expressing his appreciation of the excellent judgment and technical ability shown in the fitting up and in the equipment of the Laboratory,

carried out under the direction of Dr. Neave. The fact that this work had, for the most part been completed before the present Superintendent took charge has greatly facilitated the organisation of the work.

3. *Staff.*

A number of changes in the staff of the Laboratory have occurred since its foundation. During the initial period the activities of both the Laboratory and the Publication Office were directed by Dr. S. A. Neave. Mr. R. A. Stenton and Dr. J. G. Myers were appointed as entomologists, Miss R. N. Davenport was transferred from the Publication Office for the secretarial work, Messrs. L. F. Milton and D. Berryman were engaged as laboratory stewards, Messrs. P. Trevaskis and H. Macro as gardeners, and Mr. and Mrs. J. W. Smith as carpenter-mechanic and caretaker, respectively. Owing to the rapid increase in work in both fields and the distance between the two offices, this arrangement was found to be impracticable. Dr. Neave therefore withdrew from the Laboratory on June 9th, 1928, on which date the present Superintendent took over. The resignation of the Senior Entomologist, effective on August 31st, the transfer of the former Secretary, Miss R. N. Davenport back to the Publication Office, and the resignation of the former Head Laboratory Steward, Mr. L. F. Milton, occurred about the same time. Finally, on October 27th, 1928, Dr. J. G. Myers left for Trinidad in order to investigate, on behalf of the Laboratory, the possibilities of applying the methods of biological control to the pests of the British West Indies and adjacent territories.

Owing to the difficulty of obtaining men with the ability and training necessary for the work, it was some time before the vacancies could be filled. Dr. G. Salt was appointed as Senior Entomologist to replace Dr. Myers in the autumn of 1928, and took up his duties on December 1st of that year. Dr. W. H. Thorpe was appointed on November 15th, 1929; Mr. H. T. Rosenberg was taken on in a temporary capacity on August 13th, 1928, and was given a permanent appointment on August 1st, 1929. Mr. R. C. Jeffery was appointed as Secretary to replace Miss Davenport on July 16th, 1928, but the services of Miss Davenport were retained by special arrangement with Dr. Neave, for work on the library, the parasite catalogue and bibliographies, to which she devotes one day a week. Mr. E. Basden was appointed as additional Laboratory Steward. The Head Gardener,

Mr P. Trevaskis resigned, to take up a position in Australia, on September 14th, 1929, and was replaced by Mr. J. G. Grant. The second Gardener, Mr. H. Macro, after a prolonged absence through illness, was discharged on August 19th, and replaced by Mr. S. W. Burrows.

The taking over of the work on the insect enemies of noxious weeds also necessitated new appointments. This work was at first in charge of Dr. A. S. Watt, who was appointed as Botanist to the Laboratory on May 1st, 1929, but resigned to take up the post of Lecturer in Forest Botany in the University of Cambridge. He was replaced by Mr. E. H. Chater, who took up his duties on November 1st, 1929, and is assisted by Mr. E. Cameron, appointed in a temporary capacity as from September 27th, 1929.

Since the work on which the Laboratory is engaged renders it necessary to have collectors permanently in the field, two entomologists, Mr. P. de Rippas and Mr. S. Kozlovsky, were appointed as Field Agents in France as from July 1st, 1928, while Mr. H. S. Hanson was appointed as Field Agent for the British Isles on September 23rd, 1929.

Mr. D. S. MacLagan, a Scholar of the Ministry of Agriculture for Scotland, was given accommodation at the Laboratory at the request of the Ministry, during the first two years of his Scholarship, and has been engaged in research work on the *Smyntihurus* problem from October 1st, 1928, to the present time. Valuable gratuitous assistance was also rendered in 1928 by Mr. F. Muir, Consulting Entomologist to the Hawaiian Sugar Planters' Association, by Mr. G. H. Spooner and Mr. H. Wood of the University of Cambridge in connection with the Pine Shoot Moth work, as well as by Mr. B. Uvarov, who was given a temporary appointment for six weeks in 1928, on the Sheep Blowfly work, and by various temporary workers from the village of Farnham Royal, amongst whom, Miss R. Thorne deserves special mention. A temporary assistant to the Laboratory Steward was employed for a few months in 1927.

4. Summary.

Work on biological control is in many ways peculiarly difficult, demanding special knowledge of several extremely difficult groups of insects, and an intimate acquaintance with certain very delicate technical methods. It is emphatically rather a field for the specialist than for the ordinary economic entomologist, who has usually neither the time nor the resources to handle it in a satisfactory manner. It

is, therefore, very important to have within the Empire a central organisation capable of co-ordinating research, investigating fundamental problems, and providing practical assistance and advice in regard to the method of biological control.

The situation of the Imperial Bureau of Entomology is in this respect exceptionally favourable. As has already been pointed out, movements of insect pests occur between all countries of the globe. Nevertheless, Europe is the mother of Western Civilisation. The basic foodstuffs of Europe are of fundamental importance to its colonies. The insect pests of the plants and animals utilised in Europe are, therefore, amongst the most important in relation to the agriculture of the Empire. The fact that the United States Bureau of Entomology maintains permanent laboratories in Europe for the study of the parasites of the introduced European insects, and that a number of important Canadian, Australian and New Zealand problems have had to be taken up in Europe, is sufficient proof of this contention.

The investigation of European insect pests, accidentally introduced into the British Dominions and Colonies, will always thus be one of the primary functions of any organisation designed to centralise and facilitate work in biological control within the Empire. Such studies, and the practical work to which they lead, could, of course, be carried on by agents sent specially to Europe for the purpose. There are, no doubt, cases in which this would be desirable, and in any event an exchange of staffs between the Laboratory and the Dominion Entomological Services is to be recommended as giving opportunity for personal contact and first-hand acquaintance with conditions in the various parts of the Empire. In general, however, it is quite certain that a permanent central staff, trained in the special methods of biological control, and familiar with European conditions, languages, and customs, can carry out the investigations required by the entomologists of the Empire immensely more efficiently, rapidly and cheaply than agents sent specially to Europe for the purpose. In many cases the price of the return passage alone would more than meet the total cost of the work, and the time required for the journey would carry the project well on toward a point where the desired results could be obtained by relatively untrained assistants. The plan here advocated provides for a number of special field agents or entomological scouts working in small and essentially temporary sub-stations, situated in the principal bioclimatic areas of Europe. A mobile and flexible organisation of this kind, which is absolutely

necessary for the best results, is in a much better position to seize opportunities for practical work when they occur (and their incidence can never be predicted with certainty) than agents sent specially from distant points, who, because of their unfamiliarity with the region or because of some seasonal irregularity, arrive too late to obtain the desired material.

In many cases, even though the pests giving trouble in a colony have not come from Europe, their original home is in some region which can be reached as rapidly, or more rapidly, by way of Europe, than by any other route. In that event the Laboratory can always act as a relay station for parasite material passing through. This is especially desirable when the insects transmitted have to be fed or allowed to reproduce en route, for the absence of facilities of this kind has in the past led to the total loss of consignments of beneficial insects, gathered with great labour and at great expense.

Furthermore, the introduction of the native parasites or predators of introduced pests from the native home is not by any means the only phase of biological control which is of practical importance. The work in California on the ladybird attacking the citrophilus mealy-bug, and in England on the White-fly parasite, to which reference has already been made, shows clearly that it is in some cases possible to increase the efficiency of an existing beneficial insect by artificial methods, and the investigations carried out at the Laboratory and elsewhere on *Trichogramma* have also given very promising results. The special facilities possessed by the Laboratory easily permit an extension in its activities to cover problems of this kind.

In addition to all this, it is imperative that the Laboratory carry out research into some of the fundamental problems of biological control, which cannot be conducted to the best advantage until the causes of the insect outbreaks and the natural control of pests are better understood.

IV. THE PRACTICAL WORK.

In the preceding sections an account has been given of the organisation and possibilities of work on biological control, with special reference to the organisation and equipment of Farnham House Laboratory. The next section will give an account of the various practical operations undertaken up to the present time, with indications

regarding the methods which have been employed in particular cases, and the results which have been obtained to date. The projects taken up have been classified under the groups of economic plants and animals, attacked by the pest studied. At the end of the section there has been included a table in which the projects on hand are grouped according to the various parts of the Empire interested.

1. Parasites of Deciduous Fruit Insects.

The Codling Moth (Cydia pomonella L.).

The Codling Moth is the most important insect pest of the apple. It originated in Europe, and is now distributed over practically all parts of the world where apples are grown. The losses from this insect in the United States alone are estimated to amount to over £3,000,000 per annum. It attacks the apple, pear, quince, English walnut, crab apple, and wild plum. The injury caused by the Codling Moth in many districts is so great that it is practically impossible to obtain satisfactory crops without applying arsenical sprays several times during the season. So large is the amount of poison which has to be applied to the apples in some regions that special arrangements are necessary to remove it from the fruit and in some instances the presence of arsenical residues has created serious difficulties in marketing.

In view of the importance of this pest, it has been decided to make a thorough investigation of its parasites, more particularly as it is an insect of European origin. This work was carried on during the first season by Mr. P. de Rippas and Mr. S. Kozlovsky in North-Western France, and continued during 1929 and 1930 by Mr. Kozlovsky in all of the important apple-growing regions of France. Collections of hibernating Codling Moth larvæ and parasites were made in fifteen localities situated in nine of the principal apple-growing departments. Eighty-nine consignments, containing approximately 33,550 larvæ were sent in, together with eleven consignments of parasitic cocoons. The examination of this material is not yet completed, but up to the present date the following eleven species of parasites have been obtained:—

Ichneumonidæ .. *Trichomma enecator*, Rossi.
Pristomerus vulnerator, Panz.
Ephialtes extensor, Tasch.
Hemiteles hemipterus, F.
Hemiteles cingulator, Gr.

<i>Braconidæ</i>	..	<i>Ascogaster 4-dentatus</i> , Wesm.
<i>Chalcididæ</i>	..	<i>Eupelmus urozonas</i> , Dalm. <i>Perilampus laevifrons</i> , Dalm. <i>Dibrachys affinis</i> , Masi.
<i>Tachinidæ</i>	..	<i>Arrhinomyia tragica</i> , Meig. <i>Exorista westermanni</i> , Zett.

Hemiteles hemipterus, *H. cingulator*, *Perilampus laevifrons* and *Dibrachys affinis* are probably all hyperparasites. The status of *Eupelmus urozonas* is at present doubtful. All of the other species are primary parasites.

It is very difficult to collect in the field, numbers of Codling Moth larvæ sufficient to provide really large colonies of the parasites. For this reason we have decided to increase the numbers of parasites we wish to export by intensive breeding methods. This work has been placed in charge of Mr. H. T. Rosenberg.

The first species chosen for breeding work was one discovered some years ago attacking the Codling Moth in the United States. It was believed by the American entomologists to be a native species and described by Viereck under the name of *Ascogaster carpocapsae*. This parasite deposits its egg in the egg of the Codling Moth and emerges from the full-grown larva. It has several generations a year and in certain regions of the United States destroys a relatively high percentage of the Codling Moth larvæ.

As has already been mentioned, a few specimens of a Braconid parasite belonging to the same genus, *Ascogaster quadridentatus*, Wesm., were obtained in 1929 from the collections made in Northern France. These have been compared by Dr. Ferriere with specimens of *A. carpocapsae*, Vier., from the United States, and have been found to be the same. It thus appears that this parasite is really one of the native enemies of the Codling Moth, which has probably been introduced into America in the hibernating larvæ of the host insect.

So far, *Ascogaster quadridentatus* has been rather rare in our material. However, thanks to the kind assistance of Dr. A. L. Quaintance of the United States Bureau of Entomology, we obtained from Mr. E. J. Newcomer of his Division, in the winter of 1928-29, some 2,200 hibernating larvæ of the Codling Moth, of which some 200 were believed to be parasitised by *Ascogaster*. A satisfactory number of both moths and parasites was obtained, and after a number of experiments, a method was devised

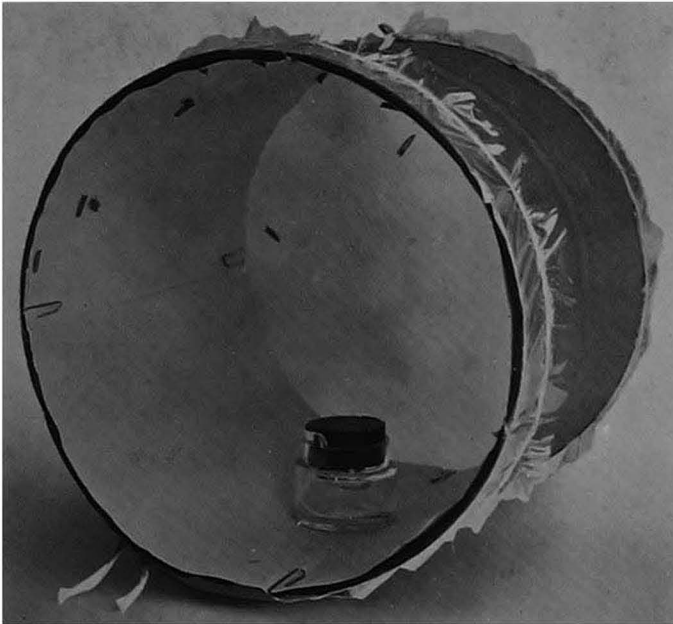
by Mr. Rosenberg, for obtaining a continuous supply of eggs of the Codling Moth, which was reared artificially in the Laboratory throughout the summer. As the Codling Moths emerged, they were placed in large cardboard cylinders lined with white or black paper, and having the ends covered with sheets of cellophane, attached by india-rubber bands. The moths were supplied with a small amount of food in the form of honey water and deposited their eggs freely upon the paper lining the cages and upon the cellophane. The pieces of paper bearing the eggs were then cut out and placed upon apples arranged in large trays, and it was found that they hatched quite successfully and were able to penetrate into the apples. After the end of the breeding period the larvæ of the Codling Moth emerged from the apple and pupated in layers of corrugated paper arranged around the trays, which were covered with fine-meshed wire gauze in order to prevent the escape of the caterpillars. In this way, it was found possible to rear the Codling Moth with great success in the Laboratory.

In order to rear the parasites the bits of paper bearing the eggs were placed in cages with the females, which oviposited freely in them. These eggs were then placed, like the unparasitised ones, on apples, in which the larvæ completed their development. A large stock of this parasite is now on hand, and the breeding work in connection with it will be continued during the course of the present season.

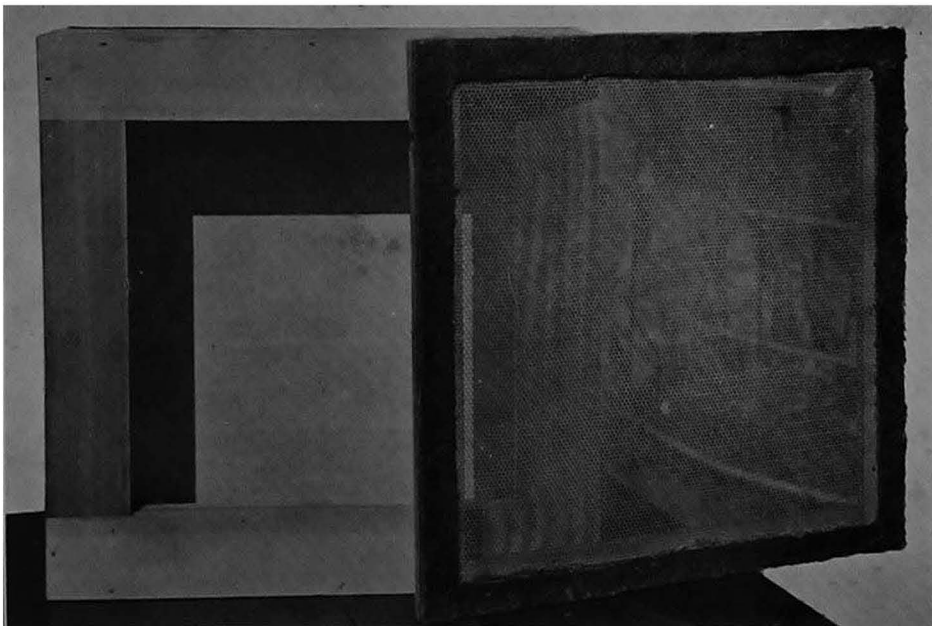
During the winter of 1929-30, Mr. Rosenberg has continued his experiments with other species and has already succeeded in breeding *Ephialtes extensor* in the laboratory. It is hoped that in the near future it will be possible to distribute stocks of the most important parasites to regions where the Codling Moth is injurious. A supply of several races of the egg parasite *Trichogramma*, which is being reared in large numbers in many parts of the world, with a view to its use as a control for Codling Moth and other Lepidopterous pests, is kept permanently at the Laboratory, together with a complete set of the apparatus used for rearing this parasite.

The Woolly Aphis (Eriosoma lanigera, Hausm.).

The Woolly Aphis of the Apple, sometimes known in England as "American Blight," is a very injurious pest, which perhaps originated in North America and has now spread practically to all parts of the world where apples are grown. Even in America it



1. Rearing of Codling Moth parasites : Oviposition cage for Codling Moths, consisting of a cardboard cylinder with a removable paper lining, closed at the ends with cellophane and mounted on a wooden block.



2. Modified Fiske Tray in deal, with cloth bottom and detachable cover of wire gauze on wooden framework, with felt strip.



1. Rearing of *Aphelinus mali* ; left, young apple tree from insectary with Woolly Aphis heavily parasitised by *Aphelinus* ; right, young apple tree from out-doors, adjacent to insectary with neither Woolly Aphis nor parasites.



2. Collection of *Sirex* parasites : Stack of logs infested by *Sirex* larvæ, constructed for the attraction of the parasites *Rhyssa* and *Ibalia*. The dark rings indicate *Sirex* tunnels.

is an insect of considerable economic importance, but its destructiveness is to some extent reduced by a number of parasitic and predaceous enemies which prey upon it, and of which the most important, judging from the available data, are the Syrphid, *Pipiza pisticoïdes*, Will., whose larvæ are predacious, and the Chalcid, *Aphelinus mali*, Hald., which is, in the early stages of its development, an internal parasite of the aphid.

In order to reduce the injury due to the Woolly Aphis, the entomologists of the apple-growing regions began, a number of years ago, to introduce *Aphelinus mali* from America, the material having been provided in most cases, if the writer is not mistaken, by the U.S. Bureau of Entomology, though a successful shipment to South Africa was made in 1923 by A. E. Lundie, to whom we owe a very valuable monograph on the biology of this parasite. The results obtained were in several cases strikingly successful; as, for example, in certain parts of New Zealand, throughout which it was energetically distributed by Dr. Tillyard.

In 1919, at the request of Dr. Paul Marchal, a shipment of *Aphelinus mali* was sent to France by the U.S. Bureau of Entomology. These specimens did not survive the journey. In 1920, a second consignment of the parasite was brought to Europe by Dr. L. O. Howard, and from this material numerous individuals of *Aphelinus* were obtained and distributed throughout France.

In 1922, a consignment of this French material was obtained from Dr. Marchal by Mr. J. C. F. Fryer, Entomologist to the Ministry of Agriculture, who has since reared it at Harpenden for distribution throughout the British Isles.

In view of the importance of the Woolly Aphis to the apple-growing regions of the Empire, and the possibility that consignments of its parasites would be requested, it was considered desirable to maintain at Farnham Royal a colony of *Aphelinus mali*. Through the kindness of the Ministry of Agriculture a stock of the species was obtained in the summer of 1927 from Harpenden, and is still flourishing.

The colony of Woolly Aphis was obtained by attaching twigs, infested with the pest, to the branches of standard apple trees, from six to eight feet in height, planted in fourteen inch pots, which were placed in an insectary with a "Vita" glass roof and sides of fine mesh phosphor-bronze gauze, and buried to the rims in sand. The

apple trees used were three "Queen Mary," two "Beauty of Bath," two "Lord Derby," and one "Newton Wonder." The apple trees were watered regularly, but were, of course, protected from rain. No other enemies of the Woolly Aphis were introduced and though occasionally an adult ladybird or Syrphid has been observed in the compartment, none of these stray invaders have ever increased in numbers.

Twigs having parasitised aphids have been removed from time to time for the purpose of making shipments, others bearing unparasitised colonies have been added on several occasions when it appeared that there was some danger of extermination of the host by its parasite. On the whole, however, the interference with the progress of events has been relatively slight.

The breeding experiment is thus of considerable interest, in that it gives an idea of the limitations of *Aphelinus mali* as a parasite of the Woolly Aphis, under the conditions prevailing in the insectary. At the end of the third season the apple trees in the insectary are still heavily infested with the Aphids, the two "Lord Derbys" being in an exceptionally bad condition. None of the apple trees in the grounds of the Laboratory, including a number of standards in pots adjacent to the insectary, show, at present, any signs of the presence of Woolly Aphis. The photograph (opposite p. 85) of one of the trees outside the insectary beside one of the more heavily infested specimens from inside, will give a very fair idea of the present state of affairs.

A careful examination of the colony in the insectary was made during the early part of October, 1929.

In spite of the fact that the *Aphelinus* had had almost the whole of three seasons to reproduce at the expense of its host, less than 50 per cent. of the individuals present contained larvæ of the parasite. In 77 parasitised individuals examined there were actually present 93 eggs and larvæ of *Aphelinus*. Had these been distributed singly within the hosts the percentage of parasitism would have been about 10 per cent. higher than it actually was.

Up to the date of this report a total of fourteen consignments of Woolly Aphis, parasitised by *Aphelinus mali*, have been despatched from Farnham Royal. Of these, two were sent to Kenya Colony, one to Poland, one to India (Saharanpur, U.P.), and the remainder to various points in England.

In view of the unsatisfactory results obtained with *Aphelinus mali* in England, an attempt has been made to obtain from America, a colony of the Syrphid, *Pipiza pisticoidea*, considered by Metcalf and Patch as the most important enemy of the Woolly Aphis in the North-Western United States, but up to the present no material of this species has been received.

Pear Slug (Caliroa cerasi, L.).

The Pear Slug, first described by Reaumur in 1742 under the name of "fausse chenille tetard," is an insect which is apparently native in Europe, but which is now distributed throughout the greater part of the world, being recorded from Canada, the United States, South America, Australia, New Zealand and Japan. It feeds almost exclusively on Rosaceous plants, the most common hosts being Pear, Cherry, and Plum, though plants belonging to other families are occasionally attacked. The damage is produced by the larvæ, which feed upon the upper surface and interior tissue of the leaves of their host plants causing a loss of assimilation surface and sometimes complete defoliation.

Although the Pear Slug can be easily controlled by arsenical and other sprays, it may, if untreated, be quite destructive. In New Zealand, it is often quite injurious, particularly, according to Thomson (1922), in the North Island, where it practically prevents the use of hawthorn as a hedge plant. In certain parts of Australia it is also rather destructive. Owing to the injury occasioned by it in New Zealand, an attempt to introduce its parasites was made in 1922 by Dr. Tillyard, with the help of Dr. A. D. Imms of Rothamsted, but this was unsuccessful.

At the request of Dr. Miller of the Cawthron Institute, Nelson, New Zealand, and of the State Entomologist of New South Wales, and Western Australia, a further attempt to procure and establish the parasites of this species is now being made. The results of the work will, it is hoped be published in detail in the near future by Mr. Rosenberg; so that only a general account of the methods used and the results obtained will be given here.

Owing to various unavoidable delays the field work on the Pear Slug was not begun until the middle of July, 1928, when two collectors were appointed and assigned to the project in France. After numerous preliminary inquiries it was decided to confine investigations to the region between the neighbourhood of Paris and the coast.

Collections were made in some fourteen localities in the Departments of Calvados, Ille et Vilaine, Oise, Seine et Oise, and Seine et Marne, from about the middle of July until the end of the first week in October. A total of about 50,000 larvæ was collected in Northern France, the great bulk of the material from the environs of Caen in the Department of Calvados, where over 40,000 larvæ were obtained. In addition, about 1,800 larvæ were collected by Mr. Rosenberg in England at Bradwell on Sea in the County of Essex.

As soon as possible after collection, and usually on the same day, the larvæ were placed on the leaves on which they were gathered, in cylindrical brass containers measuring about 3 inches in diameter by five and a quarter inches in height, provided with three oval openings, measuring about two inches in diameter by four inches in height, and covered with a fine mesh brass wire gauze. These containers were posted individually to the Laboratory in stout cardboard mailing cases, just large enough to hold one of them. Immediately on receipt of the material, it was unpacked and provided with food and placed in cold storage until suitable arrangements could be made.

Sample lots of the larvae were dissected from practically all the consignments received and it was found that at least two species of parasitic Hymenoptera and one Dipterous parasite were present. In the localities in which high parasitism was observed, the infestations were, on the whole, quite negligible. The greater part of the collecting had to be done at Caen, in spite of the fact that the percentage of parasitised larvæ in that district was relatively low.

The work of rearing the larvæ of the Pear Slug proved to be somewhat more difficult than was anticipated and a considerable number of larvæ was lost before suitable methods were involved. These various difficulties were finally solved by transferring the larvæ one by one as soon as possible after receipt, to pear twigs whose leaves were kept fresh by standing them in a bottle of water, which was placed in a tray filled with clean sterilised loam. Some days after the last of the larvæ had descended the loam was sifted and the cocoons removed. Those which were defective were left for purposes of dissection, the others were placed in earth in perforated zinc boxes, lined with copper gauze and buried in the ground out-of-doors, where they were allowed to remain during the winter. The

majority of the cocoons were used for shipment, but some were retained for rearing. The following four species of parasites were obtained, all Ichneumonids.

Mesoleius caninae, Bridgm.

M. dorsalis, Grav.

Polyblastus phygadeuontoides, Kr.

Perilissus luteolator, Gr.

No specimens of the Dipterous parasite were reared. Some adults which emerged were preserved for the Laboratory collection and the remainder were placed in an outdoor insectary with the emerging adults of the Pear Slug, and a small number of pear trees and wild plum trees in pots, in the hope of obtaining a heavily parasitised lot of Pear Slug larvæ. The Pear Slug oviposited extremely freely in captivity, and very soon the great majority of the leaves of the pears in the insectary were dotted with eggs. About 60 to 70 per cent. of these died in the leaves owing to the overheated condition of the greenhouse. This was especially noticeable among the eggs which were placed in the leaves immediately underneath the "Vita," glass roof of the insectary, the great majority of which dried up without hatching, although the leaves in which they had been placed did not seem to suffer in any way. Most of the eggs deposited were placed in the leaves of the pears, very few being deposited in the leaves of the wild plum. In spite of the heavy mortality among the eggs, many larvæ developed, so that most of the leaves were completely destroyed by the time the slugs had completed their development. Nevertheless, a relatively small number of cocoons was obtained from the earth beneath the pear trees, and in samples of these dissected very few parasites were found. The experiment, therefore, cannot be regarded as a success, but the results are encouraging, and it is considered that with suitable modifications the method can be made to yield a very large supply of parasitised Pear Slug cocoons.

Owing to the urgent demand for this material it was decided not to wait until the spring before shipping the material, and consequently two shipments were prepared. One containing 6,524 cocoons was shipped to Dr. Miller of the Cawthron Institute in December, 1928, while the other containing 6,330 cocoons was

given on October 20th to Mr. W. B. Gurney, State Entomologist for New South Wales, who took it to Australia under his personal supervision. The complete reports as to the results obtained from the shipments have not yet been received.

The Hazel-Nut Scale (Lecanium coryli, Ledgr.).

The Hazel-Nut Scale, *Lecanium coryli*, is an insect, belonging to the group of the Coccids. It is widely distributed throughout Europe, of which it is a native. It attacks a great many species of plants, and is sometimes extremely injurious, as for example in certain parts of Russia, where special measures have to be taken to combat it owing to the injuries it has caused to plums. It was accidentally introduced into British Columbia in 1903, probably on shade trees from England, and in the absence of any natural parasite has increased enormously. It is now seriously injurious to maple trees in Vancouver, causing the leaves to shrivel and drop prematurely. In the autumn of 1924, it was found that practically all the shade trees lining some twenty-five miles of boulevards in the west end of Vancouver, as well as maple trees in parks, were badly infested. In view of the severity of the infestation, parasites of this insect were requested by the Dominion Entomologist of Canada, as soon as the Laboratory was founded. The parasites and predators of *Lecanium coryli* had previously been studied by Silvestri (1919) and Imms (1918). It was, therefore, not necessary to carry out any extensive biological studies of the insect. On the other hand, owing to the fact that the distribution of the insect is somewhat irregular some difficulty was at first found in obtaining a sufficient quantity of material for parasite work. The first supply was obtained from Professor Newstead, F.R.S., in June, 1927, and an attempt was made to establish a colony of the scale and one of the parasites in an insectary, but this attempt was a failure. Accordingly, a new supply was requested from Professor Newstead, who forwarded it early in 1928. This material was placed partly in an insectary and partly in indoor breeding cages, and from it was obtained a considerable number of Chalcid parasites belonging to several species, together with a large quantity of the larvæ of the Scale. Branches of hawthorn were placed in the cages with the emerging larvæ and soon became covered with them. The branches were then transferred to the insectary and placed among the branches of young hawthorn plants in pots. Following the policy outlined in the previous chapter, it was decided to send out first only

one parasite of *Lecanium*, and for this purpose the large and important species, *Blastothrix sericea*, was selected. About 300 specimens of this Chalcid emerged during the month of June, and these were sent to Mr. A. B. Baird, in charge of the Dominion Parasite Laboratory at Chatham, Ontario, in two shipments, one on June 29th and the other on July 5th. The parasites were sent in cold storage, in glass tubes, with raisins as food. They were trans-shipped by Mr. Baird to Vancouver, where they arrived with the loss of very few individuals, and were liberated in the neighbourhood of the city. The attempt to start colonies of the scale and its parasites on the hawthorn in an insectary was believed at first to be unsuccessful, but during the course of the ensuing winter numerous individuals were found to be present on the plants. Samples were dissected and many were found to be parasitised by *Blastothrix sericea*, which had been liberated in the insectaries at the same time as the scale. These emerged during the spring and again attacked the scale, which resulted in a considerable increase in the number of parasites. A total of 1,250 scales was eventually obtained from this experimental colony, of which the great majority was parasitised, and these were shipped to Canada early in June. In the meantime a number of collections of the scale were made in the Midlands by Mr. Wadsworth of the University of Manchester, and placed in rearing cages at the Laboratory. From these we obtained a total of about 766 adults of *Blastothrix* which were shipped to Canada in July, and then trans-shipped from Chatham to Vancouver like the preceding shipments. All of this material arrived in good condition. The larvæ obtained during the time the parasites were hatching were again placed upon hawthorn in the insectaries. Thousands of scales are now present. These will be used as a basis for further attempts to rear the parasite in large numbers in the insectary and will be sent to Canada during the course of the summer.

The Oriental Peach Moth (Cydia molesta, Busck.).

The Oriental Peach Moth is an insect of Japanese origin, closely allied to the Codling Moth and almost equally destructive in certain regions. It is distributed over a considerable part of the United States, where it was first discovered in 1916, and has also spread to the fruit-growing regions of Southern Ontario. It attacks plum, peach, cherry, apple and quince. The larvæ of the first generation attack the growing tips of the branches, destroying a large proportion

of the terminal buds, and bore into the tender shoots. The later generations burrow through the fruit, causing it to decay, and also burrow into the more mature twigs. It also exists in Australia. A number of years ago the Oriental Peach Moth became established in the French and Italian Riviéras. The French and Italian entomologists who studied the insect found it was sometimes attacked by the native parasites of various species. The Dominion Entomologist of Canada therefore requested us to investigate the European parasites of the Peach Moth, in the hope of finding some which would be useful in controlling this pest in Canada. Mr. de Rippas was detailed to this work at the beginning of 1929 and continued it throughout the whole season, working partly in the region of Antibes in France, and partly on the Italian Riviera, where he made his headquarters at Chiavari, at the Pathological Laboratory directed by Dr. G. Paoli. Thanks to the help of Dr. Paoli and his assistants, Mr. de Rippas was able to carry investigations of the parasites of the Peach Moth in a great number of different localities. Owing to the fact that the work was not undertaken until rather late in the season, considerable difficulty was found in obtaining a sufficient quantity of the material for the work. However, a very fair idea of the parasites attacking the Peach Moth in the Mediterranean zone was obtained from the specimens collected. Four parasites, which seem to be primary parasites of the Peach Moth, were reared. The most important of these is *Pristomerus vulnerator*, Panz., while *pomorum*, *Pimpla Ascogaster 4-dentatus*, and a Tachinid, which seems to belong to the genus *Actia*, were also reared. All of these are, of course, species which are normally parasitic on other European insects, and more especially on Micro-Lepidoptera. *Pristomerus vulnerator* and *Ascogaster*, the most important parasites collected, have been found to be parasitic in Northern France, on the Codling Moth, from which they can probably be collected more easily than from the Peach Moth. The United States Bureau of Entomology have now detailed one of their investigators to this work. He is located at Antibes in Southern France and will work during the coming season in co-operation with Mr. de Rippas.

The Leaf-Curling Pear Midge (Dasyneura pyri, Bouché).

This insect is generally distributed throughout Northern and Western Europe, where it attacks all varieties of pears, and seems, in general, to be of no importance; but in New Zealand, where it was accidentally introduced a number of years ago, it has done a great deal of damage

in the pear-growing districts, attacking all commercial varieties. In 1925, investigations of the parasites of the Pear Midge in Europe, were begun by Dr. R. T. Fisher and Dr. J. G. Myers, working under the direction of Dr. Marshall. Four consignments of parasitised material were shipped by Dr. Fisher and Dr. Myers to New Zealand in the summer and autumn of 1925. From these consignments a considerable number of specimens of *Misocyclops marchali*, Kieff., one of the most important of the parasites, was obtained and liberated in some of the infested districts. In 1928, the Entomologist of the Cawthron Institute reported that the parasites had since become abundant in the infested areas, from some of which satisfactory crops had been obtained for the first time for many years.

In addition to the insects mentioned above, investigations were begun in the summer of 1928 on the Apple Bud Moth (*Eucosma ocellana*, Schiff.) and the Apple Sucker (*Psylla mali*, Schmid). Investigations of the natural enemies of the Peach Twig Borer (*Anarsia lineatella*, Zell.), the Queensland Fruit Fly (*Dacus ferrugineus*, Fabr.), the Bronze Beetle (*Eucolaspis brunnea*, Fabr.), and the Australian Apple Leaf Hopper (*Typhlocyba australis*, Frogg.) have also been requested.

2. Parasites of Forest Insects.

The Pine Shoot Moth (Rhyacionia buoliana, Schiff.).

The Pine Shoot Moth is a small moth, very widely distributed throughout Europe, where it causes, in certain seasons, severe damage to pine. It has been accidentally introduced into the United States and Canada, where it is now a rather serious pest in certain districts. In view of the damage caused by this species in Southern Ontario, we were asked in 1927 by the Dominion Entomologist to investigate and collect any parasites likely to be useful in checking its ravages. In the summer of 1928 a heavy infestation by the Pine Shoot Moth was reported from one of the Forestry Commission's plantations in Norfolk and this was immediately investigated. These revealed the presence of a number of parasites, and arrangements for large scale collections were at once made.

With the permission of the Forestry Commission, employees in the district were detailed to the work, and in the course of about a couple

of weeks about 100 bags of infested material, estimated to contain 100,000 infested shoots were gathered and despatched to the Laboratory. Very careful preliminary studies of the material were made with the help of Mr. Spooner and Mr. Wood of the University of Cambridge. In order to obtain information as to the status of the various parasites and their relative importance as controlling factors of the Pine Shoot Moth, part of the material was placed in incubators at relatively high temperatures in order to accelerate the development of the parasites, so that they could be identified before the material had reached its destination. In the meantime the infested shoots from the field were picked over by a gang of temporary workers from the village of Farnham Royal. None of these workers had, of course, any previous training or experience in work of this kind, but they rapidly acquired sufficient knowledge to deal satisfactorily with the material. All of the infested shoots were opened and the larvæ and chrysalids of the Pine Shoot Moth, and the cocoons of the parasite, were removed, after which the shoots were sterilised in order to destroy any other insects which they might contain. Finally, after they had been carefully dried, the shoots were packed with larvæ in boxes specially constructed for the purpose. After a few experiments it was found that the larvæ could be as successfully packed between layers of tissue paper as among sterilised pine shoots, and this method was employed during the later part of the work. As the investigations progressed it was found that the larvæ parasitised by the two most important species present, developed a good deal more slowly than the others, so that by the time the work was completed and all the chrysalids removed, approximately 90 per cent. of the living larvæ remaining for shipment were parasitised. The vast majority of the parasites present belonged to two species: the one was an Ichneumonid (*Cremastus interruptor*, Grav.) and the other a Braconid (*Orgilus obscurator*, Nees.). Two shipments, comprising in all from 25,000-30,000 larvæ of the Pine Shoot Moth were despatched to Canada in cold storage. They arrived in very fair condition and although the mortality among the larvæ was very heavy owing to injuries received during the preparation of the material, about 600 specimens of the two species of parasites were reared and liberated in the infested districts.

In the following summer collections from these areas showed that these parasites had become established, and had been able to pass the severe Canadian winter successfully.

The complete list of the primary and secondary parasites reared from the Pine Tortrix during the course of this work is as follows :—

- Ichneumonidæ* .. *Cremastrus interruptor*, Grav.
Eulimneria rufifemur, Thoms.
Gelis fallax, Forst. ?
Hemiteles bicolorinus, Grav. ?
H. palpator, Grav. ?
H. spp.
Hypsantyx impressus, Grav. ?
Lissonota transversa, Bridg.
Omorgus borealis, Zett.
O. ensator, Grav.
O. mutabilis, Holmg.
Phaeogenes spp.
Pimpla brevicornis, Grav.
P. detrita, Holmg. ?
P. examiner, F.
P. pomorum, Ratz.
P. robusta, Morl.
P. ruficollis, Grav.
- Braconidæ* .. *Apanteles falcatus*, Nees.
Microbracon abscissor, Nees.
Orgilus obscurator, Nees.
Eubadizon extensor, L.
- Chalcididæ* .. *Habrocytus acutigena*, Thoms.
Eutelus sp.
Trichogramma evanescens, West.

A great many of these parasites had never before been recorded from the Pine Shoot Moth in England. A paper embodying some of the information obtained concerning their biology is being prepared by Dr. W. H. Thorpe.

Wood Wasps (Sirex spp.).

The Wood Wasps or Horntails are large wasp-like insects allied to the sawflies, whose larvæ bore into the wood of trees. Most of the forest entomologists who have studied the habits of these insects in

Europe and America are of the opinion that they do not ordinarily attack healthy trees, and must be considered to be rather indicators of pathological conditions than the cause of them. They not only attack standing trees but also felled timber, in which they sometimes do a good deal of damage. However, Chrystal ('28), who has devoted considerable attention to the problem of the wood wasps, is of the opinion that in many cases the logs attacked by *Sirex* have previously been weakened by fungus, and thus rendered worthless quite apart from the work of the insects. On the other hand, according to Tillyard ('27) and Miller ('25), the Wood Wasps are a much more serious pest in New Zealand. The chief host tree in New Zealand is *Pinus radiata*, of which the Wood Wasp not only attacks felled logs, but also living trees. The pest was originally discovered on the west coast of the North Island, but in the year 1925, it became evident that its range had considerably extended.

Owing to the anxiety caused by the work of this insect and its increase in numbers, the New Zealand Government approached the Imperial Bureau of Entomology with a request for the investigation of its parasites, with the hope that they might be introduced into New Zealand. The investigations were carried out in co-operation by Dr. R. N. Chrystal, of the Forestry Institute of Oxford, and Dr. J. G. Myers, of Farnham House Laboratory, with the assistance of Mr. H. S. Hanson. The habits of the Wood Wasps, their slow development, and the very extensive manual labour necessary in order to obtain material for study made this investigation and the task of obtaining parasite material for shipment, unusually arduous. However, in spite of these difficulties, Messrs. Myers and Chrystal succeeded in elucidating completely the life history of the *Sirex* and its inter-relations with its parasitic enemies. The results of these investigations have already been published by these authors and further papers upon the same subject by Dr. Chrystal and Mr. Hanson are now in press. Two important parasites, *Rhyssa persuasoria* and *Ibalia leucospoides* were discovered. After careful consideration it was decided for the moment to restrict the exportation to the former species.

The task of obtaining a sufficient number of the parasites of a wood-boring insect like the Wood Wasps was, of course, a problem of unusual difficulty. In order to solve it a very ingenious method was devised by Mr. Hanson. During the early summer, Mr. Hanson collected in the area in which he was working a large number of trees

infested by the Wood Wasp. These trees were felled and the logs placed in piles, arranged as shown in the accompanying photograph (Plate VIII, 2) at a considerable number of points, fairly widely separated from each other. In all, thirty of these piles of infested logs were prepared. The object of this arrangement was to secure the congregation of the parasites in large numbers. It had previously been observed by entomologists that many types of insects are attracted in large numbers to points where dense populations of their host occur, and it was hoped that by gathering together in certain isolated spots large numbers of the logs infested by the *Sirex*, a more satisfactory parasitisation would be obtained than from isolated logs or trees scattered through the whole area. Although no comparative studies were made in order to determine the efficiency of the method, the results obtained from it were remarkably satisfactory. At the close of the season, the logs were cut up and opened by Mr. Hanson, who obtained over 1,300 larvæ of *Rhyssa persuasoria*, which were shipped to New Zealand during the winter of 1928-29. The rearing of larvæ which have spent their lives in tunnels within the wood of trees or the tissues of plants often present considerable difficulties. This problem was satisfactorily solved by Dr. Myers. The larvæ of the *Rhyssa*, as collected, were placed in gelatin capsules filled with sawdust, and this method gave very good results, being much superior to that obtained by the use of glass tubes. A large number of the specimens shipped to New Zealand issued in good condition, and were liberated by Dr. Miller in infested areas where they have been observed attacking larvæ of the *Sirex* within their burrows. It is hoped that they are already established, but in any case arrangements have been made for securing a further supply of the insect next season.

The Larch Case Bearer (Coleophora laricella, Hubn.).

The Larch Case Bearer is so-called because the caterpillar of this insect constructs for itself out of portions of the injured leaves of the larch a case lined with silk in which it lives, feeds, and in which it passes the winter. The Larch Case Bearer sometimes causes rather severe damage by feeding upon the leaves of the Larch, the effects of its work being, in appearance, very similar to that of frost or singeing by fire. It has been accidentally introduced into Canada and is one of the problems which we have been asked to take up by the Dominion Entomologist. Work on this insect was begun by Dr. G. Salt in the summer of 1929, but at the time it was not found

possible to collect a sufficient amount of material. Later in the same year, Mr. H. S. Hanson was detailed to the work of collection, and during the course of the autumn and winter he visited a considerable number of localities and succeeded in collecting in Cambridgeshire and Shropshire a number of large sacks of larch twigs, bearing the hibernating caterpillars of the pest. Specimens of these caterpillars were dissected from each of the various areas and at least three species of parasites were discovered. The study of these parasites is now being continued by Dr. Thorpe. One of them seems to be of considerable importance as a controlling agent of the Case Bearer and it will not be difficult to obtain a quantity sufficient for shipment.

In addition to these forest pests investigations, investigations have been begun on the Beech Coccus (*Cryptococcus fagi*, Baren); and the Larch Sawfly (*Lygaeonematus erichsoni*, Htg.), but have not as yet yielded any definite results. We have also been requested to find parasites or predators of the Pine Chermes (*Chermes pini*, L.), the Hemlock Looper (*Ellopija fuscicollis*, Gn.), the Pine Bud-moth (*Exoteleia dodecella*, Linn.), the Willow Sawfly (*Nematus pallidiventris*), the Spruce Aphis (*Myzaphis abietina*, Wlk.), the Satin Moth (*Stilpnotia salicis*, Linn.), and the Spruce Bud-worm (*Tortrix fumiferana*, Clem.).

3. Parasites of Insects of Cereal and Forage Crops.

The Lucerne Springtail (Symnethurus viridis, L.).

The Lucerne Springtail belongs to one of the lowest orders of insects, which is very widely distributed throughout Europe, and has become accidentally introduced into Australia. In Europe the damage it causes though certainly not negligible in certain cases and at certain times, has probably been attributed to other species, and consequently has attracted very little attention. In Australia and more particularly in Western Australia, in certain regions where Lucerne is very extensively grown, this insect has proved to be a very injurious pest. It is especially destructive to young plants.

An investigation of the natural enemies of this species was begun in 1927. No parasites were discovered, but several predacious insects which feed upon the Springtails were found by Dr. J. G. Myers. However, it soon became evident that without a general investigation it was impossible to come to any conclusion as to the importance of these predators as controlling factors of the Springtail. It was therefore decided to investigate the natural control of

Smynturus viridis as completely as possible. This work was assigned to Mr. D. Stewart MacLagan, a scholar of the Ministry of Agriculture for Scotland, who has continued it without interruption from the autumn of 1928, until the present time. The list of predators of various kinds has been considerably extended and a great deal of valuable information has been obtained pertaining to their relative value under laboratory conditions. If investigations in Australia show that some of the more important of these predators are absent, steps will be taken to introduce them into the infested areas. However, it is not considered advisable to attempt this at present, as the work of breeding and shipping these predators is likely to be extremely difficult and laborious. Furthermore, the investigations carried on by Mr. MacLagan show conclusively that while these predators undoubtedly play some small part in the natural control of *Smynturus viridis*, the fluctuations in numbers of this insect are primarily dependent upon the meteorological factors. The work carried on by Mr. MacLagan in connection with this species constitutes a very valuable contribution to the problem of natural control, and it is hoped that it will soon be published.

The Wheat Stem Sawfly (Cephus cinctus, Nort.).

The Wheat Stem Sawfly is an insect native to North America, which has gradually spread from wild grasses to cultivated grain crops, and will probably become more and more injurious as time goes on. Its larva bores in the stem of the wheat plant and before it forms its cocoon it partly cuts through the wall of the wheat stem, just above the place where it intends to pupate. This weakens the stem so that it breaks off very easily, and of these fallen stalks a great many are, of course, destroyed or lost during the work of harvesting. This insect is considered by the Canadian entomologists to be the most serious pest of wheat in the Western Provinces. Heavy infestations have occurred repeatedly. In 1922 serious damage was caused, 12,000 acres being affected in Manitoba in that year; in 1926, the loss in Saskatchewan alone was estimated to be in the neighbourhood of 12,000,000 dollars. Parasitic insects, native to Canada, are said to keep the pest under control in the wild grasses, but they have proved to be quite ineffective in the grain fields; one reason apparently being that their ovipositors are too short to reach the larva of the Sawfly in the Wheat stem. As has already been stated the Wheat Stem Sawfly is a native of Canada and does

not exist in Europe. It is, however, replaced here by a European Sawfly (*Cephus pygmaeus*, L.), which is very similar in structure and habits. A study of this insect and its parasites was therefore undertaken in the hope that they might be of use in controlling the Wheat Stem Sawfly.

During the course of the investigations, which have been in charge of Dr. G. Salt, examples of wheat stubble have been examined from a total of about 70 fields in several parts of the country. In no case was the Sawfly found to be abundant. In fields at Rothamsted, which have been under wheat for a very long period, the most heavily infested fields had only from ten to twelve per cent. of the stems affected, though 60 to 70 per cent. infestation is not uncommon in north America. The reason for the apparent scarcity of the insect seems to be that it is very heavily attacked by several parasites. During the course of the investigations, Dr. Salt and his assistants have examined a total of approximately 34,000 stems. Five principal parasites have been discovered, which destroy, taken together, from 70 to 100 per cent. of the larvæ of the Sawfly. Of these parasites one is particularly important and accounts alone, on the average, for about 60 per cent of the Sawfly larvæ. It has not, of course, been proved that this species will attack the Canadian Wheat Stem Sawfly, but there is every reason to suppose that it will, because it is commonly found as a parasite of another sawfly attacking wheat (*Trachelus tabidus*) which is much less closely related to the Canadian species than is the European Wheat Stem Sawfly. Another point of interest concerning this parasite is that it is commonly found attacking the Wheat Stem Sawfly in Russia, where, as is well known, the climatic and other conditions are very similar to those of the great wheat-growing areas of the Canadian West. Dr. Salt is at present carrying on a very careful investigation of the biology and the inter-relations of the parasites of the Wheat Stem Sawfly, and has shipped to Canada approximately 9,000 specimens of the most common species, which arrived in excellent condition. However, in view of the vast extent of the infected area and the magnitude of this problem, it is obvious that in order to obtain relief from the attack of this insect within reasonable time, the work on the collection and shipment of parasites must be organised on a very much larger scale. So far as we know the principal parasite of the Sawfly has only a single generation a year, so that it is not possible to rely upon artificial breeding methods for obtaining it in large numbers. In this case the collection over large areas is the only practicable method that can be applied.

The list of parasites obtained from the Wheat Stem Sawfly is as follows :—

Collyria calcitrator, Grav.

Pimpla detrita, Holgr.

Hemiteles hemipterus, Fabr.

Hemiteles, sp.

Microbracon terebella, Wesm., var. *Wesmaeli*, Fabr.

Pleurotropis benefica, Gahan.

Eurytoma appendigaster, Boh.

Homoporus, sp.

Of these, *Collyria calcitrator*, *Pimpla detrita*, *Microbracon terebella* and *Pleurotropis benefica* are apparently primaries; the status of the remainder is, as yet, uncertain.

In addition to these pests we have been asked to obtain the natural enemies of an Australian White Grub (*Anodontonyx tetricus*), the Red Mite (*Bryobia praetiosa*, Koch.), the Corn Ear Worm (*Heliothis obsoleta*, Fabr.), the Clover Weevil (*Listroderes praemorsa*), the New Zealand Cockchafer (*Odontria Zealandica*, White), the Grass Moths (*Porina* spp.), and the European Corn Borer (*Pyrausta nubilalis*, Hubn.).

4. Parasites of Insects of Vegetable and Garden Crops.

The European Earwig (Forficula auricularia, L.).

The common Earwig is an insect generally distributed throughout Europe, North Africa, and Western Asia, which has been accidentally introduced into Tasmania, Australia, East Africa, the East Indies, North America, and New Zealand. It is a polyphagous insect, feeding on both animal and vegetable matter, but is sometimes distinctly injurious to vegetation. In North America, where it now occurs in the States of California, Oregon, and Washington and in the Province of British Columbia in the West, and in the State of Rhode Island in the East, and in New Zealand, it is regarded as a rather serious pest owing to its habits of entering houses and the fact that it feeds on fruit and flowers. The earwig is attacked in

Europe by two Dipterous parasites, *Digonochaeta setipennis*, Fall., and *Rhacodineura antiqua*, Meig. (Thompson, 1928) of which the former is by far the more important.

A number of years ago, with the co-operation of Dr. A. D. Imms, Dr. Tillyard attempted to introduce the parasites of the Earwig into New Zealand, but as far as can be ascertained, these introductions were unsuccessful, though, at least one of the parasites was bred through two generations in captivity. It was, therefore, decided to make further attempts to introduce it, especially since material was also requested by the Dominion Entomologist for distribution in Western Canada.

Both of the parasites of the earwig can be bred in captivity, but in view of the labour entailed by this method, we have not adopted it, but have obtained our material of the parasite from a professional collector, Mr. B. S. Harwood of Sudbury, who, after having been given specimens and instructions can practically always be relied upon to collect a sufficient number of puparia in the field. In order to avoid any risks from such hyperparasites as may be present, the puparia are isolated in gelatin capsules in which they are shipped during the period of hibernation.

From March, 1928, to the present date, four shipments, with a total of 1,185 puparia of *Digonochaeta* have been sent to New Zealand, and six shipments with a total of 1,218 puparia to Canada. All of these shipments arrived in good condition, and produced healthy flies which were liberated in the infested areas.

The Diamond Back Moth (Plutella maculipennis, Curt.).

This insect is a native of Europe, but now exists also in Greenland, Spitzbergen, North America, the Argentine, Cuba, South and East Africa, India, Australia, New Zealand and Hawaii. It attacks principally Cruciferous plants, such as cabbage, swedes, kale, turnip, etc., on which it sometimes causes very serious damage. The larvæ first mine within the leaves, but later feed externally.

Both the Governments of Canada and New Zealand have requested us to supply parasites of this pest, which has, in Europe, a number of natural enemies. Preliminary investigations in North-Western France were made by Mr. Kozlovsky during the course of 1928. One parasite, *Angitia plutellæ*, Vier., was obtained in fair numbers, and successfully bred by Mr. Kozlovsky in the laboratory; but no shipments have yet been made.

Woodlice (Porcellio and Oniscus, spp.).

These creatures, which are widely distributed throughout the world and occasionally assume the status of a pest, should, strictly speaking, be placed in a separate section, since they are not insects but Crustacea, belonging to the group of the Isopoda.

In New Zealand, they sometimes do a good deal of damage, both in greenhouses and in the open, and were included in a list of projects submitted to the Laboratory by the entomologist of the Cawthron Institute.

A general study of the parasites of Woodlice, begun a number of years ago by the Superintendent, is now being continued. The insect parasites found infecting Woodlice are all Diptera and are as follows:—

- Plesina maculata*, Fall.
- Stevenia umbratica*, Fall.
- Philocerina atramentaria*, Meig.
- Styloneuria discrepans*, Pand.
- Frauenfeldia rubricosa*, Meig.
- Melanophora roralis*, L.
- Phyto melanocephala*, Meig.
- Rhinophora lepida*, Meig.
- Cyrtillia angustifrons*, Rond.

All of these appear to be closely related forms. Two shipments, comprising about 14,019 Woodlice, collected for the most part in North-Eastern France by Mr. Kozlovsky and known to contain several of the parasites mentioned, were shipped to New Zealand in May, 1929.

The Carrot Rust Fly (Psila rosae, L.).

The Carrot Rust Fly is a native of Europe, but has been known in Canada from as early as the year 1885. In the years following its introduction it spread southward, and is now distributed through the Northern United States from Maine to Michigan. It attacks the roots of celery and burrows into carrots and parsnips, continuing its work in stored carrots, even during the winter.

Requests for the parasites of this insect have been received from both the Dominion Entomologist in Canada and from the Entomologist of the New York Experiment Station. Three species

of Hymenopterous parasites, two of the genus *Dacnusa* and another known as *Aphaereta cephalotes*, Hal., were bred a few years ago from the puparia by Smith and Gardner.

Preliminary collections, which now comprise about 2,000 larvæ and pupæ, have been made by Mr. Hanson in the Midlands, and as soon as the biology of the parasites is satisfactorily known, shipments of the most promising species will be made.

The Potato Tuber Moth (Phthorimaea operculella, Zell.).

This insect is a cosmopolitan pest, whose origin is at present not certainly known. It is particularly injurious to Potato, attacking not only the leaves and stems, but also the tubers, especially those which have been placed in storage. Some years ago it appeared in Southern France, and is now present in Cyprus.

In response to a request for parasites of the insect from the Entomologist of Cyprus, the United States Bureau of Entomology was asked to supply us with a consignment of *Microbracon Johanseni*, Vier., which is an important enemy of the pest in California. The attempts to secure this parasite in 1929 were unsuccessful, owing to the unfavourable season, but it is hoped that it will be sent to us during the present summer.

In addition to the above insects we have been asked to investigate the parasites of the Potato Stem Borer (*Gortyna micacea*, sp.), the Onion Maggot (*Hylemyia antiqua*, Meig.), the Onion Thrips (*Thrips tabaci*, Lind.), and the Current Sawfly (*Pteronus ribesi*, Scop.).

5. *Parasites of Tropical Field Crop Insects.*

The Pink Boll-worm (Platyedra gossypiella, Saund.).

This insect is a very important pest of cotton, which was first described from India, though its native home is uncertain. It now exists in many parts of the world, including the Sudan, the United States, where it was first discovered in 1917, and the West Indies, where it appeared in 1920.

In response to a request from the Entomologist of Barbados, a consignment of cocoons of *Microbracon kirkpatricki*, Wilk., an important parasite of the Pink Boll-worm, which attacks it in the Sudan, was obtained in 1929 from Mr. H. H. King, Chief Entomologist

of the Sudan, and sent on at once, with the help of the West India Committee, to Barbados. The material arrived in very fair condition, but owing to unavoidable accidents it was not found possible to breed it. Further consignments in a somewhat more favourable condition have now been received from the Sudan. One consignment has been sent to the West Indies, and two others, from material bred in the Laboratory by Dr. Thorpe, have been despatched to the United States Bureau of Entomology, whence a further request for this parasite was received.

The most important work on Tropical Crops is, of course, that being carried out by Dr. J. G. Myers.

6. Parasites of Citrus Fruit Insects.

The Fluted Scale (Icerya purchasi, Mask.).

The Fluted Scale is an insect of Australian origin, which, in the absence of its natural enemies, has been in many parts of the world a most devastating pest of citrus fruits. The use of the Vedalia Ladybird (*Rodolia cardinalis*, Muls.) against this scale constitutes one of the most remarkable examples of successful biological control. In practically all parts of the world where the ladybird has been introduced the infestations have been practically annihilated in an extraordinarily short time.

Some years ago the Fluted Scale began to be troublesome in certain districts of the Madras Presidency and after unsuccessful attempts to secure the Vedalia Ladybird elsewhere, the Entomologist of the Presidency, Mr. Y. Ramachandra Rao, applied to the Imperial Bureau of Entomology for a consignment. This was secured early in 1929 from California, through the kind assistance of Professor H. S. Smith, and at once despatched to Colombo. Here it was met by an assistant from the entomological department of the Madras Presidency and taken at once to Coimbatore. Breeding work was at once begun and according to the last report received (July 31st, 1929) the stock had been increased to 380 adult beetles, 350 pupæ, 5,000 larvæ and 5,000 eggs. Preparations for the distribution of the material in the infested areas were then being made.

Other insects of Citrus Fruits, whose parasites have been requested are the White Wax Scale (*Ceroplastes ceriferus*, And.), the Pink Wax

Scale (*Ceroplastes rubens*, Mask.), the Orange Snow Scale (*Chionaspis citri*, Comst.) and the Mediterranean Fruit Fly (*Ceratitis capitata*, Wied.).

7. Parasites of Greenhouse Insects.

The White Fly (Trialeurodes vaporariorum, Westw.).

This well-known pest of greenhouse plants is generally distributed throughout Europe and America, and the same or similar species exist in other parts of the world, such as New Zealand. Until recent years it has been necessary to fight the White Fly by fumigation, which is sometimes injurious to the plants. Now, however, owing to the careful and painstaking work of E. Speyer, Entomologist of the Research Station of Cheshunt, it has been found possible to utilise an imported Chalcid parasite (*Encarsia formosa*, Gahan) very effectively against the pest. By the employment of ingenious special methods Mr. Speyer has succeeded in breeding the parasite artificially in very large numbers for distribution throughout the greenhouses of this country. A combination of a relatively small colony of these parasites, with a light fumigation has proved an excellent practical remedy for the White Fly.

By special arrangement material of this parasite is available for distribution by Farnham Royal to any part of the Empire where it may be required. A shipment comprising from 15,000 to 20,000 specimens of *Encarsia formosa* was sent to Canada in 1928, at the request of the Dominion Entomologist and the parasites liberated in infested greenhouses. It was then found that the species was already present in the district, but the introduction has served good purpose in calling the attention of the entomologists of the Dominion to the useful rôle of the parasite.

8. Parasites of Insects affecting Man and Domestic Animals.

The Sheep Blowflies (Lucilia sericata, Meig., etc.).

This group of pests includes a number of species commonly known as Greenbottles or Bluebottles, which in the earlier stages usually live in decomposing animal matter, but sometimes attack living animals producing what is technically known as myiasis. In countries where flocks are small and carefully tended the trouble is not serious, but fairly heavy losses occur in the vast sheep farms in many parts of

America, Australasia and South Africa. In Queensland, approximately 5 per cent. of the sheep are lost through the Blowflies, in New Zealand the losses are estimated at about 1 per cent. in spite of careful attention, while in South Africa it is believed that the annual loss from this cause is over £78,000 (Smits, '29).

The relative importance of the various species of flies associated with myiasis in sheep is not at present well understood. It seems, however, that one of the most important forms is the common Greenbottle, *Lucilia sericata*, Meig., an insect of European origin, which is now distributed all over the world. The parasites and predators of this species have, therefore, received special attention from all those interested in this problem.

A careful study of the biology of *Alysia manducator*, Panz., the principal parasite of *Lucilia sericata* was published in 1920 by Altson, but in view of the demand for this parasite and the growing importance of the problem, the Director of the Imperial Bureau of Entomology decided to reopen the investigation, which was assigned to Dr. J. G. Myers early in 1927. As a result of this work, three shipments of parasitised puparia of *Lucilia*, containing over 1,800 specimens were sent to the entomologists of New South Wales, Western Australia and New Zealand, in the autumn of the same year. In the early part of 1928, another lot of 100 puparia was sent to the Entomologist of New South Wales, and another comprising 1,220 puparia and 2,690 larvæ was despatched to him in October of the same year. In November, 1928, a consignment of 800 parasitised puparia was shipped to South Africa. All of these consignments arrived in a satisfactory condition, and provided a large number of adults of the parasite, which were either liberated in the infested areas or used for breeding work. It is satisfactory to be able to report that Dr. D. Miller of the Cawthron Institute has now recovered *Alysia manducator* from the field so that it has evidently established itself in New Zealand.

The development of the breeding methods used in the work is of considerable interest. During the work carried on in 1928, the Blowflies were reared on dead cats, which were obtained, freshly killed, from London and sent to the Laboratory in sealed sacks. These cats were placed in large shallow enamelled pans in a special insectary, situated at some distance from the main buildings of the Laboratory, and identified females of *Lucilia sericata* liberated in it. Within a short time the carcasses of the cats were swarming with the maggots

of the Blowflies. Attracted by the odour of the decomposition, various carrion-feeding insects, together with their parasites and predators began to congregate in the vicinity of the insectary. Among these were numerous specimens of *Alysia manducator*, which were collected and introduced into the compartment with the Blowflies, where they at once began to search for maggots in the decomposing carcasses. As the maggots of the Blowflies completed their larval development they left the trays and fell to the floor, where they assembled between large sheets of brown paper placed there for the purpose. In order to avoid hyperparasitism by the Chalcid *Nasonia brevicornis*, which attacks the puparia of the Blowfly, the maggots were removed before pupation and stored in sand in large glass jars, which were closed with heavy cloth covers and buried to the neck in earth in another insectary, situated some distance away.

In this way a supply of some 200,000 maggots of *Lucilia sericata*, of which many were parasitised by *Alysia manducator*, was easily obtained.

However, after further very careful investigations it was found by Dr. Salt that a supply of freshly killed animals was unnecessary, and that oviposition could be obtained and larvæ reared with much greater economy in space, material and time, on minced butchers' meat. Finally, instead of allowing the parasite to search for the larvæ of the Blowfly in the carrion it has been found much better to place larvæ of a suitable size in small glass containers with *Alysia* females ready to oviposit, removing the maggots one by one as fast as they are stung by the parasite. Furthermore, all the specimens obtained by this method are known to contain larvæ of *Alysia*, so that there is no loss through the storage and shipment of unparasitised material.

Up to the present date, seven shipments, comprising a total of 6,600 puparia, parasitised by *Alysia manducator* have been sent from the Laboratory, four to Australia, one to New Zealand and one to South Africa. A reserve stock of the parasite is kept permanently on hand in case further shipments are required. Stocks of other important parasites and predators of Blowflies will be bred up as the occasion arises.

Bluebottle (Calliphora spp.).

The Braconid parasite (*Alysia manducator*, Panz.) of the Sheep Blowfly not infrequently attacks other carrion-feeding flies of the same group, and is often reared from the Bluebottle (*Calliphora*

spp.). These latter insects are a great nuisance in the Falkland Islands, owing to their habit of entering houses. With the hope of reducing their numbers a shipment of parasitised puparia was requested by the authorities of the Islands. This was sent out in the autumn of 1927, and parasites from the same stock are still being bred.

The Horn Fly or Buffalo Fly (Lyperosia irritans, L.).

This insect and certain closely allied forms are serious pests of cattle in many parts of the world (North America, New Zealand, Australia). The larvæ live in freshly deposited manure, but the adults are blood-sucking congregating in masses around the bases of the horns of the host animals.

Parasites of this insect have been requested by the Governments of both Canada and New Zealand, and investigations are now under way on this project in North-Eastern France, where Mr. Kozlovsky has found the Horn Fly in fair numbers in certain districts (Caen and St. Pierre-sur-Dives (Calvados)).

Other pests affecting domestic animals, we have been asked to investigate, are the New Zealand Cattle Tick (*Haemaphysalis bispinosa*, Neum.) and the Warble Flies (*Hypoderma bovis*, Degeer and *lineatum*, Vill.).

In all, fifty-seven consignments of the parasites and predators of insect pests, comprising a total of 115,000 individuals, have been sent out from the Laboratory; at least 21 species of beneficial insects attacking pests belonging to 14 species have been included in these shipments.

9. Investigations in the West Indies.

In October, 1928, Dr. J. G. Myers left for the West Indies, in order to investigate the possibilities of the method of biological control in the Islands, with special reference to the pests of Sugar Cane.

As it was obviously undesirable to attempt the introduction of beneficial parasites from one West Indian island to another until precise information was available as to the actual position of each of the Colonies, Dr. Myers' work during the past year has had to be almost entirely of an exploratory nature. He has visited Trinidad, British Guiana, Surinam, Barbados, Cuba, Jamaica, and Haiti, and

many thousands of insect pests have been dissected or reared in captivity in order to ascertain what parasites were already present in each country, and the percentage of parasitism. A large body of useful preliminary information has thus been accumulated.

The position with regard to the Hymenopterous parasites of the small moth borers of sugar-cane (*Diatraea*) in Trinidad and British Guiana was found to be so complex and puzzling, that it will be necessary to investigate the matter much more fully before the introduction of parasites is undertaken, and it is probable that arrangements will be made locally for the appointment of a special entomologist to study the problem in each country. An apparently valuable parasite of these insects occurs in Cuba, a Tachinid fly (*Lixophaga*), and arrangements have been made with the Harvard Biological Laboratory in that island to collect a supply of this insect for introduction this spring into Barbados, in the first instance.

Attempts to obtain parasites of the large cane borer (*Castnia*), the cacao beetle (*Stirastoma*), and the sweet potato weevil (*Euscepes*), on the mainland of South America unfortunately failed on account of the extreme rarity of these insects on their natural food-plants, and time was not available for any extensive search. But this very rarity indicates that important controlling factors are in operation, and these should be worth examining when an opportunity is available.

The freedom of sugar-cane from froghoppers in Cuba was found not to be due to any control by parasites. Possibly an important factor is the occurrence of lime in the soil in large quantities.

10. Noxious Weed Work.

The devastating effects often exerted by Phytophagous insects upon vegetation constitutes the most important problem in economic entomology. However, these insects attack noxious as well as useful plants, and must therefore, in many cases, be considered as beneficial organisms. The idea of utilising them for the destruction of weeds and other harmful plants is relatively new and seems to have originated with Perkins and Koebele in relation to Lantana in Hawaii. It was adopted a number of years later by the Australian authorities against Prickly Pear, and extended to other noxious plants in New Zealand and Australia by Tillyard.

The most injurious weeds of European origin in New Zealand are the Blackberry (*Rubus fruticosus*), the Gorse (*Ulex europaeus*) and the Ragwort (*Senecio jacobaea*), while Foxglove (*Digitalis purpurea*) and Bracken (*Pteris aquilina*) are also rather troublesome.

The work on the European insects attacking these plants was carried on in the first instance at Rothamsted and Leeds, but centralised in 1929 at Farnham Royal. In view of the fact that the problem of weed control by insects is in a very large measure a botanical problem, it was decided to organise it upon new lines, and to combine with the entomological work previously carried on, a careful ecological study of the natural control of the weeds mentioned in their native haunts, and a detailed investigation of the effect produced by their insect enemies in limiting their growth, distribution and increase. During the season of 1929 this work was in the charge of Dr. A. S. Watt, formerly Lecturer in Forest Botany and Zoology in the University of Aberdeen. On October 1st, 1929, Dr. Watt resigned to take up the post of Lecturer in Forest Botany at the University of Cambridge, and was replaced by Mr. E. H. Chater, formerly Lecturer in Ecology in the University of Aberdeen, who took up his duties on November 1st. Mr. E. Cameron, a graduate of the University of Edinburgh was given a temporary appointment as from September 27th, 1929, to assist Mr. Chater.

In spite of the delays and interruptions the work has proceeded in a very satisfactory manner. A great deal of valuable information concerning the natural control of Gorse and Ragwort, and the work of their insect enemies has been gained.

The collection and shipment of several of the most important insects attacking Gorse, Blackberry, and Ragwort has been carried on as rapidly as possible. Seven shipments, comprising a total of 90,000 individuals of *Apion ulicis*, a weevil attacking the seeds of Gorse, five shipments comprising a total of 78,028 individuals of *Tyria jacobaeae*, a moth, whose caterpillar is very destructive to Ragwort and four shipments, comprising 1,317 rose stocks infested with *Coraeus rubi*, a Buprestid beetle injurious to Blackberry, as well as 768 eggs and adults of this species, had been made up to the end of February, 1930. This material seems to have arrived, for the most part, in excellent condition, and is being used either for experimental studies or for distribution in the field.

In addition to the work of preparing and sending off shipments of parasites to New Zealand, a general study is being made of the

conditions of growth of *Ulex europaeus* and *Senecio jacobaea*. Work of this nature is determined by seasonal opportunities and up to the present the study of *Ulex* has mainly centred on two aspects of the problem, firstly, the conditions of germination of the seed, which process is markedly irregular on account of the impermeable nature of many of the seed coats, and secondly, the observation and measurement on marked plots at regular intervals of the appearance, establishment, and growth of seedlings, their colonisation of burnt ground and their competition with different plant communities.

In addition, laboratory experiments are being carried out to investigate the following points:—Root development in different types of soil; growth in acid and calcareous soils; infestation of seedlings by nitrogen fixing bacteria.

In the summer of 1929, the effect of phytophagous insects on *Ulex* was studied by Dr. Watt; this aspect will again be emphasised especially with regard to seed mortality as soon as the fruiting period commences.

Ragwort investigations are being carried out along several lines, entomological, botanical, and partly agricultural. Various facts regarding the effectiveness of the Cinnabar Moth, *Tyria jacobaeae* as a means of control are being brought to light, and a fairly complete study of its parasites, both insect and fungi with a view to determining its mortality throughout the year is being made. Lists of other insects, which may prove useful, are being made, and the study of the damage or control effected by each will be carried out during the coming season. Several puparia of a fly, *Phorbia seneciella*, which appears to be helpful in certain parts of the country have been obtained.

From the botanical aspect, conditions of germination, relation to soils, temperature and relative humidity, are being looked into, and a more or less complete ecological study will be made of the plant, although this will take second place to the entomological investigations.

As an agricultural weed in England, a survey is being made of its occurrence throughout the southern part of the country, and its relation to land types, together with the competition it suffers from various grasses and agricultural plants. Notes will also be made on its poisonous properties and the behaviour of farm and wild animals towards it.

In all 16 consignments of three species of phytophagous insects, attacking three weeds of major importance in New Zealand, and comprising in all a total of 170,113 individual insects have now been sent out from the Laboratory.

11. *General Investigations.*

In addition to the essentially practical work described in the last section, a number of lines of research on fundamental problems are being carried on. The Superintendent is continuing a series of theoretical studies on the problems of natural control, considered mainly from the quantitative standpoint, as well as certain special studies on the biology of parasites and their inter-relations with their hosts. Dr. G. Salt is making a careful analytic study of the inter-relations between the Sheep Blowfly and its parasite, *Alysia manducator*, Panz., more particularly from the numerical standpoint, and has also in preparation a comprehensive paper on the biology and larval forms of the parasites of the Wheat Stem Sawfly. Dr. W. H. Thorpe is making plans for an investigation of the interaction between predacious insects and their hosts. Mr. H. T. Rosenberg is engaged in the preparation of monographs of the parasites of the Pear Slug and the Codling Moth. Mr. D. S. MacLagan has practically completed a very valuable study of the bionomics and natural control of the Lucerne Springtail. Finally Mr. E. H. Chater and Mr. E. Cameron are devoting special attention to the part played by phytophagous insects in the natural control of vegetation. Fifteen articles on various aspects of the work have been published by Dr. J. G. Myers, Dr. G. Salt, and the Superintendent.

12. *Summary of the Projects submitted to the Laboratory.*

CANADA.

Noxious Insects.

- Peach Twig Borer (*Anarsia lineatella*, Zell.).
- ♁ Pear Slug (*Caliroa limacina*, Retz.).
- Wheat Stem Sawfly (*Cephus cinctus*, Nort.).
- Larch Case Bearer (*Coleophora laricella*, Hubn.).
- Beech Coccus (*Cryptococcus fagi*, Baren).

♁ The sign ♁ indicates that the project is being investigated for more than one of the Governments shown above.

- Oriental Peach Moth (*Cydia molesta*, Busck.).
- ø Codling Moth (*Cydia pomonella*, L.).
- Hemlock Looper (*Ellopiia fiscellaria*, Gn.).
- Apple Bud Moth (*Eucosma ocellana*, Schiff.).
- Pine Bud Moth (*Exotelia dodecella*, L.).
- ø European Earwig (*Forficula auricularia*, L.).
- Potato Stem Borer (*Gortyna micacea*, Esp.).
- Warble Flies (*Hypoderma bovis*, De Geer and *Hypoderma lineatum*, Vill.).
- Hawthorn Scale (*Lecanium coryli*, Ldgr.).
- Larch Sawfly (*Lygaeonematus erichsoni*, Htg.).
- Horn Fly (*Lyperosia irritans*, L.).
- Willow Sawfly (*Nematus pallidiventris*).
- Onion Maggot (*Hylemyia antiqua*, Meig.).
- ø Diamond Back Moth (*Plutella maculipennis*, Curt.).
- ø Carrot Rust Fly (*Psila rosae*, Fabr.).
- Apple Sucker (*Psylla mali*, Schmidb.).
- Currant Sawfly (*Pteronius ribesii*, Scop.).
- European Corn Borer (*Pyrausta nubilalis*, Hubn.).
- Pine Shoot Moth (*Rhyacionia buoliana*, Schiff.).
- Satin Moth (*Stilpnota salicis*, L.).
- Onion Thrips (*Thrips tabaci*, Lind.).
- Spruce Budworm (*Tortrix fumiferana*, Clem.).
- Greenhouse White Fly (*Trialeurodes vaporariorum*, Westw.).

AUSTRALIA.

New South Wales.

- White Grubs (*Anodontonyx tetricus*).
- ø Pear Slug (*Caliroa limacina*, Retz.).
- Mediterranean Fruit Fly (*Ceratitis capitata*, Wied.).
- White Wax Scale (*Ceroplastes ceriferus*, And.).
- Pink Wax Scale (*Ceroplastes rubens*, Mask.).
- Orange Wax Scale (*Chionaspis citri*, Comst.).
- ø Codling Moth (*Cydia pomonella*, L.).
- Queensland Fruit Fly (*Dacus ferrugineus*, Fabr.).
- ø Corn Earworm (*Heliothis obsoleta*, Fabr.).
- ø Sheep Blowfly (*Lucilia sericata*, Meig., etc.).

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

Western Australia.

- Red Mite (*Bryobia praetiosa*, Koch.).
- ø Pear Slug (*Caliroa limacina*, Retz.).
- ø Corn Earworm (*Heliothis obsoleta*, Fabr.).
- Clover Weevil (*Listroderes praemorsa*).
- ø Sheep Blowflies (*Lucilia sericata*, Meig.).
- Lucerne Springtail (*Smynthurus viridis*, L.).

SOUTH AFRICA.

- ø Sheep Blowfly (*Lucilia sericata*, Meig.).

NEW ZEALAND.

- ø Pear Slug (*Caliroa limacina*, Retz.).
- Pine Chermes (*Chermes pini*, L.).
- Pear Leaf-curling Midge (*Dasyneura pyri*, Bouché).
- Bronze Beetle (*Eucolaspis brunnea*, Fabr.).
- ø European Earwig (*Forficula auricularia*, L.).
- Cattle Tick (*Haemaphysalis bispinosa*, Neum.).
- ø Sheep Blowflies (*Lucilia sericata*, Meig.).
- Spruce Aphis (*Neomyzaphis abietina*, Walk.).
- New Zealand Cockchafer (*Odontria zealandica*, White).
- ø Diamond Back Moth (*Plutella maculipennis*, Curt.).
- Woodlice (*Porcellio* spp.).
- Grass Moths (*Porina* spp.).
- Wood Wasps (*Sirex* spp.).
- Apple Leaf Hopper (*Typhlocyba australis*, Frogg.).

INDIA.

United Provinces.

- Woolly Aphis (*Eriosoma lanigerum*, Hausm.).

Madras Presidency.

- Fluted Scale (*Icerya purchasi*, Mask.).

WEST INDIES.

- ø Pink Bollworm (*Platyedra gossypiella*, Scund.).

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

CYPRUS.

- ø Codling Moth (*Cydia pomonella*, L.).
- Potato Tuber Moth (*Phthorimaea operculella*, Zell.).

FALKLAND ISLANDS.

- Bluebottles (*Calliphora* spp.).

UNITED STATES OF AMERICA.

- ø Pink Bollworm (*Platyedra gossypiella*, Saund.).
- ø Carrot Rust Fly (*Psila rosae*, L.).

Noxious Weeds.

NEW ZEALAND.

- Gorse (*Ulex europaeus*, L.).
- Blackberry (*Rubus fruticosus*, L., etc.).
- Ragwort (*Senecio jacobaea*, L.).
- Foxglove (*Digitalis purpurea*, L.).
- Bracken (*Pteris aquilina*, L.).

Up to the date on which this manuscript was sent to the press, a total of 73 consignments of beneficial insects, containing approximately 285,000 living individuals have been sent out by the Laboratory. About twenty-four species of beneficial insects attacking seventeen species of pests have been included in these shipments. In addition, Mr. Stanley Garthside has shipped to Australia four lots of the three Chrysomelids attacking St. John's Wort, comprising 28,798 individuals in various stages of development.

ø The sign ø indicates that the project is being investigated for more than one of the Governments shown above.

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CONTENTS.

	PAGE
I.—Introduction	5
II.—Apples—	
(i) The importation of Canadian Apples	7
(ii) Types of Wastage in Imported Canadian Apples	11
(iii) Rot-producing Fungi	12
(iv) Scab	19
(v) Internal Breakdown	22
(vi) Other Physiological Diseases	36
III.—Other Fruits—	
(i) Pears	41
(ii) Plums	42
(iii) Peaches	48
IV.—Summary	50
Acknowledgments	53
List of References	53

Appendices.

I.—Varieties of Canadian Apples Examined during the Survey	54
II.—Exports of Canadian Fruits	55
III.—Development of Wastage in Canadian Plums Retained under Observation	56

WASTAGE IN IMPORTED CANADIAN FRUIT.

I.—INTRODUCTION.

DURING the past three years the Empire Marketing Board has carried out a systematic survey of the nature and extent of deterioration in imported fruit with the object of identifying the more serious types of wastage and assessing their relative importance. This work was primarily undertaken in connection with the Board's economic studies of the marketing of Empire fruit: in addition, it has served to indicate research problems of commercial importance and has formed a useful supplement to the laboratory study of wastage undertaken by the Cambridge Low Temperature Research Station of the Department of Scientific and Industrial Research. Special attention has been directed towards methods of controlling wastage under commercial conditions, and in certain cases it has been possible to arrange experimental shipments in co-operation with oversea Departments of Agriculture. An investigation of this nature, in connection with the control of internal breakdown in British Columbian Jonathan apples, is described below.

A short progress report containing an account of a preliminary survey of the condition of Canadian apples during the latter part of 1926-27 season has already been published.(3)*

The present report deals with a further survey during the two seasons 1927-28 and 1928-29. In Section II a brief account is given of the importation of Canadian apples into the United Kingdom, including particulars of the quantities and varieties shipped, the methods of packing and the carrying temperatures. The principal types of wastage observed are described and discussed in relation to such factors as variety, grade, size and maturity. Section III deals similarly with the condition of pears, plums and peaches. A further report will shortly be issued on enquiries into the causes of slackness in barrels of apples, a source of considerable loss to Eastern Canadian shippers.

* Throughout this report, figures in brackets refer to the list of references on page 53.

The method of procedure followed during the present survey has been substantially the same as that described in previous reports (3, 4). Most of the work has been carried out at the docks, as experience has shown that an extensive examination of imported fruit can be most conveniently undertaken at that point. The fruit is there concentrated into a comparatively small area and facilities for opening the packages are more readily available. After unloading, shipments were examined as thoroughly as possible before removal from the dock, notes being taken of the origin, quality and maturity of the fruit, the extent and nature of the wastage present and any further observations that appeared to be of interest. In addition, many ships were boarded during unloading and observations taken of the temperatures in the holds and the methods of stowage of the cargo.

Detailed examinations could be carried out more effectively with boxed than with barrelled apples. Opening a barrel is a somewhat lengthy process, and if many apples are removed, the pack may be disturbed sufficiently to cause the barrel to become slack, thus reducing its market value. The examinations of barrelled apples have, therefore, been less complete and no estimate of the extent of wastage in these apples has been possible.

The greater part of the dock survey was undertaken during the 1927-28 season and was carried out mainly at London and Liverpool, though cargoes have occasionally been examined at other ports. During the following season, the time was largely occupied with a special investigation into the extent and causes of slack barrels, and with experimental work on internal breakdown.

There is reason to believe that, in some instances, considerable wastage may occur between the discharge of the fruit at the dock and its arrival in the retail shop, and attempts have, therefore, been made to extend the work to include a re-examination at the stores and warehouses of wholesale and retail merchants. In view of the wide distribution of the fruit, however, and the difficulty of tracing individual consignments, it has not been possible to secure sufficiently representative data. It is hoped that further information on this subject will be obtained in the course of an investigation into the retail marketing of fruit which is at present in progress.

II.—APPLES.

(i) *The Importation of Canadian Apples.*

Apples are imported into the United Kingdom from three Canadian provinces—Nova Scotia, Ontario and British Columbia. The first arrivals reach the British market towards the middle of September, and consist principally of early varieties of Nova Scotian apples, notably Gravenstein, Dudley, Wolf River and, later, Blenheim Orange, King, Cox's Orange Pippin and Ribston Pippin. The "peak" shipments from Nova Scotia arrive during November and December, with large quantities of Baldwin, Stark, Ben Davis, Golden Russet and other late varieties, which continue until the end of the season in March or April. Shipments of apples from Ontario are considerably smaller than those from Nova Scotia. The varieties exported are largely the same, among the most important being Baldwin, Ben Davis, Golden Russet, Greening, Northern Spy and Stark. British Columbian apples begin to arrive about the end of September. The first shipments consist mainly of Wealthy, Cox's Orange, McIntosh Red and Jonathan apples, the last-named continuing until February. Considerable quantities of such varieties as Delicious, Grimes' Golden and Rome Beauty are shipped towards the middle of the season, together with consignments of Yellow Newtown and Winesap. The two latter varieties constitute the bulk of the later shipments and continue until the end of March.

A list of apple varieties from each Province examined in the course of the survey is given in Appendix I. The quantities imported into the principal ports during the two seasons under review are set out in Appendix II.

Packing.—All British Columbian apples are packed in the wired, bushel, pinewood box, which is also universally employed in New Zealand and the Western United States. The internal measurements of the box are 18 by 11½ by 10½ inches and the full bushel content is only achieved by means of a slight bulge on the top and bottom boards, which are made of thinner wood than the rest of the box. This bulge takes up any shrinkage which occurs in the fruit and the pack, therefore, remains firm for a considerable time. Many instances have been observed, however, when the bulge was excessive and the pack so tight that the contents had been severely bruised in spite of the protective layer of plain or corrugated cardboard interposed between the lid and the outside layer of fruit. Apples injured in this way are frequently invaded by rot-producing fungi.

The apples are individually wrapped in oiled or plain paper and packed in the well-known diagonal manner, the number of apples, variety, grade and car-lot number being stamped on the outside of the box. Three quality grades are packed: Extra Fancy, Fancy and C grade. These are defined as follows by the Canadian Fruit Act:—

Extra Fancy Grade:

(a) "Extra Fancy", which shall include only firm, mature, clean, smooth, handpicked, well-formed fruit of one variety, of good colour for the variety, free from all insect pests, diseases, bruises, spray burns, limb rub, visible water core, skin punctures or skin broken at the stem, russetting, except that russetting at the basin of the stem shall be permitted, and properly packed.

Fancy Grade:

(b) "Fancy", which shall include only firm, mature, clean, smooth, handpicked, well-formed fruit of one variety, of fair colour for the variety and free from all insect pests, diseases, bruises, spray burns, visible water-core, skin punctures or skin broken at the stem, provided that limb rub not exceeding one-half inch in diameter, and leaf rub and russetting up to 10 per cent. of the surface shall be permitted, and properly packed.

C grade:

(c) "C", which shall include only fruit free from infection, soft bruises and broken skin, provided that this grade may include healed over stings and scab spots not to exceed one-half square inch in the aggregate and properly packed.

The great majority of Ontario and Nova Scotian apples are packed in barrels containing about 140 lb. of fruit,* though a few are shipped in half barrels or bushel boxes. Four quality grades are permitted: No. 1, No. 2, Domestic and No. 3; these are defined as follows by the Canadian Fruit Act:—

No. 1 Grade:

(a) "No. 1", which shall include only well-grown, hand-picked specimens of one variety, sound, of not less than medium size and of good colour for the variety, of normal shape and less than 90 per cent. free from scab worm-holes, bruises and other defects, no culls, and properly packed.

* Formerly the Nova Scotian barrel contained about 120 lbs., but the 140 lb. Standard barrel, always used in Ontario, has now been adopted for some years for all shipments from Eastern Canada.

No. 2 Grade :

(b) " No. 2 ", which shall include only hand-picked specimens of not less than nearly medium size and some colour for the variety, sound and not less than 85 per cent. free from scab wormholes, bruises, and other defects, no culls, and properly packed.

Domestic Grade :

(c) " Domestic ", which shall include only hand-picked specimens of not less than medium size for the variety, sound and not less than 90 per cent. free from wormholes (but may be slightly affected with scab and other minor defects), no culls, and properly packed.

No. 3 Grade :

(d) " No. 3 ", which shall include only hand-picked specimens, no culls, and shall be properly packed.

Methods of packing barrels are discussed in detail in a report on slack barrels to be issued shortly, and this matter will, therefore, not be considered further in the present report.

Shipment to the United Kingdom.—Canadian apples are exported to this country by two routes. Nova Scotian and Ontario consignments are shipped from Eastern Canadian ports, notably Montreal, Halifax and St. John. Considerable quantities of British Columbian apples are also exported by this route after rail haulage across the continent, but in addition large consignments are shipped direct to the United Kingdom via the Panama Canal, usually on the same vessels which carry direct shipments of Washington and Oregon apples. During the 1927-28 season, about 100,000 cases, nearly 30 per cent. of the total British Columbian shipments to Europe, were exported in this way. The following season this quantity increased to nearly 140,000 cases, or rather less than 20 per cent. of the total shipments to Europe.

The voyage from Eastern Canada is comparatively short, normally lasting about eight or ten days, and a large proportion of the shipments are carried during the winter months when the prevailing temperatures are low. Shipments of apples from these ports are, therefore, usually carried without refrigeration, which is, however, generally employed for cargoes of pears and other soft fruits. Direct shipments of apples from British Columbia are carried in cool storage.

Apples shipped without refrigeration are carried both in 'tween decks and lower holds. Barrels are usually stowed on their sides and are not, as a rule, piled to a greater height than four or five tiers, to avoid undue weight on the bulge. Boxed apples are stowed on their sides so that no pressure may be exerted on the bulge at the top and bottom of the box. When carried in refrigeration, the boxes are separated by dunnage to maintain air spaces and thus ensure a more uniform temperature distribution.

Temperature conditions in the hold during the comparatively short journey from Eastern Canada are naturally less important than in the case of a longer voyage, such as that from Australia, when the fruit has to be held in cold storage for more than a month and transported through the Tropics. Nevertheless, this factor cannot be overlooked, and thermographs are installed in most fruit cargoes by the Canadian Department of Agriculture to record the temperatures obtaining during the voyage. By the courtesy of the Department, blue prints of the charts from these thermographs were made available to the Board's officers and afforded information of considerable interest. As a rule, however, only one thermograph is installed in each hold, usually towards the centre of the cargo, and it is probable that the temperatures in other parts of the cargo may differ somewhat from those recorded.

Fairly high temperatures are prevalent in unrefrigerated holds during the early part of the season, more than 60° F. being recorded in some instances. These temperatures can be associated with a type of wastage occurring at this time, particularly in Domestic grade apples, caused by the fungus *Trichothecium roseum*. This fungus usually invades the apple through scab injuries and develops only at fairly high temperatures. With the approach of winter, a noticeable fall is apparent in the average carrying temperatures; from mid-October to mid-November, these are of the order of 50° F., while in January and February the usual temperature has fallen to about 38° to 40° F. Apples are often carried in holds which also contain timber; during the winter months this is frequently covered with ice and is then probably of value in maintaining a low temperature in the hold. In a few instances, temperatures several degrees below freezing point were recorded, where apples were stowed next to refrigerated holds containing meat and other perishable products, but these conditions did not appear to persist for more than a short time and no serious losses from freezing injury have been observed during the dock examinations.

It appears from a study of the thermograph charts, that considerable temperature changes may sometimes occur in one part of an unrefrigerated hold in the course of the comparatively short voyage from Eastern Canada, particularly during the early part of the season, variations of as much as 20° F. being recorded in some instances.

A few long-distance thermograph charts taken from direct refrigerated shipments from British Columbia have also been received. The temperatures recorded have been comparatively uniform and usually ranged from 30° to 35° F.; these may be regarded as satisfactory.*

The work of unloading the fruit on arrival is carried out either by cranes on the quay side or by the ship's tackle. Large nets, loops of rope or grapnels are used during this process to support the barrels which are carefully lowered on to a pad or spring-board to avoid any severe jar liable to break the staves or cause the barrels to become slack. The barrels are then transferred on trolleys to the dock shed, where they are sorted and stacked on end to a height of two or three tiers, care being taken to ensure that the upper barrels rest on the staves and not on the faces of those below. Pads are also used to prevent any jar when the barrel is removed from the trolley. Boxed apples are usually stacked on large wooden trays for removal from the hold, but rope nets of the type used for barrels are occasionally employed.

(ii) *Types of Wastage in Imported Canadian Apples.*

The condition of Canadian apples on arrival in the United Kingdom is generally good and many consignments appeared to have suffered very little deterioration in transit. This may perhaps be largely attributed to the comparatively short period of transit and to the low temperatures prevailing during the greater part of the season.

From observations at the docks and markets, and from information supplied by members of the fruit trade, fungal rotting appears to be the most serious cause of deterioration, more particularly in barrelled apples, where the extensive bruising which seems inseparable from this method of packing greatly facilitates the entry of fungi. It is,

* A detailed account of modern refrigerating practice in relation to the transport of fruit will be found in publications of the Food Investigation Board (13), and of the South African Department of Agriculture (6), while a brief review is included in Special Report No. 3 of this Series.

however, extremely difficult to form any estimate of the extent of this type of wastage. At the docks it does not appear to be serious in more than a comparatively few instances, but it should be noted that rotting is almost invariably most severe in the lower part of a barrel, and it is not possible to determine the extent of the injury without examining the entire contents; this is, of course, usually impracticable. Later, in the markets and in samples retained under observation, rotting is more evident and it seems probable that it may often develop fairly rapidly after the arrival of the fruit. Fungal rotting is discussed briefly in the following Section; it will be considered more fully in the later report on slack barrels.

Two other diseases, internal breakdown and scab, have also been observed to cause serious deterioration and are discussed below in some detail. Scab is extremely common in shipments from Eastern Canada where a special Domestic grade is packed; this grade permits the inclusion of apples affected by scab and other minor defects, but otherwise sound and of good quality. Internal breakdown has been observed in a number of varieties, but was extensive only in British Columbian Jonathan apples. An experimental shipment in connection with this disease, undertaken in co-operation with the Summerland Experimental Station, is described below and appears to indicate a promising method of control. Certain non-parasitic diseases less frequently encountered are considered in Section (vi) under the heading "Other Physiological Diseases".

A brief account of recent scientific literature dealing with certain diseases of apples was given in Special Report No. 3 of the Empire Marketing Board and little elaboration of this resumé will be attempted here. For more detailed information, reference should be made to the original publications quoted in this and in the earlier report.

(iii) *Rot-producing Fungi.*

The observations described in this section have been mainly directed towards the extent and causes of the wastage, rather than to the nature of the injury and no attempt has been made to compile an exhaustive list of the fungi occurring in Canadian apple shipments. In general, it appears that the greater part of the wastage is caused by the more common and well-known apple rot fungi. *Penicillium expansum* was the fungus most frequently observed in shipments from all three Provinces. Usually it invaded the apple at bruises or other wounds and produced a soft, watery rot with a characteristic odour;

the rots were light brown in colour, while green spore masses often developed on the surface of the diseased tissue. Other fungi which have been observed to cause fairly serious rotting and which were dominant in some consignments include species of *Botrytis*, *Mucor*, *Fusarium*, *Trichothecium*, *Alternaria* and *Rhizopus*.

British Columbian Shipments.

Comparatively little wastage from fungal rotting has been observed in British Columbian apples during the course of the survey, though it is possible that a considerable increase may occur in some instances after the fruit is removed from the quay. The percentage observed in some of the more important varieties is given in Table I. In view of the small size of the samples and the variation in the condition of different shipments, no great significance is attached to these figures, but they are sufficient to give a rough indication of the extent of wastage on arrival, while the order assumed by the varieties supports the general impression of the incidence of wastage gained at the dock examination. In a large proportion of instances, the rotting organism appeared to have entered by way of mechanical injuries, such as case bruises and stem and nail punctures. Other rots had originated at the calyx or stem end, or at lenticels. Rotting secondary to internal breakdown frequently occurred, but as far as possible such cases have been omitted from the table. In the later stages of infection, however, it is often difficult to determine the origin of the injury.

TABLE I.
Percentage of Fungal Rotting Observed in British Columbian Apples at Dock Examinations, 1927-28.

Variety.	No. of Boxes Examined.	Fungal Rotting (per cent.).
McIntosh Red	81	1.5
Cox's Orange Pippin	36	1.3
Delicious	25	0.9
Jonathan	395	0.7
Wealthy	23	0.7
Spitzenberg	30	0.5
Grimes Golden	42	0.4
Yellow Newtown	50	0.3
Winesap	52	0.2

Eastern Canadian Shipments.

Rotting appears to be of greater importance in barrelled than in boxed apples and constitutes the principal cause of wastage in the former class of fruit. Many consignments of barrelled apples arrive in very sound condition and develop little wastage for some considerable time afterwards, but there is reason to believe that, in some instances, rotting increases rapidly, more especially if the fruit has reached an advanced stage in its storage life.

On account of the difficulty of effecting a satisfactory examination of barrelled apples, it has not been possible to form any estimate of the average percentage of rotting on arrival in the principal Eastern Canadian varieties. From observations at the docks and markets, it appears that rotting is more serious in early varieties, such as Gravenstein and Blenheim, than in Stark, Baldwin, Golden Russett and other varieties shipped later in the season. This may probably be largely attributed to the thinner skins and softer texture of the early varieties and to the higher temperatures prevailing at the beginning of the season. In all varieties, rotting tends to become more severe as the maturity of the fruit increases towards the end of its shipping season.

Causes of Wastage.—The greater part of the rotting in barrelled apples originates from bruises, which appear to be caused mainly by the pressure exerted in closing the barrel during the process of packing. For this operation the barrel is inverted and filled with apples, which are closely settled together by "racking" the barrel from time to time. This process is continued until the final layer of apples is level with, or slightly above the top of the staves, when the fruit is forced down to the correct level by means of a screw press and the bottom of the barrel is nailed in. The effect of this treatment is immediately evident when a barrel of apples is opened at the bottom. The lowest layer of apples is almost invariably found to be extensively bruised, sometimes so severely that many fruits are flattened or even split by the pressure. Serious bruising continues for several layers towards the centre, while a large proportion of the apples throughout the barrel are injured to a less serious extent. In addition, stems are often forced into adjacent apples. These mechanical injuries naturally render the fruit very liable to develop fungal rots, particularly when it becomes fully ripe and its resistance to fungi is diminished.

The serious influence of the packing treatment on wastage is illustrated by the following table, showing the average number of rotted apples in the upper, middle and lower thirds of 96 barrels of Nova

Scotian apples. Samples of sixteen fairly comparable barrels of No. 1 grade fruit were selected for detailed examination from three shipments of Gravenstein and Blenheim apples, each successive shipment being rather more advanced in maturity. It will be seen that in every case rotting was most severe in the lower part of the barrel, where the apples received direct pressure in the pressing-down operation during packing. The less severely bruised fruit in the middle and upper thirds of the barrel showed progressively less rotting. The total rotting was greater in each successive shipment as the fruit became more mature.

TABLE II.
Average Number of Rotted Apples in the Upper, Middle and Lower Thirds of Barrels of Nova Scotian Apples Examined in Detail.

Group.	Average Number Rotted Apples in whole Barrel.	Average Number Rotted Apples in Upper Third of Barrel.	Average Number Rotted Apples in Middle Third of Barrel.	Average Number Rotted Apples in Lower Third of Barrel.
Gravenstein—				
1st shipment ..	19	2	5	12
2nd " ..	29	5	7	17
3rd " ..	71	14	21	36
Blenheim—				
1st shipment ..	6	1	1	4
2nd " ..	14	2	2	10
3rd " ..	24	2	4	18

As smaller number of rots originating at sources other than mechanical injuries, including the stem end, the calyx, lenticels and other points of entry were also observed. Several spotting fungi cause appreciable deterioration in some shipments of barrelled apples. These fungi usually invade the fruit at lenticels and produce sunken, brown, circular spots which considerably disfigure the fruit. During the early part of the season, a somewhat similar disfiguration is often produced on Domestic and No. 3 grade apples by the fungus *Trichothecium roseum*, which most frequently invades the fruit through scab

injuries. Sunken brown areas which rarely penetrate far into the flesh are formed around the "scab", and pink fructifications occasionally develop on the surface of the diseased tissue. The injury is sometimes very widespread. On one occasion, for example, a small shipment of Domestic grade Dudley apples showing nearly 100 per cent. of *Trichothecium* infection was observed. Such occurrences are, of course, exceptional, but the disease is commonly found on shipments of Nova Scotian apples up to the middle of November. Fairly high temperatures are necessary for the rapid development of the fungus, and with the approach of winter its activity is greatly reduced.

An analysis of the origin of rotting in a fairly large sample of Nova Scotian Blenheim Orange apples is set out in Table III below, and may probably be taken as roughly characteristic of the mass of Canadian barrelled apples in this respect. It will be noted that in this case nearly 90 per cent. of the total rotting originated at mechanical injuries, only 7 per cent. being definitely attributable to invasion at the calyx, stem end or lenticels. Under the heading "Unclassified" are included all cases where the origin of the rot was uncertain, usually because of the advanced stage of the injury.

TABLE III.
Origin of Rotting in Sixty Barrels of Nova Scotian Blenheim Orange Apples examined in Detail.

Average Percentage of Rotting in Sample.	Percentage of Total Rotting Originating from			
	Bruised or Split Apples.	Stem or Nail Punctures.	Calyx, Stem end or Lenticels.	Unclassified.
5	73	15	7	5

Cases are occasionally encountered, however, in which points of ingress other than mechanical injuries are of importance. The occurrence of extensive *Trichothecium* rotting originating from scab injuries on a shipment of Dudley apples has already been quoted. Another example was furnished by a number of experimental shipments of Nova Scotian Gravenstein apples in which extensive wastage was caused by a *Botrytis* rot originating at the calyx. The relative importance in these shipments of the various points of ingress is

set out below and may be compared with the similar analysis in Table III. In later shipments of more mature but otherwise comparable Gravenstein apples, fungal wastage originating from bruises was greatly increased and was responsible for some 70 per cent. of the total wastage.

TABLE IV.

Origin of Rotting in Forty Barrels of Nova Scotian Gravenstein Apples Examined in Detail.

Average Percentage of Rotting in Sample.	Percentage of Total Rotting Originating from				
	Calyx.	Bruised or Split Apples.	Stem or Nail Punctures.	Stem end or Lenticels.	Unclassified.
7	32	39	9	2	18

Rate of Deterioration—It is difficult to obtain adequate information on the rate of deterioration of barrelled apples, although there is reason to believe that in some instances it may be fairly rapid. The only direct evidence available is that obtained from the detailed examination of a number of samples of Nova Scotian Gravenstein, Blenheim and Golden Russet apples, which formed part of a series of experimental consignments received in connection with investigations on slackness in barrelled apples. Consignments were received at the beginning, middle and end of the shipping season of each variety. On arrival, the shipments were usually divided into three samples, one of which was examined at once, while two were stored in a cool warehouse at a temperature of 40° to 50° F. and examined at intervals of two or three weeks. The method of storage may be taken as similar to that usually employed in commercial practice.

The results obtained are set out in the following table and are seen to be somewhat variable. In view of the fairly favourable conditions of storage, rotting developed somewhat rapidly in all the Gravenstein consignments. It should be noted, however, that the last shipment was made at a somewhat later date than is usual for this variety, and it is doubtful if such extensive wastage often occurs

in commercial shipments. The early and mid-season Blenheim apples developed comparatively little wastage, but serious rotting occurred in the last shipment after a few weeks' storage. All consignments of Golden Russet apples were practically free from wastage on arrival, but the storage period for this variety was extended to six weeks, at the end of which time an appreciable amount of wastage was present.

TABLE V.
*Development of Rotting in Nova Scotian Apples Stored at
40° to 50° F.*

Variety.	Time of Shipment.	Percentage of Rotting.						
		On Arrival.	First Week.	Second Week.	Third Week.	Fourth Week.	Fifth Week.	Sixth Week.
Gravenstein.	Early season .. (arrived Oct. 3)	4.8	6.1	8.8	11.4	—	—	—
	Mid season .. (arrived Oct. 17)	5.8	8.3	9.3	—	—	—	—
	Late season .. (arrived Oct. 31)	13.3	—	17.5	—	23.2	—	—
Blenheim Orange	Early season .. (arrived Oct. 17)	0.4	1.5	—	—	2.75	—	—
	Mid season .. (arrived Oct. 31)	2.0	—	2.2	—	—	3.3	—
	Late season .. (arrived Nov. 22)	4.5	—	5.8	—	24.8	—	—
Golden Russet	Early season .. (arrived Nov. 22)	0.4	—	1.4	—	—	7.5	—
	Mid season .. (arrived Dec. 4)	Nil	—	—	3.0	—	—	6.5
	Late season .. (arrived Jan. 3)	0.7	—	—	—	5.0	—	—

Note.—The early-season shipments of the Gravenstein and Blenheim varieties each consisted of 10 barrels; the mid and late-season shipments of 20 barrels. The first Golden Russet shipment consisted of 8 barrels and the two later of 16 and 11 barrels respectively.

It is not claimed that the above samples are representative of the mass of Canadian apples, but they indicate that, while in some instances the fruit may be stored for some weeks without excessive wastage, in other cases extensive rotting may occur after a not unduly prolonged period of storage, as a result mainly of an advanced state of maturity and of bruises sustained in packing. This matter will be discussed more fully in the later report on slack barrels. It may be noted here, however, that the conditions obtaining in a barrel are extremely favourable to fungal rotting. The humidity inside the barrel is probably high on account of the restricted ventilation and this would favour the germination of fungal spores (5). There is no wrapping paper to hinder the spread of infection from one apple to the next. Further, as has been shown above, a large proportion of the apples are bruised, at least sufficiently to facilitate the entry of rotting fungi. Once, therefore, that fungal deterioration sets in, it is likely to spread rapidly throughout the barrel, particularly in the later stages of the storage life of the fruit when its resistance to fungi is considerably reduced. These considerations appear to indicate an inherent defect in the system of packing apples in barrels. They certainly suggest that "pressing down" and other processes likely to injure the fruit should be reduced to the minimum compatible with securing a pack sufficiently firm not to settle away from the head of the barrel, and that packing should be delayed until immediately before the fruit is shipped in order to reduce as far as possible the period during which rotting may take place.

(iv) *Scab (Venturia inaequalis)*.

In almost all apple-growing countries extensive losses are incurred annually by scab infection. The disease is particularly severe in Eastern Canada, where the moist climate probably favours its development and a large proportion of all shipments of Nova Scotian and Ontario apples show signs of the injury. Scab also occurs on imported British Columbian apples, but in this case the infection is less serious and probably has comparatively little effect on the market value of the fruit. It is not known whether this may be attributed to greater initial freedom from the disease, to more effective control measures, or to more rigorous grading.

Apple scab is caused by the fungus *Venturia inaequalis*, which often affects the stalks, twigs and flowers, but which most frequently develops on the leaves and fruits, where it produces the characteristic

black, scabby spots. In severe cases of infection, the scab covers a large proportion of the skin and may cause the fruit to become cracked or misshapen. The fungus penetrates the skin, beneath which a mass of mycelium is developed. This spreads beneath the surface, but does not grow deeply into the flesh. In due course the epidermis is ruptured, liberating a mass of dark-coloured spores from the scab. Silvery fragments of broken skin are often visible at the margin of the injury. Apples which are only moderately affected by scab are usually sold at reduced prices, but in serious cases the fruit becomes so badly cracked and deformed as to be almost valueless. A further loss occurs through the ingress of secondary rot-producing fungi, notably *Penicillium*, *Botrytis* and *Trichothecium*. A closely allied fungus, *Venturia pyrina*, is the cause of pear scab, a disease which has occasionally been observed on shipments of Eastern Canadian pears. The general appearance of the two diseases is very similar.

The control methods recommended for scab are well known and include spraying with Bordeaux mixture and lime-sulphur, pruning away and burning infected wood, and extreme cleanliness of cultivation. The latter measure is adopted as the spores are harboured in any dead leaves, fruit or other vegetation left in the orchard. For the same reason sod-cultivation is not recommended.

It is evident, however, that in the barrelled-apple districts of Eastern Canada the measures at present employed are not entirely effective in controlling scab infection. There the disease has assumed such dimensions that a special "Domestic" grade of fruit is packed, consisting largely of scabbed apples which are otherwise sound and of good quality. In this connection, it may be of interest to refer to the regulations defining the four grades of Canadian barrelled apples quoted on page 7 above. It will be seen that fruit packed under the "Domestic" and "No. 3" grades may show as much as 100 per cent. of slightly scabbed apples, and that 10 per cent. and 15 per cent. respectively are permitted in the "No. 1" and the "No. 2" grades. In practice, the fruit packed in the two latter grades usually falls well within the prescribed limits of scab infection, and in many cases the amount present is almost negligible. "Domestic" grade apples, on the other hand, are usually very extensively affected. Size rather than scab infection often appears to be the deciding factor in determining the grade of "No. 3" fruit, which is somewhat

variable in this respect. Scabbed apples are, however, almost always present to some extent in this grade, and it is by no means unusual for nearly 100 per cent. of the apples to be affected. In Table VI the percentage of Eastern Canadian apples shipped under each grade to the Liverpool Auction are shown. These figures have been extracted from the auction catalogues and, while they refer to a fraction only of the total Eastern Canadian crop, the samples are of considerable size and give a rough indication of the extent of scab infection in shipments of Ontario and Nova Scotian apples.

TABLE VI.
Percentage of Eastern Canadian Apples shipped under each Grade to Liverpool Auction.

Province.	Grade.	1926-27.		1927-28.	
		No. of Barrels Catalogued.	Per cent. of Total.	No. of Barrels Catalogued.	Per cent. of Total.
Nova Scotia ..	No. 1 ..	22,908	30.4	45,617	36.3
	No. 2 ..	16,294	21.6	17,527	14.0
	Domestic ..	15,278	20.2	36,643	29.2
	No. 3 ..	21,023	27.8	25,795	20.5
	Total ..	75,503	100.0	125,582	100.0
Ontario ..	No. 1 ..	9,299	60.5	11,262	43.2
	No. 2 ..	3,639	23.7	3,676	14.1
	Domestic ..	1,460	9.5	6,632	25.4
	No. 3 ..	977	6.3	4,520	17.3
	Total ..	15,375	100.0	26,090	100.0

It will be seen that during the 1926-27 season over 15,000 barrels of "Domestic" and 21,000 barrels of "No. 3" grade Nova Scotian apples were sold at the Liverpool Auction, the two together con-

stituting some 48 per cent. of the total number catalogued ; in the following season the corresponding figure was about 50 per cent. The proportion of Ontario fruit packed in the scab tolerated grades was comparatively low during 1926-27, but in the succeeding season rose to about 43 per cent., a figure comparable with that for Nova Scotia. It is, of course, uncertain how far the fruit sold at the Liverpool Auction may be taken as representative of the total Eastern Canadian crop. In particular, the number of barrels of Ontario apples catalogued is comparatively small and it is doubtful if the sample is typical of the mass of the fruit. The Nova Scotian estimates, however, are based on a considerably larger sample and are probably more reliable. In any case, the figures are sufficient to indicate the magnitude of scab infection, even allowing for fruits which have been included in the lower grades for some reason other than scabbing. From the standpoint of an observer in this country, the control of scab appears to be one of the most serious problems of the Eastern Canadian fruit industry. It is evident that the control measures at present employed are by no means effective. Whether the methods themselves are inadequate or whether their application is not sufficiently thorough can only be decided by investigations in Canada ; but whatever the cause, it would appear that this is a matter in which further efforts are urgently necessary. In Ontario, a spray service for growers has, it is understood, been recently inaugurated and is carried on by the co-operation of the Fruit Branch of the Department of Agriculture, the agricultural representatives of the Province and the Guelph Agricultural College. This appears to be a very promising method of approach to the problem and is already receiving widespread support.

(v) *Internal Breakdown.*

The term " Internal Breakdown " has been applied to two diseases of apples, which closely resemble each other in appearance, but which differ widely in their causal conditions. Both are characterised by a mealiness and brown discolouration of the affected tissue, which generally shows no definite demarcation from the healthy flesh. Later, the fruit becomes soft and assumes a dull, water-logged appearance. Apples suffering from breakdown are readily invaded by rot-producing fungi and extensive rotting usually accompanies the disease.

One form, known as the "low temperature" type, has been shown to occur only when certain varieties, notably Bramley's Seedling (7), Sturmer Pippin (8) and Yellow Newtown (10), are stored at too low a temperature. It is, however, in no way connected with freezing and frequently develops at a temperature of 34° F. or even higher. The other form is usually called the "Jonathan" type of breakdown, since it occurs characteristically in that variety. This type appears to be the more important in imported Canadian apples. Investigations conducted by Palmer (11) at the Summerland Experimental Station have shown that it may be closely correlated with the maturity of the fruit and is only severe in apples which have passed a certain stage of maturity at the time of harvesting. Its onset is retarded, but not prevented, by storage at low temperatures. A more detailed account of Palmer's investigations is given later in this report.

Internal breakdown is frequently met with in imported Canadian apples. It has occasionally been observed in late shipments of several varieties of Nova Scotian and Ontario apples, including Gravenstein, King, Ribston, Blenheim, Golden Russet, Baldwin, Gano and Stark. Many of these apples had certainly not been held in cold storage and it is doubtful if any had been treated in this way. It is, therefore, probable that the breakdown was of the Jonathan type. The last three-named varieties, however, were shipped during the late winter and the ordinary storage temperatures in Canada may possibly have been sufficient to induce low temperature breakdown. In general, the percentage of Eastern Canadian apples affected with breakdown appears to be extremely low.

Breakdown has also been observed in several British Columbian varieties, but here again the extent of the injury was in most instances negligible, amounting to considerably less than 1 per cent. of the apples examined. A few late shipments of Cox's Orange Pippin, however, showed extensive wastage from this injury, and the trouble has also been very serious in many consignments of Jonathan apples. These varieties are well known to be particularly susceptible to breakdown and shipments from Australia and New Zealand often show severe losses from the disease. The percentage of breakdown observed in the principal British Columbian varieties during the 1927-28 season is set out in the following table, which is based on the examinations carried out at the Liverpool docks.

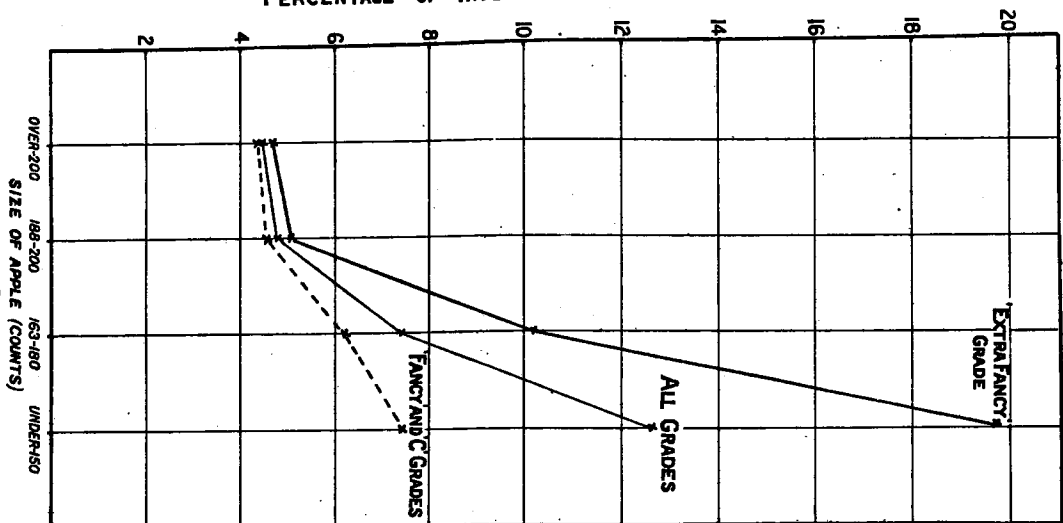
TABLE VII.
*Percentage of Breakdown Observed in British Columbian
 Apples, 1927-28.*

Variety.	Number of Boxes Examined.	Breakdown (per cent.).
Jonathan	395	7
Cox's Orange Pippin	36	4
Delicious	25	Less than 1
Grimes Golden	42	"
McIntosh Red	81	"
Rome Beauty	25	"
Spitzenberg	30	"
Wealthy	23	"
Winesap	52	"
Yellow Newtown	50	"

The Distribution of Breakdown in Shipments of Jonathan Apples.

In a previous report (3) it was noted that "Extra Fancy" grade apples appeared to be more susceptible to breakdown than the "Fancy" grade, and it was suggested that this was perhaps due to the highly coloured, first grade fruit being, on the average, rather more mature at the time of picking. The average percentage of breakdown observed in the two grades during the 1926-27 season is shown in Table VIII; no "C" grade apples were examined at that time. The corresponding figures for the following season are also included and will be seen to be in substantial agreement, some 9 per cent. of breakdown occurring in the "Extra Fancy" grade apples examined, compared with little more than 6 per cent. in the "Fancy" grade. There appears to be no significant difference between the percentage of breakdown in the two lower grades. The greater susceptibility of the "Extra Fancy" grade is shown graphically in Fig. 1.

PERCENTAGE OF INTERNAL BREAKDOWN.



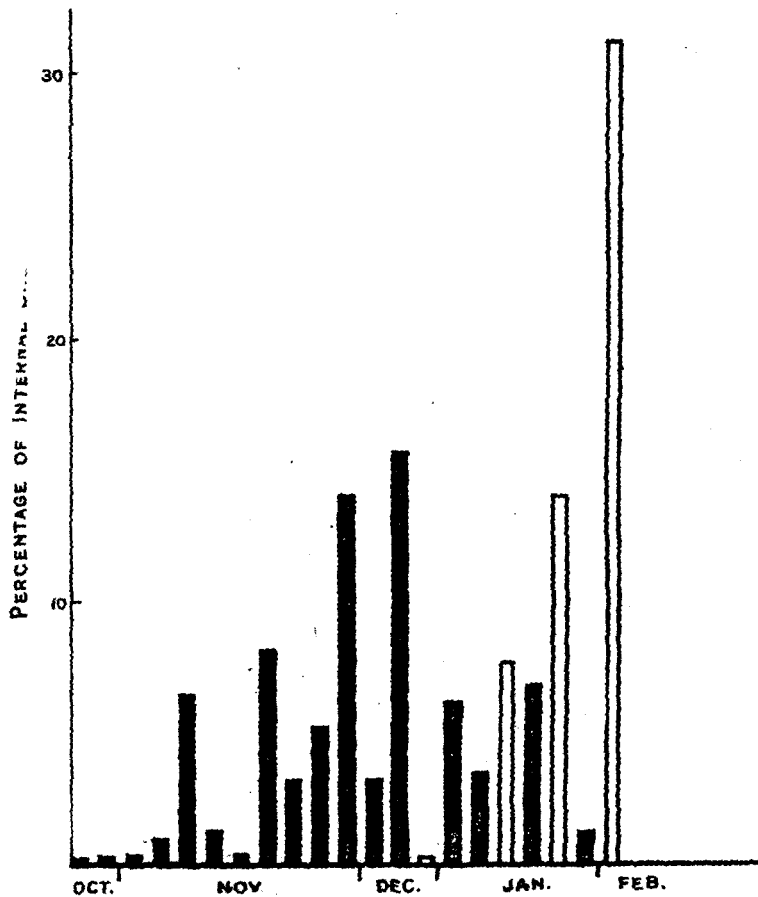


FIG. II. PERCENTAGE OF JONATHAN BREAKDOWN IN SUCCESSIVE SHIPMENTS TO LIVERPOOL, 1927-1928.

Shipments from Eastern Canadian ports are represented by black blocks; direct shipments via Panama by outlined

TABLE VIII.
*Percentage of Breakdown Observed in different Grades of British
 Columbian Jonathan Apples.*

Season.	Extra Fancy Grade.		Fancy Grade.		" C " Grade.	
	No. of Boxes Examined.	Breakdown (per cent.).	No. of Boxes Examined.	Breakdown (per cent.).	No. of Boxes Examined.	Breakdown (per cent.).
1926-27	82	7.1	83	3.5	—	—
1927-28	75	9.0	158	6.1	162	6.7

It is generally recognised that susceptibility to physiological diseases is greater in large than in small apples. The results obtained during various investigations on imported apples are in entire agreement with this theory, which is illustrated by a number of graphs shown in an earlier report (4), dealing with Australian and New Zealand fruit. A similar tendency has been observed in British Columbian Jonathan apples and is shown graphically in Fig. 1. In this figure all the Jonathan apples examined during the two seasons have been grouped arbitrarily into counts of 150 and lower; counts 163-180 inclusive; counts 188-200 inclusive; and counts higher than 200. Similar curves have been included for the "Extra Fancy" grade and the combined "Fancy" and "C" grades, in order to bring out the greater susceptibility of the first grade fruit independently of the size factor.

Shipments of British Columbian Jonathan apples to this country are maintained from October to February by holding stocks of fruit in Canada. In this respect the Canadian apple trade differs from that of Australia, where the fruit is exported shortly after harvesting. It might be anticipated that the Canadian practice would materially increase the risk of wastage from breakdown and that shipments of British Columbian Jonathan apples would tend to show an increasingly higher percentage of the disease as the season advanced. In point of fact, this does not appear to be the case. The percentage of breakdown observed in the principal shipments

examined at Liverpool during the 1927-28 season is shown diagrammatically in Fig. II. In some instances, the percentages are based on comparatively small lots of fruit, but in these cases the shipments themselves were small and the results of the examination were confirmed by independent reports of trade representatives. It is therefore believed that the data represent the condition of the fruit with fair accuracy. It will be seen that there is little evidence of any definite trend, except that the first few shipments of the season were comparatively free from wastage. It is not certain whether this may be attributed to non-susceptibility of the first shipments through early harvesting or whether the fruit was liable to develop breakdown later in its storage life. In any case, this period of immunity was comparatively brief and by the middle of November shipments which had developed a considerable amount of breakdown began to arrive. Thereafter, there appears to have been little association between the percentage of breakdown in a consignment and the time at which it was shipped. Consignments showing comparatively little wastage continued until late in the season, alternating with shipments in which extensive deterioration occurred.

It should be mentioned here that the chart indicates the percentage of wastage only and bears no relation to the real extent of the injury. Thus some 30 per cent. of breakdown occurred in the last consignment shown, but this shipment was comparatively small; in some earlier shipments in which the percentage of breakdown was less striking, the absolute extent of the injury was very considerable and involved more serious losses.

It is difficult to account for the very wide fluctuations in the extent of breakdown in successive shipments. In the earlier consignments it is possible that the storage temperature during transit was a contributing factor, since breakdown develops more rapidly the higher the temperature. As a rule, however, the disease has developed to its maximum extent in any batch of apples within two months of harvesting, and in the later shipments the carrying temperature would probably have little influence on the extent of breakdown. Further, from a comparison of the Panama and Eastern Canadian cargoes, it does not appear that the method of shipment bears any marked relation to the development of breakdown. From a detailed examination of the information available, it appears that the fluctuations must be attributed principally to differences in the constitution of the shipments. The high points on the chart correspond not only to

shipments containing a high proportion of large and "Extra Fancy" grade fruit, but also to consignments from certain packing exchanges which appeared throughout the season to be shipping fruit more than usually susceptible to breakdown.

Mention was made in a previous report of the wide variation observed during the latter part of the 1926-27 season in the condition of British Columbian Jonathan apples from different localities. The percentage of breakdown in the fruit from various packing exchanges examined at that time is set out below :—

TABLE IX.

Percentage of Breakdown Observed in British Columbian Jonathan Apples from Three Packing Exchanges : Season 1926-27.

Packing Exchange.	No. of Car Lots Examined.	No. of Boxes Examined.	Internal Breakdown (per cent.).
A	5	67	10.8
B	8	63	1.5
C	5	31	.13

It may be remarked that the fruit examined from each exchange was comparatively uniform, consisting of approximately equal quantities of "Extra Fancy" and "Fancy" grade apples of counts ranging from 150 to 234. All the fruit was shipped on the same boats and arrived at Liverpool during January and February, 1927. It is, of course, uncertain how far the shipments examined were representative of the whole season's export. Nevertheless, the breakdown is so much more extensive in the apples from Exchange A than in the fruit from the other exchanges that the difference appears to be significant.

Similar but rather less marked variations in the fruit from different exchanges were noted during the 1927-28 season, when samples of most car-lots of Jonathan apples shipped to Liverpool were examined. The data obtained are set out in Table X below. It is not suggested that the percentages can be taken as a measure of the relative susceptibility to breakdown of the fruit from the different exchanges. The samples were less uniform than during the previous season and

differed widely in respect of time of shipment, grade and size. Here again, however, there appears to be a distinct difference in the behaviour of the fruit from the various localities. In the absence of definite information concerning the earlier history of the fruit, no suggestion can be advanced to account for these variations, but the problem seems of sufficient interest to merit further investigation.

TABLE X.
Percentage of Breakdown Observed in Jonathan Apples from Various Packing Exchanges : Season 1927-28.

Packing Exchange.	No. of Car Lots Examined.	No. of Boxes Examined.	Internal Breakdown (per cent.).
A	4	38	15.5
C	19	112	8.3
D	6	31	4.1
B	14	64	2.7
E	4	21	1.9
F	5	20	0.3
Other Exchanges	26	109	7.4

The above discussion on breakdown in British Columbian Jonathan apples may be summarised briefly as follows:—(a) "Extra Fancy" grade fruit appeared to be more susceptible to breakdown than the lower grades, but no significant difference was observed in the susceptibility of "Fancy" and "C" grade apples: (b) Large apples were more liable to develop breakdown than the smaller sizes: (c) The first few shipments of the season were fairly free from breakdown; otherwise there was little evidence to indicate that the disease became increasingly serious as the shipping season continued: and (d) There was considerable difference in the extent of breakdown in the fruit from the various packing exchanges.

Investigations in British Columbia.—At this stage it will be convenient to include a brief account of the systematic investigations on breakdown carried out by Palmer in British Columbia during the past six years, since the experimental shipment described below is a direct outcome of that work. These investigations are discussed in

detail in the annual reports of the Summerland Experimental Station from 1925 to 1927, and probably constitute the most important contribution yet made to the literature of Jonathan breakdown.

It has been definitely established that the disease is serious only in apples that have passed a certain stage of maturity at the time of picking; earlier harvesting, therefore, appears to be an effective method of control. Determining the optimum harvesting maturity, however, often presents considerable difficulties and investigations have been undertaken to obtain satisfactory criteria for some of the principal varieties. Pressure tests, seed colour and ease of separation from the spur have not proved reliable criteria in the case of the Jonathan variety, and it may be noted that this variety adheres fairly firmly to the tree for some time after it is ready to be picked. The most satisfactory indication of maturity was found to be the gradual yellowing of the unblushed portion of the skin and a colour chart, consisting of three shades ranging from a slightly yellowish green to an almost clear yellow, was devised to facilitate the measurement of this change. Arrangements have been made whereby British Columbian growers may obtain copies of this chart from the Summerland Station.

It was found that no breakdown developed in apples which had not passed Stage 2 of the chart at the time of harvesting. The disease sometimes occurred in fruit picked at a maturity intermediate between Stages 2 and 3, but usually only in apples from trees bearing a light crop; fruit from heavily laden trees often failed to develop breakdown even though it had reached Stage 3 when picked. The greater susceptibility to breakdown of fruit from lightly loaded trees has been verified year after year and it, therefore, appears important to ensure early harvesting of these trees. In commercial practice, the reverse procedure has often been followed. The apples from lightly laden trees are commonly slow in taking on red colour, with the result that there is a tendency to leave them on the trees until after the more highly coloured fruit from the full crop trees has been picked.

Breakdown in Jonathan has also been found to be associated with the amount of water-core present at picking time and it appears advisable to harvest the variety before water-soaked areas develop. Other factors, such as the influence of weather conditions during the growing season, type of soil, irrigation, pruning, thinning and manurial treatment, have been investigated. In general, it appears that anything tending to produce over-vigorous growth in the fruit increases its susceptibility to breakdown.

Temperature appears to be the only storage factor that materially influences the disease. Storage at low temperatures retards its development, but does not prevent it and there is no evidence to suggest that storage conditions are its primary cause. Breakdown usually appears about a month after harvesting and, in the Jonathan variety, it is rare for the disease to continue to develop after two months.

Experimental Shipment of Jonathan Apples.—In the autumn of 1928, an experimental shipment was undertaken, in co-operation with the Summerland Station, in order to test, under commercial conditions, the methods of controlling breakdown outlined in the preceding paragraphs. In this way it was hoped to demonstrate effectively the value of these methods in preventing the disease.

The consignment consisted of 18 boxes of Jonathan apples picked from a commercial orchard at Penticton, British Columbia. Six trees, about 20 years old and growing on a rich, silt loam soil, were set aside for the experiment. A hairy vetch crop had been grown in the orchard for the preceding five or six years and the soil was in excellent physical condition. Irrigation water was applied four times during the summer and the trees had never suffered from lack of moisture. The fertilizing treatment received by each tree since 1925 is set out in Table XI. During this period the trees had been pruned rather heavily and had made a good deal of new growth. The trunk diameter of each tree and the yield in boxes during the four years are shown in Table XI.

TABLE XI.

Experimental Shipment of Jonathan Apples. Pre-Shipment Record.

(a) Fertilizer treatment (Amount of fertilizer applied, in pounds per tree).

Tree Number.	April 1, 1925.	March 16, 1926.	March 16, 1927.	March 30, 1928.
Q2	2K	2K	2K	3K 8N
O4	—	—	2K 6N	3K 8N
U4	—	—	—	8N
S12	5P	5P	5P	6P 8N
O2	—	—	—	8N
U10	5P	5P 5N	5P	6P 8N

Note.—N indicates nitrate of soda ; P indicates superphosphate of lime ; K indicates muriate of potash.

(b) Trunk diameter and yield.

Number.	Trunk Diameter in Inches (1928).	Yield in Boxes (30 lb.) per Tree.				
		1925.	1926.	1927.	1928.	Average.
Q2	9.1	14.5	25	12.5	26.0	19.5
O4	11.2	13.0	17	23.0	14.0	16.7
U4	11.4	22.0	21	21.0	15.5	19.9
S12	10.3	17.0	22	11.0	23.0	18.3
O2	11.1	25.0	18	18.0	33.0	23.5
U10	10.2	13.0	17	10.5	19.0	14.9

Note.—Trees Nos. O2 and O4 unthinned in 1928 ; remainder thinned to one apple to a spur.

It may be noted that the trees were comparatively uniform in size and that, in 1928, two (O4 and U4) carried a crop lower than the average, while the others yielded more fruit than the average during the four-year period.

On 1st October, 1928, a bushel box of apples was gathered from each tree, each lot of fruit being picked from several branches as it was thought that this method of harvesting would have little influence on the remainder of the crop and would ensure a sample representative of the average maturity of the fruit on that date. At the time of picking, an attempt was made to estimate the maturity of the fruit from each tree by means of a colour chart of the type already described ; the results are set out in Table XII. Apples of maturity intermediate between two colour stages are classified as $1\frac{1}{2}$ or $2\frac{1}{2}$, as the case may be. It may be noted that on two trees (O4 and U4) the fruit had already reached an advanced stage of maturity when the first picking was made, while on others (Q2 and O2) it was still quite green. A second picking consisting of two boxes from each tree was made on 22nd October. At that time the fruit had advanced about one stage in maturity, according to the colour chart (Table XII).

The whole consignment of 18 boxes was despatched from the Summerland Station during November, 1928, and shipped to the United Kingdom via Montreal and Southampton as part of a com-

mercial consignment. Exact particulars of the transcontinental rail journey are not available. The fruit was shipped from Montreal on 21st November, arrived at Southampton on the 29th, and was delivered at Covent Garden Laboratory, London, on the 4th December. The temperature in the hold during the voyage, as recorded by thermographs installed by the Canadian Department of Agriculture, rose steadily from 40° F. at the time of loading to rather more than 50° F. on arrival.

A first examination of the consignment was carried out on 5th and 6th December. Each fruit was unwrapped and graded according to maturity, as judged by the standard colour chart. Observations were also taken of the quality and condition of the fruit in each box. Apples rotted by fungi or suffering from breakdown were set aside, while the sound fruit was spread on trays, stored in a cool, dark, underground room, and re-examined on four occasions at monthly intervals. The temperature in this room, as recorded by means of a thermograph, varied only slowly with the outside temperature and for the greater part of the storage period was in the neighbourhood of 42° F.; 47° F. and 35° F. respectively were the highest and lowest temperatures recorded. The doors and windows of the room were kept closed, but did not fit sufficiently tightly to prevent adequate ventilation, and this was further aided by an open chimney. Although no measurements were taken, the humidity of the store was probably fairly high and little shrivelling was noted, except in a few of the least mature apples, until late in the storage period.

The results of the four examinations are set out in Table XII. In this Table the percentages of breakdown and rotting for the second and subsequent examinations are, in all cases, inclusive of those shown in the preceding column and represent the total amount of disease which had developed up to that date. Practically no breakdown, however, developed after the second examination.

It will be seen that the experiment affords a very satisfactory confirmation of the value under commercial conditions of the methods of controlling breakdown suggested by Palmer as a result of his investigations. Extensive breakdown occurred in the late harvested fruit from some trees, but in all instances the earlier gathered apples showed only a negligible amount of the disease.

(cont)

TABLE XII.

Wastage in Experimental Shipment of Jonathan Apples.

Tree No. and Comparative Yield in 1928.	No. of Box.	Date of Harvesting.	Maturity at Time of Harvesting.	No. of Apples in box.	Percentage Breakdown on				Percentage Fungal Rotting on			
					Dec. 6.	Jan. 4.	Feb. 4.	Mar. 8.	Dec. 6.	Jan. 4.	Feb. 4.	Mar. 8.
O2 (140% average)	5	Oct. 1	1 -1 $\frac{1}{2}$	200	0-0	0-0	0-0	0-0	0-0	0-0	1-5	1-5
	15	Oct. 22	2 -2 $\frac{1}{2}$	175	0-0	1-1	1-1	1-1	1-7	2-3	2-3	2-9
	16	Oct. 22	2 -2 $\frac{1}{2}$	138	0-0	0-7	0-7	0-7	0-7	0-7	2-9	3-6
Q2 (133% average)	1	Oct. 1	1 -1 $\frac{1}{2}$	175	0-0	0-0	0-0	0-0	0-0	0-0	2-3	2-9
	7	Oct. 22	2 -2 $\frac{1}{2}$	138	0-0	3-6	3-6	3-6	0-7	0-7	0-7	2-2
	8	Oct. 22	2 -2 $\frac{1}{2}$	113	0-0	1-8	1-8	1-8	0-9	5-3	8-0	8-0
U10 (128% average)	6	Oct. 1	2 -2 $\frac{1}{2}$	125	0-0	0-8	0-8	0-8	0-8	1-6	2-4	4-0
	17	Oct. 22	2 $\frac{1}{2}$ -3	125	0-0	3-2	3-2	3-2	0-8	0-8	1-6	2-0
	18	Oct. 22	2 $\frac{1}{2}$ -3	96	4-2	9-4	9-4	9-4	0-0	2-1	2-1	3-1
S12 (122% average)	4	Oct. 1	2 -2 $\frac{1}{2}$	163	0-0	0-0	0-0	0-0	0-6	0-6	1-2	1-2
	13	Oct. 22	2 $\frac{1}{2}$ -3	125	0-0	0-8	0-8	0-8	0-0	1-6	3-2	4-0
	14	Oct. 22	2 $\frac{1}{2}$ -3	138	0-0	0-0	0-0	0-0	0-7	0-7	0-7	1-4
O4 (84% average)	2	Oct. 1	2 $\frac{1}{2}$ -3	150	0-6	0-6	0-6	0-6	0-0	0-0	2-3	2-3
	9	Oct. 22	3	138	14-5	21-0	21-0	21-0	6-5	10-2	13-0	14-5
	10	Oct. 22	3	113	14-1	31-0	31-0	31-0	4-4	4-4	6-2	7-1
U4 (78% average)	3	Oct. 1	2 $\frac{1}{2}$ -3	125	0-0	0-0	0-0	0-0	0-8	0-8	1-6	1-6
	11	Oct. 22	3	96	17-7	30-2	34-2	34-2	2-1	3-1	3-1	4-2
	12	Oct. 22	3	125	18-4	26-4	27-2	27-2	2-4	2-4	4-0	4-0

33

The distribution of breakdown among the late picked apples from the six trees also follows the lines that would be anticipated from the Summerland experiments. The fruit from trees bearing a heavy crop was fairly resistant to the disease and the percentage of breakdown in these is much lower than in the highly susceptible apples from the lightly laden trees U4 and O4. The evidence in this respect is, however, rather less conclusive than might have been hoped, since the apples from these trees ripened somewhat earlier than any of the others and had definitely reached maturity Stage 3 at the time of picking, while the maturity of the most advanced fruit from the heavily laden trees was classified as only $2\frac{1}{2}$ -3.

A certain amount of fungal rotting occurred in all the boxes of the consignment and continued to develop throughout the storage period. A considerable proportion of the rotting, particularly at the first two examinations, had occurred as the result of slight bruises presumably received in transit, while some was undoubtedly secondary to breakdown. As far as possible, fruits in which the fungal decay had obviously followed breakdown were included under the latter heading, but in some instances the rotting was so advanced that the origin of the infection could not be ascertained. Rots developing late in the storage period often originated at lenticels or calyx and it is probable that a large proportion of the fruit would have succumbed ultimately to this form of attack had the observations been continued.

In addition to the two diseases specified in Table XII, a certain amount of Jonathan spot was present in several boxes.

In general, the quality of the experimental fruit was very good. On arrival the early gathered fruit appeared to have advanced about half a stage in maturity since harvesting, but the late picked fruit showed little change in this respect. Ripening continued during storage and at the end of three months all the apples were fully yellow. Two boxes, however, numbers 1 and 5, definitely appeared to have been picked too early as the apples were deficient in colour, of poor eating quality and showed a certain amount of shrivelling even at the first examination. After two months' storage this shrivelling became very pronounced. It will be observed that these apples had been picked at a maturity corresponding to Stage 1- $1\frac{1}{2}$ of the colour chart. Stage 2- $2\frac{1}{2}$ appears to be the earliest at which Jonathan should be harvested. Apples picked at that stage were of good quality, showing 50 to 80 per cent. of blush, did not develop excessive shrivelling in storage and were suitable for the British market. The fruit

harvested at Stage 2½-3, however, was even more satisfactory in these respects and showed the highest quality of any in the consignment. It may, therefore, be advisable to leave fruit on the tree until it attains this stage of maturity, provided that consideration of the size of the crop and other factors influencing susceptibility suggests that this may be done without risk of breakdown. In this connection, it may be noted that boxes 2 and 3 from the most susceptible trees (O4 and U4) were actually harvested at this stage and failed to develop the injury to any appreciable extent. Nevertheless, the apples picked at Stage 2-2½ were of good quality and in doubtful cases it appears desirable to err on the side of caution and complete harvesting before the fruit has passed that maturity.

Discussion.—The above results, taken in conjunction with the Summerland investigations, suggest very strongly that the extensive losses from breakdown which have been shown to occur in British Columbian Jonathan apples may be largely prevented by earlier harvesting. This appears to be a simple solution to the breakdown problem. In the report of the Summerland Station for 1927, however, attention is drawn to a number of practical difficulties involved :—

“ Numerous complications are encountered in applying it (early harvesting) under commercial conditions. Of special significance is the fact that breakdown seldom makes its appearance until a month or so after the fruit leaves the orchard. This characteristic of the disease makes it very difficult to convince the grower that he is responsible for the injury During the past few years, the majority of growers have made an honest endeavour to arrange their picking programme so as to minimise the danger of loss from breakdown. That their efforts have not been entirely successful seems to be due mainly to two factors. One of these is the fact that many orchards contain heavy plantings of such varieties as McIntosh Red, Grimes Golden and Delicious, which tend to overlap the picking season of the Jonathan and so increase the difficulty of harvesting this variety during the comparatively short season that it remains in satisfactory picking condition. The second factor which has militated against the successful prevention of breakdown has been the lack of an effective maturity test simple enough for the grower to use in the orchard. While the results of this investigation do not indicate that there is any infallible test of this nature, they do suggest that losses from breakdown can be very materially reduced by an intelligent use of the colour chart.”

Further objections to the method of early harvesting may be noted. It has been shown (11) that the diameter of an apple continues to increase at a fairly uniform rate while it remains attached to the tree. Early harvesting, therefore, may adversely affect the yield, in spite of a saving in windfalls. Further, it must be admitted that picking the fruit at a comparatively early stage of maturity may, in some instances, result in a certain loss of quality. It therefore appears desirable to employ the method with discrimination. Fruit from trees bearing a light crop should undoubtedly be harvested before passing a maturity stage corresponding to Shade 2-2½ of the colour chart: heavily laden trees might with advantage be left somewhat later. Special precautions should, however, be taken with the fruit from those localities and packing exchanges which have in the past shown severe losses from breakdown, and further investigations into the causes of the apparent greater susceptibility of this fruit might usefully be undertaken.

Apart from questions of yield, experience has shown that very large or highly coloured "Extra Fancy" grade apples are particularly liable to breakdown, and special attention should be paid to these classes of fruit, or to apples which for any other reason are believed to be susceptible to the disease. As far as possible, it appears desirable that such fruit should be marketed at the beginning of the season, since it has been shown that at ordinary temperatures the disease develops until about a month after harvesting, although this period may be somewhat prolonged by cold storage. If practicable, it would also be advantageous to pack fruit only as it is required for marketing; apples which had developed breakdown could then be graded out immediately before shipment and so kept off the market. Such methods can, however, in no way replace more fundamental methods of control which aim at preventing the occurrence of the disease. Up to the present, the results obtained by early harvesting are extremely promising and it seems probable that, with the co-operation of growers, the Jonathan variety may be successfully marketed without the recurrence of the severe losses which have so adversely affected its reputation in recent years.

(vi) *Other Physiological Diseases.*

Five physiological diseases, other than internal breakdown, have been observed in imported Canadian apples, namely, bitter pit, Jonathan spot, surface scald, soft scald and water core. In most instances, the losses caused by these diseases were not large and only a brief amount of their occurrence need be given in this section.

Bitter Pit.—Bitter pit is a physiological disease which often makes its first appearance on the tree and which continues to develop in storage. The flesh of an affected apple shows a number of small brown spots which, as a rule, are most numerous just beneath the skin towards the calyx end of the fruit; externally they are visible as small sunken areas with a brownish tinge.

The disease has been reported from almost all apple-growing areas, but is especially severe in Australia, where it is the cause of extensive losses in certain varieties, notably Cox's Orange Pippin, Ribston Pippin, Cleopatra and Sturmer (4). Apples that have been picked before reaching full maturity appear to be peculiarly susceptible and for this reason the first few Australian shipments of the season are often extensively pitted; delayed harvesting may therefore be expected to give some measure of control. A detailed account of the disease will be found in a report issued by the Food Investigation Board (14); this publication also contains a bibliography of the scientific literature dealing with the subject.

During the 1927–28 season, bitter pit was observed in a large number of varieties, but its occurrence was never extensive except in British Columbian Cox's Orange Pippins. The limited extent of the disease in other British Columbian varieties, in which only isolated apples were affected, will be seen from the following Table :—

TABLE XIII.
*Percentage of Bitter Pit in British Columbian Apples
Examined 1927–28.*

Variety.	No. of Boxes Examined.	Bitter Pit (per cent.).
Cox's Orange Pippin	36	6
Grimes Golden	42	2
Jonathan	395	Less than 1
McIntosh Red	81	"
Yellow Newtown	50	"
Wealthy	23	"
Delicious	25	None observed
Rome Beauty	25	"
Spitzenberg	30	"
Winesap	52	"

It is probable that the estimate quoted above for the British Columbian Cox's Orange Pippins is somewhat low, as extensive pitting was reported in certain consignments which were not examined by the Board's officers. In this variety the disease was very unevenly distributed, some boxes showing 20 to 30 per cent. of affected apples, while in others none was observed. In general, pitting was most severe in the larger sizes. The disease was by no means confined to the early part of the season, as appears to be the case in certain Australian varieties, and extensive bitter pit occurred in late shipments of Cox's Orange Pippins which arrived towards the end of November. It should be noted, however, that this fruit may have been harvested fairly early in the season and held in storage for some time before shipment; this procedure is seldom adopted in Australia.

Bitter pit has also been observed to a small extent in the following varieties of Nova Scotian and Ontario apples:—Baldwin, Blenheim Orange, Cranberry Pippin, Cox's Orange Pippin, Stark, King, Nonpareil, Rhode Island, Greening, Ribston Pippin. Blenheim Orange and Cox's Orange Pippin appeared to be the most extensively affected varieties, but even in these the percentage of diseased apples was very small and the pitting was seldom sufficiently pronounced to disfigure the fruit at all seriously.

Jonathan Spot.—Several varieties of apples are susceptible to this disease, but it is especially common in the Jonathan variety. The skin of an affected apple develops black or brown spots, which are darker than bitter pit spots and seldom extend appreciably into the flesh of the apple. In the early stages of the disease, only the superficial colour-bearing cells are affected and the spots are very small. Later, the spots may enlarge to a considerable size and become slightly sunken, while the few layers of flesh cells immediately beneath them may become brown. The spots usually occur at lenticels. In the later stages of the disease, rot fungi are often present, species of *Alternaria* being particularly common.

The disease appears to be fairly common in British Columbian Jonathan apples and was observed to a greater or less extent in almost every shipment examined. It is doubtful, however, if the trouble is sufficiently serious to be of any great commercial importance in more than a comparatively few instances. It may be noted that the disease most frequently occurs on the bluish side of the fruit and is, therefore, less apparent on account of the dark red background. As counts were

not taken of its occurrence in the Jonathan apples examined, no estimate can be given of the approximate percentage of apples affected. In other varieties, Jonathan spot was seldom observed.

Surface Scald.—Surface scald is a storage disease which is extremely destructive in the United States, where it is reported to be responsible for greater losses than any other injury. It has been extensively studied in that country by Brooks, Fisher and Cooley (1), who describe it as follows :—

“ In mild cases of scald the apple is merely tinted with brown, the skin remaining firm, but in more severe cases the skin tissue may be broken down to the extent that it sloughs off readily from the underlying flesh Scald differs from all other apple diseases in being more prevalent on the green side of the apple. Bright red fruit surfaces are highly resistant to scald, and yellow surfaces are much more resistant than those that are green or show the first stages of turning from green to yellow An apple that has had its skin killed by scald becomes the ready prey of the various rot organisms, and they soon finish the work of destruction that the scald has begun.”

The most effective methods of control appear to lie in efficient ventilation of the fruit and in the use of wrappers impregnated with mineral oil. The more susceptible, unblushed varieties of British Columbian apples, are as a rule, wrapped in papers which have been treated in this way. American shippers of barrelled apples often strew shredded oiled-paper throughout the barrel. This practice seems likely to be valuable in controlling scald, but is not generally employed in shipments of Ontario or Nova Scotian apples. In these apples, however, the disease never appears to develop to the extent that it attains, for example, in Virginian York Imperial apples. Nevertheless it is frequently observed on Eastern Canadian apples, notably on such varieties as Blenheim Orange, Ribston Pippin, Rhode Island Greening, Baldwin and Stark.

Scald was also occasionally present in the British Columbian shipments examined during the 1927-28 season and was noted in the Grimes Golden, Jonathan, Yellow Newtown, Black Twig and Winter Banana varieties. In general the disease was not serious and only in the case of the two last named varieties was any considerable percentage of the fruit affected. These apples were included in three direct shipments via the Panama Canal which arrived towards the end

of the season. In each instance, the consignments were small and the matter did not therefore assume the importance it might have done had larger quantities been shipped.

Soft Scald.—Soft scald is one of the less common storage diseases and one that appears to affect only a few varieties of apples, notably Rome Beauty and Jonathan. In the earlier stages of the disease, the skin only is involved. Later, the injury is characterised by irregular but sharply defined areas of soft, light brown tissue which may extend a considerable distance into the flesh and cover the greater part of the surface of the fruit. The portions of the apple adjacent to the stem and calyx seem, however, to be immune, and, in the most seriously affected apples, the soft scald extends round the fruit in an irregular band. After a certain stage of development, no further extension of the affected areas occurs and the diseased tissue dries up and becomes sunken. The injury appears to be connected with storage at too low a temperature.

Only one outbreak of soft scald was observed during the 1927–28 season; this occurred in “C” grade Jonathan apples. The disease did not appear to be serious and only three examples were discovered in seventeen cases from the affected carlot. Two of the apples were practically girdled by the diseased tissue, which had extended to about one-eighth of an inch into the flesh; the third apple was only slightly affected on one side. Soft scald is more common on Jonathan apples from Australia and New Zealand and fuller references to the injury will be found in an earlier report (4) dealing with fruit from these countries.

Water Core.—Water core is a condition characterised by the development of translucent, water-soaked areas in the flesh of the apple. As its name implies, these areas usually occur in the neighbourhood of the core and can then only be detected by cutting the fruit. Occasionally, however, they are found near the surface, giving rise to the condition known in the Trade as “glass eye”, on account of the transparent appearance of the skin above the affected tissue.

Water core occurs mainly in fruit which has been left on the tree, and earlier harvesting would, therefore, materially reduce its incidence. In storage, the condition tends to disappear after a time, but affected apples are somewhat susceptible to breakdown (cf. page 29 above).

The injury does not appear to be of great importance in imported Canadian apples. It has sometimes been noted in association with breakdown in British Columbian Jonathan apples, while occasional examples of the external form have been met with in several varieties from all three apple shipping provinces.

III.—OTHER FRUITS.

(i) *Pears.*

Comparatively small but fairly regular shipments of Canadian pears arrive on the United Kingdom market from about mid-September until the end of November. Ontario and British Columbia supply the greater part of the fruit, but small quantities of barrelled pears are also shipped from Nova Scotia (Appendix II). No extensive observations on the condition of the fruit have been made, and the following notes refer only to a number of shipments, mainly from Ontario, examined during the 1927 season.

Three different methods of packing were noted. The greater part of the fruit examined was shipped in boxes resembling the standard apple case, but rather smaller, its internal measurements being 18 inches by 11½ inches by 9½ inches. The pears were individually wrapped in paper and packed in the boxes in standard counts. Others, again wrapped, were packed somewhat similarly in flat trays which were wired together in bundles of two or three to form a crate. These methods of packing appeared well adapted for the export of pears, both from the point of view of protection of the fruit and its appearance. Considerable quantities were also shipped in barrels or half barrels: this method did not appear to be altogether suitable for pears on account of their relative softness on reaching maturity, and, as a rule, the best quality fruit was not packed in this way.

Most of the Ontario pears examined arrived in good condition and their quality and appearance were often excellent. In one or two shipments, cases of over-ripe and sleepy pears were observed, the varieties most frequently affected in this way being Bartlett and Clapp's Favourite. With the exception of a little fungal rotting, principally in the riper shipments, no other wastage was noted. The condition of the principal Ontario varieties examined is summarised in Table XIV. Comparatively few pears from other Provinces were examined.

TABLE XIV.
Condition of Ontario Pears Examined, 1927.

Variety.	Total No. Cases Examined.	No. Cases containing Firm, Green Pears.	No. Cases containing Pears beginning to Soften.	No. Cases containing Over-ripe or Sleepy Pears.
Bartlett	62	21	39	2
Keiffer	15	7	8	0
Duchesse	12	12	0	0
Beurre Clairgau	10	7	3	0
Clapp's Favourite	7	1	1	5
Other Varieties	22	15	7	0

(ii) *Plums.*

The export of Canadian plums to the United Kingdom is a comparatively recent development of the fruit industry and may be regarded as being still, to a large extent, in the experimental stage. It was therefore thought of interest to obtain information on the condition of these early consignments both on and after arrival. Preliminary observations were carried out during 1927 and the work was extended in the following season, when nearly every shipment reaching the United Kingdom was examined. At the end of the 1928 shipping season, a report summarising the results of the observations was prepared for the Canadian Fruit Branch.

The methods adopted for the survey closely resembled those followed in the case of shipments of apples. The plums were first examined at the docks or shortly after arrival at the merchants' warehouses, when notes were taken of the quality and maturity of the fruit, the nature and extent of the wastage present and other matters of interest. In addition, many samples were retained under observation in the laboratory to determine the behaviour of the fruit after its removal from the ships' refrigerators. For this purpose, half the fruit was, as a rule, examined at once and spread on trays to be re-examined from time to time: the remaining half was left undisturbed for about a week, when its condition was compared with that of the fruit previously unpacked. In this way allowance was

made for any wastage caused by the extra handling of the fruit spread on trays. Both sets of fruit were stored at ordinary room temperature in the neighbourhood of 60° F. The results of the observations are discussed below and are summarised in Appendix III.

One consignment of British Columbian Italian Prunes was encountered during the survey, but with this exception all the fruit examined originated from Ontario and had been shipped by two packing houses only. These are referred to in Appendix III as "Marks" A and B. The quantities shipped during the two seasons under review are set out in Appendix II.

All consignments of plums examined during the survey were shipped in refrigeration and in many instances thermographs were installed to record the temperatures in the cool chambers. From the thermograph charts it appears that the carrying temperatures were usually fairly low. In several instances an even temperature from 34° F. to 36° F. was registered, while in only one case was a temperature higher than 40° maintained for any considerable time.

Packing.—Canadian plums were exported in two types of package. In some cases the fruit was shipped in a flat tray in which the plums were packed in one or two layers, each plum being wrapped in paper and protected with wood wool. Three such trays were wired together to form a bundle. This type of package was used only for high-grade fruit and appeared to be effective in protecting the plums from mechanical injury, no bruises or cuts being noticed on any fruits packed in this way.

More frequently, the fruit was packed in a crate with complete sides and top but with a skeleton bottom constructed of laths. Two crates were wired together to form a bundle. Each crate contained four square chip-punnets with tin tops in which the fruit was packed in one of three ways :—(a) the plums were individually wrapped in paper and packed in regular layers ; (b) the plums were not wrapped, but were packed in layers separated by a continuous strip of paper ; and (c) the plums were not wrapped and jumble-packed in the punnets. Apart from occasional slight bruises in the top layer, the individually wrapped plums showed little injury and the paper appears to be fairly effective in preventing contact rots and in reducing shrivelling. The plums packed without paper wrappings showed considerably more injuries. The fruit was often damaged by the tin tops of the punnets or by the stems of adjacent plums, and these injuries were frequently

followed by fungal rotting. In addition, contact rots were fairly common in the unwrapped fruit and in a few instances small nests of rotted plums were observed. Some measure of separation was effected by interposing a paper strip between the layers, but this method was less satisfactory than individual wrapping. On the whole it appears desirable to employ paper wrappings for plums intended for export, except where the small size of the fruits would render this impracticable.

Condition of the Fruit.—Considerable variation was apparent in the condition of the plums when examined on arrival. Some consignments were rather over-ripe and had already developed extensive wastage when first unloaded, but in the majority of instances the fruit was in fairly sound condition and of fresh and attractive appearance. It was often found, however, that the more sound consignments were somewhat firm and unripe on arrival and were consequently of poor eating quality. Frequently a week elapsed before samples of such fruit became satisfactory in this respect, when it was by no means unusual for extensive wastage to have developed. In some instances the plums appeared to have been picked at rather too early a stage of maturity and they did not attain satisfactory eating quality even after a lengthy period of storage. Nevertheless, samples of several consignments ripened successfully without excessive deterioration.

The wastage observed was of two distinct types. Rotting by various fungi, notably *Sclerotinia* *sp.*, accounted for the greater part of the wastage in most consignments; but serious losses also occurred from a type of physiological breakdown. The two forms of wastage are considered separately in the succeeding paragraphs.

Fungal Rotting.—It will be seen on reference to Appendix III that very extensive wastage from Brown Rot frequently occurred in samples retained under observation. The injury was also observed at dock examinations and was sometimes serious even at that stage. It is caused by a species of *Sclerotinia* (15), perhaps the most destructive and most difficult to control of all fungal diseases of stone fruits. In some instances, the fungus had invaded the fruit at the stem end, at wounds caused by the skin splitting or at some mechanical injury, but, as a rule, no definite point of ingress was apparent, the rot developing on any portion of the surface. Where the fruits were not individually wrapped, the fungus often appeared

to have spread by contact, many adjacent rots and a few nests of rotted plums being noted. The rot first appeared as a small, dark brown, decayed spot, which gradually increased in size until the whole fruit was involved. Before this stage was reached, however, small tufts of brownish grey spores usually appeared on the surface of the plums.

The fungus occurs in the orchard where it attacks shoots, leaves and blossoms as well as fruits and, to be effective, control measures must be applied at that stage. The methods usually advocated include spraying, dusting with sulphur, the removal of infected shoots and mummies from trees and ground, and cultivation of the soil prior to blossoming and after pruning. For a more detailed account reference should be made to certain publications (2, 12) quoted in the list of references on page 53.

A small amount of rotting caused by *Rhizopus nigricans*, *Penicillium sp.* and *Alternaria sp.* was also observed, but an exhaustive mycological examination of the plums was not attempted and it is possible that other fungi were also present. *Rhizopus nigricans* was occasionally seen on decayed plums in conjunction with *Sclerotinia* and usually appeared to be secondary to the latter fungus. A typical, wet rot was produced and, later, greyish white mycelia and large, black, spore-bearing pustules appeared on the surface. *Rhizopus nigricans* was also observed as a primary stem end rot on British Columbian Italian Prunes. *Penicillium sp.* sometimes occurred secondary to *Sclerotinia*, and, in addition, caused a few rots in plums which had previously received mechanical injuries. The most extensive wastage caused by this fungus, however, occurred on British Columbian Italian prunes, principally as a stem end rot. The wastage in this fruit did not develop until it had been removed from the ship's refrigerator for a considerable time, but a fortnight after discharge amounted to some 30 per cent. A few stem end rots due to *Alternaria sp.* occurred on the prunes, this being the only example observed of wastage resulting from that fungus.

In some consignments, an attempt had been made to control fungal rotting by dusting the surface of the plums with sulphur. No comparative observations to ascertain the effect of this treatment were possible, but in some instances extensive rotting had developed on the dusted fruit.

Physiological Wastage.—In addition to fungal rotting, considerable losses occurred in some varieties through a physiological type of breakdown often spoken of as “bladdery breakdown.” This was the principal source of wastage in Burbank plums, where it was very extensive, but other varieties suffering to some extent included Greengage, Monarch, Quackenboss, Shiro and Yellow Egg. The disease has also been observed on imported South African plums (5). The affected plums became extremely soft and their “dead,” “bladdery” feel gave the impression that they had degenerated into a liquid sludge held together by the skin. The injury was also characterised by the dark, translucent appearance of the skin above the affected tissue. The diseased flesh was insipid, but not noticeably abnormal in taste. In some instances, only one side of the plum developed breakdown while the other portion of the flesh remained moderately firm and normal in texture, a fairly definite demarcation existing between the healthy and affected tissue. This tendency was most common in the Shiro and Greengage plums. Plums suffering from breakdown became very susceptible to the invasion of fungi, particularly *Sclerotinia*, and secondary rot usually developed shortly after the onset of the physiological disease.

With the information at present available, no suggestion can be advanced to account for the development of this disease. The trouble may have been due to unsuitable storage conditions in transit, harvesting at too early or too late a stage of maturity, or to some other factor. On the other hand, the condition may represent normal over-ripeness and senescence in the varieties susceptible to it. Definite information on the causal conditions and methods of control is, however, essential for the successful shipment of Canadian plums, particularly of the Burbank variety and it is probable that this information will be more easily obtained by experiments in Canada than by a series of experimental shipments. It is suggested that storage tests should be carried out at different temperatures with plums picked at various stages of maturity in order to ascertain whether any measure of control may be obtained, and to gain some idea of the storage life under varying conditions of different varieties of plums. These tests should include observations on the condition of the fruit some days after its removal from refrigeration.

Other Types of Deterioration.—In addition to the types of wastage described above, a small amount of freezing injury was observed on one shipment of Shropshire damsons. On removal from the hold a

few of the plums were seen to be encrusted with ice. Several of these fruits were retained under observation and after some hours in a warm room the tissue immediately beneath the skin became soft and semi-liquid, though the more deep-seated tissue remained fairly normal. The plums were retained for a week and then dissected. At that time no fungal rots had developed and the condition of the fruit appeared unchanged.

Deterioration after arrival.—The results of a number of storage tests are summarised in Appendix III. It will be seen that different samples of fruit varied considerably in their behaviour after removal from the ship's refrigerated chambers, but that in many instances deterioration was fairly rapid. It therefore appears important that shipments of plums should be moved into consumption with the least possible delay after unloading.

It should be emphasised that the data are not sufficient for a satisfactory comparison to be made of the carrying qualities of the different varieties. Samples taken from a number of commercial shipments will necessarily vary widely in many respects and it is evident that wastage, where present, may have been due to unsuitable harvesting, transport or other conditions rather than to poor keeping quality inherent in the variety.

Discussion.—Comparatively few workers appear to have investigated the storage qualities of plum varieties. After a fairly extensive series of storage trials with Californian plums Overholser (9) recommended the following varieties as suitable for shipment under refrigeration :— Kelsey, Wickson, Prune d'Agen, Grand Duke, Satsuma, Pond's Seedling, Climax, Tragedy Robe de Sergeant and Beauty. Experience with South African plums has indicated Kelsey, Santa Rosa, Gaviota and Beauty as some of the best shipping varieties. It is not known how many of the above varieties are grown in Canada.

It is unlikely that very extensive fungal rotting can take place during the short voyage from Canada at the relatively low temperatures recorded in the holds. Further, little relation has been observed between the carrying temperatures and the condition of the fruit on arrival, somewhat ripe and wasty cargoes having been sometimes discharged from holds in which very low temperatures were recorded. It therefore appears probable that wastage was in some cases connected with high pre-shipment temperatures and it may be suggested that pre-cooling and rapid shipment might effect considerable improvement in the condition of the fruit.

It may also be noted that some consignments appeared to have been harvested at too early a stage of maturity, since the fruit did not ripen satisfactorily after its removal from refrigeration. If later picking is found desirable to ensure good eating quality, pre-cooling and rapid transport at carefully controlled temperatures would appear to be even more necessary for successful shipment. During 1927, an experimental consignment of Burbank plums was shipped to this country, all but a few cases having been pre-cooled. On this occasion the shipping temperatures were rather high; both sets of plums were rather too ripe on arrival and deteriorated rapidly from breakdown and brown rot. At all times, however, the pre-cooled fruit was firmer and in better condition, while its rate of wastage was considerably less rapid than that of the untreated plums (Appendix III). No information is available as to how far pre-cooling was adopted during 1928.

The above observations may be summarised briefly as follows:—

(a) Most consignments of Canadian plums shipped to the United Kingdom during the two seasons under review arrived in fairly sound condition, but the fruit often deteriorated rapidly after its removal from refrigeration. (b) Brown rot was the most serious type of wastage in most shipments and more effective control of this disease is essential for the successful export of Canadian plums. (c) Considerable losses also occurred in some varieties, notably Burbank, through a type of physiological breakdown and it is suggested that experiments should be undertaken in Canada to determine whether this can be controlled by suitable harvesting and storage procedure. (d) In some instances, the plums failed to attain satisfactory eating quality, even when fully ripened, and it appeared probable that they had been picked at too early a stage of maturity. (e) Pre-cooling and rapid shipment at carefully controlled temperatures appear to be desirable to reduce wastage, more particularly if later picking is found necessary. (f) The packing of the plums was generally satisfactory, but it is recommended that the fruits should always be individually wrapped in paper, unless their small size renders this impracticable.

(iii) *Peaches.*

Comparatively few consignments of Canadian peaches were shipped to the United Kingdom during the past two seasons. Most shipments were examined at the docks or markets and, in some instances, small

samples were retained under observation. All the peaches examined had been consigned by one shipper and were of the Elberta variety. Each fruit was wrapped in tissue paper and packed with wood wool in flat wooden trays, similar to those used for the shipment of plums, three trays being wired together to form a crate. The type of package appeared to be very suitable and comparatively few injuries were noticed, though some peaches were slightly bruised by adjacent fruits. This bruising would have been prevented if a layer of wood wool had been placed between the individual peaches, a precaution always adopted by South African packers.

The fruit was normally shipped under refrigeration, but in the case of one consignment of 200 trays despatched during 1927, 180 trays were carried in this way and the remainder in ordinary stowage. On this occasion, the cool-stored peaches arrived in good condition, while those carried without refrigeration were over-ripe and showed up to 50 per cent. wastage.

When first discharged, most of the consignments were very firm, slightly unripe and practically free from wastage. The samples retained under observation did not become sufficiently ripe for consumption until several days after their removal from the ship's cool store, by which time a considerable amount of wastage had developed. In some instances, the fruit did not attain satisfactory eating quality, even after continued storage; the flesh remained somewhat dry and the flavour was poor. This may have been due to picking the fruit at too early a stage of maturity.

The wastage developing in the peaches retained under observation was entirely due to fungi. As in the case of plums, *Sclerotinia* sp. was responsible for the greater part of the wastage, producing a firm, brown rot which later became black. A few peaches developed soft, wet rots caused by *Rhizopus nigricans* or *Penicillium* sp.; these fungi also sometimes invaded fruits which had been previously attacked by *Sclerotinia*. In many instances, fungal infection originated at the wound caused by the removal of the stalk; other rots appeared to have developed at slight bruises or by direct penetration of the epidermis.

The following table shows the rate of development in a sample of peaches from a shipment which arrived at Liverpool in October, 1928, and may be taken as typical of the behaviour of the peaches retained

under observation. On this occasion, the eating quality of the fruit was not satisfactory until the fourth examination, nearly two weeks after arrival :—

TABLE XV.

Ontario Elberta Peaches, Liverpool, 8th October, 1928.
Development of Wastage in Sample Retained under Observation.

Type of Wastage.	Percentage of Wastage.				
	Fruit Spread on Trays (120 peaches).				Undisturbed Fruit (64 peaches).
	Oct. 11.	Oct. 13.	Oct. 16.	Oct. 21.	Oct. 21.
Sclerotinia ..	1	15	31	68	44
Penicillium ..	Nil.	Nil.	1	4	2
Rhizopus ..	Nil.	Nil.	1	2	5
Total ..	1	15	33	74	51

In general it appears that, as in the case of plums, pre-cooling and rapid shipment at carefully controlled temperatures are essential for the carriage of peaches. The success of South Africa in marketing both fruits in the United Kingdom suggests that there should be no insuperable difficulty in shipping them the shorter distance from Eastern Canada.

IV.—SUMMARY.

Apples.

(1) In some consignments of Canadian apples examined on arrival, fairly extensive deterioration due to fungal rotting, scab, and internal breakdown was observed. Other types of wastage noted include bitter pit, Jonathan spot, surface scald, soft scald and water core.

(2) Fungal rotting appears to be the most serious cause of deterioration, particularly in barrelled apples, where extensive

mechanical injuries, apparently sustained in packing, greatly facilitate the ingress of fungi. It seems important that "pressing down" and other packing processes likely to injure the fruit should be reduced to the minimum compatible with securing a pack sufficiently firm not to settle away from the head of the barrel. As conditions inside the barrel are particularly favourable to the development of rotting, packing should be delayed until the latest possible date before shipment.

Over-mature apples are liable to develop rotting very rapidly when packed in barrels and should not be shipped long distances in this type of package.

(3) A large proportion of Eastern Canadian apples of the lower grades are seriously disfigured by scab. The control of this disease appears to be one of the most serious problems of the industry and further efforts in that direction are urgently necessary. Relatively little scab was observed in British Columbian shipments.

(4) Internal breakdown, mainly it appeared of the Jonathan type, was observed in many varieties of apples from all provinces and was responsible for serious losses in British Columbian Jonathan apples. The first few shipments of this variety were fairly free from the disease; otherwise, though later shipments varied in the extent of breakdown, there was little evidence to indicate that it became increasingly serious as the season advanced. It was noted that, in general, breakdown was more severe in "Extra Fancy" than in lower grade fruit and in large than in small apples. There was considerable difference in the extent of breakdown in the fruit from the various packing exchanges; this is a matter which might usefully be further investigated in Canada.

(5) An experimental shipment was carried out in co-operation with the Summerland Experimental Station to test under commercial conditions the efficacy of early harvesting as a method of controlling breakdown. Satisfactory control of the disease was obtained in the early-harvested fruit; most of the later picked samples developed breakdown to a greater or less extent. Apples from lightly laden trees proved more susceptible than apples from trees bearing a heavy crop.

(6) Fairly extensive bitter pit was observed in British Columbian Cox's Orange Pippins and the disease was also noted, though to a less extent, in several other varieties from all provinces. It appears from investigations on Australian fruit, that apples picked before

reaching full maturity are particularly susceptible to the disease ; delayed harvesting may, therefore, be expected to provide some measure of control.

Pears.

(7) Only pears from Ontario were examined in quantity ; a few consignments were over-ripe, but the majority arrived in sound condition. The method of packing in boxes and trays was generally satisfactory ; packing in barrels appeared less suitable on account of the relative softness of the fruit and its liability to injury when mature.

Plums.

(8) Most consignments of plums were fairly free from wastage on arrival, but often deteriorated rapidly after removal from refrigeration. Brown rot was the most serious type of wastage and more effective control of this disease is essential for the successful export of Canadian plums.

(9) Considerable losses also occurred in some varieties, notably Burbank, through a type of physiological breakdown, and it is suggested that experiments should be undertaken in Canada to determine whether this can be controlled by suitable harvesting and storage procedure.

(10) In some instances the plums failed to attain satisfactory eating quality, even when fully ripened, and it appeared probable that they had been picked at too early a stage of maturity.

(11) Pre-cooling and rapid shipment at carefully controlled temperatures are desirable, more particularly if later picking is found to be necessary.

(12) It is recommended that the fruits should always be individually wrapped in paper, unless their small size renders this impracticable.

Peaches.

(13) Most consignments of peaches were firm, slightly unripe and in sound condition when first discharged ; but samples retained under observation did not become sufficiently ripe for consumption till some time after removal from the ship's cool store when fairly extensive wastage had developed. Wastage was mainly due to brown rot.

(14) The packing was generally satisfactory, but a few peaches were slightly bruised by adjacent fruits. This could be avoided by placing a layer of wood wool between the individual peaches.

ACKNOWLEDGMENTS.

The Board's Officers were in close touch with Mr. G. E. McIntosh, Dominion Fruit Commissioner, during his visit to the United Kingdom in 1927 and are indebted to him for valuable information regarding cultural, grading and marketing practice in the Dominion. They also desire to record their appreciation of the assistance rendered during the course of the survey by Mr. J. Forsyth Smith, Canadian Government Fruit Trade Commissioner, and by the staff of the Low Temperature Research Station, Cambridge.

Acknowledgment and thanks for facilities afforded is due to the Port of London Authority, Mersey Docks and Harbour Board, Liverpool Port Sanitary Authorities and City Markets Department, Shipping Companies, and members of the wholesale and retail Fruit Trades at London, Liverpool and Southampton.

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APPENDIX I.

VARIETIES OF CANADIAN APPLES EXAMINED DURING THE SURVEY.

Nova Scotia.

Baldwin.	Maiden's Blush.
Ben Davis.	Mann.
Black's Red.	Nonpareil.
Blenheim Orange.	Northern Spy.
Cox's Orange Pippin.	Northern Star.
Cranberry Pippin.	Ontario.
Duchess of Oldenburg.	Pewaukee.
Dudley.	Red Russett.
Early Williams.	Red Stark.
Emperor.	Rhode Island Greening.
Fallowater.	Ribston Pippin.
Gano.	Rome Beauty.
Golden Russet.	Salome.
Gravenstein.	Seek.
Grimes Golden.	Stark.
Hubbardston.	Wagener.
Hurlbert.	Wealthy.
Jonathan.	Wellington.
King.	Winter Banana.
King Pippin.	Wolf River."

Ontario.

Baldwin.	Mann.
Baxter.	McIntosh Red.
Ben Davis.	Northern Spy.
Canada Red.	North Western Greening.
Cranberry Pippin.	Ontario.
Fallowater.	Pewaukee.
Golden Russet.	Rhode Island Greening.
Greening.	Salome.
Grimes Golden.	Snow.
Jonathan.	Stark.
King.	

British Columbia.

Arkansas Black.	King David.
Baldwin.	McIntosh Red.
Ben Davis.	Northern Spy.
Canada Red.	Rome Beauty.
Cox's Orange Pippin.	Snow.
Delicious.	Stayman Winesap.
Esopus Spitzenberg.	Wealthy.
Golden Russet.	Winesap.
Grimes Golden.	Winter Banana.
Jeffries.	Yellow Newtown.
Jonathan.	

APPENDIX II.

Exports of Canadian Fruits to Europe, 1927-28 and 1928-29.

Apples.

Province.		United Kingdom Ports.					Con- tinen- tal Ports.	Destination not stated at Time of Shipment.	Total.
		London.	Liverpool.	Glasgow.	Man- chester.	Other Ports.			
Nova Scotia (Barrels)	1927-28	193,770	154,500	30,800	93,900	37,100	200	Nil	510,270
	1928-29	254,900	164,500	23,800	68,900	43,600	82,200	Nil	637,900
Ontario (Barrels)	1927-28	1,000	29,300	14,100	300	5,800	1,800	Nil	52,300
	1928-29	1,300	22,600	3,300	500	6,000	7,900	Nil	41,600
British Columbia (Boxes)	1927-28	15,000	73,000	137,100	5,500	25,900	24,000	68,300	348,800
	1928-29	45,200	219,400	299,300	20,400	195,800*	54,200	13,000	847,300

* Includes 140,000 boxes shipped to Southampton.

Other Fruits.

Season.	Pears.				Plums.		Peaches.
	Nova Scotia.	Ontario.		British Columbia.	Ontario.	British Columbia.	Ontario.
1927-28	(Barrels.) 600	(Barrels.) 1,100	(Boxes.) 2,200	(Boxes.) 5,500	(Packages.) 1,900	(Packages.) Nil	(Packages.) 200
1928-29	1,250	600	8,200	11,000	18,850	400	1,500

Note.—The above tables are compiled from cabled advices of shipments received from the Canadian Government Fruit Trade Commissioner. Half barrels are expressed in terms of barrels.

APPENDIX III.

Development of Wastage in Canadian Plums Retained under Observation (1928).

(a) Ontario.

Variety.	Date of Arrival.	Sample.	Type of Wastage.	Percentage of Wastage.				
				(i) Fruit spread on Trays.			(ii) Undisturbed Fruit.	Combined Sample.
Black Diamond	Oct. 1	<i>Mark A.</i> † * (i) 108 plums (ii) 108 „	Brown Rot	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				2	7	11	13	—
Burbank	Sept. 19 (1927).	<i>Mark A.</i> Pre-cooled fruit : (i) 110 plums Fruit not pre-cooled : (i) 107 plums	Brown Rot and Breakdown Do.	Sept. 19.	Sept. 21.	Sept. 24.	—	—
				5	6	26	—	—
	Sept. 17	<i>Mark A.</i> (i) 100 plums	Breakdown Brown Rot Total Wastage	Sept. 19.	Sept. 21.	—	—	—
				32 4	92 6	—	—	—
				36	98	—	—	—
	Sept. 17	<i>Mark B.</i> (i) 233 plums	Brown Rot Breakdown Total Wastage	Sept. 19.	Sept. 24.	—	—	—
				8 12	12 57	—	—	—
				20	69	—	—	—

† All the Ontario plums were shipped by two packing houses, which are referred to here as "Mark A" and "Mark B".

* In this column (i) indicates the sample spread on trays; and (ii) the sample left undisturbed (see page 42).

APPENDIX III—*continued.*

Variety.	Date of Arrival.	Sample.	Type of Wastage.	Percentage of Wastage.				
				(i) Fruit spread on Trays.			(ii) Undis- turbed Fruit.	Com- bined Sample.
Grand Duke	Oct. 1	<i>Mark A.</i> (i) 112 plums (ii) 116 "	Brown Rot	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				5	7	7	3	—
	Oct. 29	<i>Mark A.</i> (i) 180 plums	Brown Rot	Oct. 31.	Nov. 5.	Nov. 14.	—	—
				21	34	61	—	—
	Oct. 29	<i>Mark B.</i> (i) 337 plums	Brown Rot	Oct. 31.	Nov. 5.	Nov. 14.	—	—
				22	54	81	—	—
Greengage	Sept. 3	<i>Mark A.</i> (i) 174 plums (ii) 165 "	Brown Rot Breakdown	Sept. 4.	Sept. 6.	Sept. 10.	Sept. 11.	Sept. 15.
				2	2	2	0	17
			8	10	32	22	50	
			Total Wastage	10	12	34	22	67
	Oct. 1	<i>Mark B.</i> (i) 208 plums (ii) 190 "	Brown Rot	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				20	22	25	38	—
	Oct. 15	<i>Mark B.</i> (i) 141 plums (ii) 151 "	Brown Rot	Oct. 19.	Oct. 23.	—	Oct. 23.	Oct. 31.
				7	20	—	36	44
	Oct. 29	<i>Mark A.</i> 200 plums	Brown Rot	Oct. 31.	Nov. 5.	Nov. 14.	—	—
				22	33	67	—	—
Lombard	Oct. 1	<i>Mark A.</i> (i) 194 plums (ii) 187 "	Brown Rot	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				24	41	50	33	—

APPENDIX III—*continued.*

Variety.	Date of Arrival.	Sample.	Type of Wastage.	Percentage of Wastage.				
				(i) Fruit spread on Trays.			(ii) Undis- turbed Fruit.	Com- bined Sample.
Monarch	Sept. 24	<i>Mark A.</i> (i) 274 plums	Brown Rot	Sept. 26.	Sept. 29.	Oct. 4.	—	—
				22	54	86	—	—
	Oct. 16	<i>Mark A.</i> (i) 107 plums (ii) 108 „	Breakdown Brown Rot	Oct. 19.	Oct. 23.	—	Oct. 23.	Oct. 27.
				14 45	17 64	— —	8 75	17 81
		Total Wastage	59	81	—	83	98	
Niagara . .	Sept. 17	<i>Mark A.</i> (i) 200 plums	Brown Rot	Sept. 19.	Sept. 21.	Sept. 24.	—	—
				42	51	66	—	—
	Sept. 24	<i>Mark A.</i> (i) 89 plums (ii) 102 „	Brown Rot	Sept. 26.	Sept. 29.	Oct. 3.	Oct. 3.	Oct. 8.
			11	33	74	81	94	
Orleans . .	Sept. 17	<i>Mark A.</i> 341 plums	Brown Rot	Sept. 19.	Sept. 21.	Sept. 24.	—	—
				13	30	47	—	—
	Sept. 24	<i>Mark A.</i> 398 plums	Brown Rot	Sept. 26.	Sept. 29.	—	—	—
			90	98	—	—	—	
Pond's Seedling	Sept. 24	<i>Mark A.</i> 171 plums	Brown Rot	Sept. 26.	Sept. 29.	—	—	—
				86	99	—	—	—
Quacken- boss	Oct. 1	<i>Mark A.</i> (i) 95 plums (ii) 93 „	Brown Rot Breakdown	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				5 0	22 0	24 50	29 52	— —
				Total Wastage	5	22	74	81

APPENDIX III—*continued.*

Variety	Date of Arrival.	Sample.	Type of Wastage.	Percentage of Wastage.				
				(i) Fruit spread on Trays.			(ii) Undis- turbed Fruit.	Com- bined Sample.
Shiro ..	Sept. 3	<i>Mark A.</i> (i) 99 plums (ii) 99 "	Brown Rot Breakdown	Sept. 4.	Sept. 6.	Sept. 10.	Sept. 10.	Sept. 15.
				2 0	2 0	3 10	3 20	5 28
		Total Wastage	2	2	13	23	33	
Shropshire Damson	Oct. 16	<i>Mark A.</i> 977 plums	Brown Rot	Oct. 19.	Oct. 23.	Oct. 31.	—	—
				9	14	19	—	—
Yellow Egg	Sept. 24	<i>Mark A.</i> (i) 97 plums (ii) 89 "	Brown Rot Penicillium Breakdown	Sept. 26.	Sept. 29.	Oct. 3.	Oct. 3.	Oct. 8.
				11 0 0	30 0 0	63 0 0	48 0 0	76 1 10
				Total Wastage	11	30	63	48	87
	Oct. 1	<i>Mark A.</i> (i) 174 plums (ii) 174 "	Brown Rot	Oct. 4.	Oct. 6.	Oct. 9.	Oct. 9.	—
				36	56	80	75	—

(b) British Columbia.

Italian Prune	Oct. 1	(i) 220 plums (ii) 186 plums	Brown Rot Penicillium Rhizopus Alternaria	—	Oct. 2.	Oct. 8.	Oct. 8.	Oct. 16.
				—	1	1	2	2
—	0	3	2	33				
—	0	0	0	2				
—	0	0	0	1				
Total ..	—	1	4	4	38			

NOTE.

The Board issues for the benefit of Empire fruitgrowers "Weekly Fruit Intelligence Notes" giving early information as to fruit supplies, shipments, crop conditions, official and unofficial crop forecasts, etc., in all the principal fruit-producing countries of the world. Fruitgrowers interested will be placed on the list for circulation on application to the Secretary, Empire Marketing Board, 2, Queen Anne's Gate Buildings, London, S.W.1.

E.M.B. 31.



THE PRODUCTION OF TUNG OIL IN THE EMPIRE

MEMORANDUM PREPARED BY
THE IMPERIAL INSTITUTE

WITH THE CO-OPERATION OF THE
TUNG OIL SUB-COMMITTEE OF
ITS ADVISORY COMMITTEE

ON OILS AND OILSEEDS

AND ISSUED BY

THE EMPIRE MARKETING BOARD



JUNE, 1930

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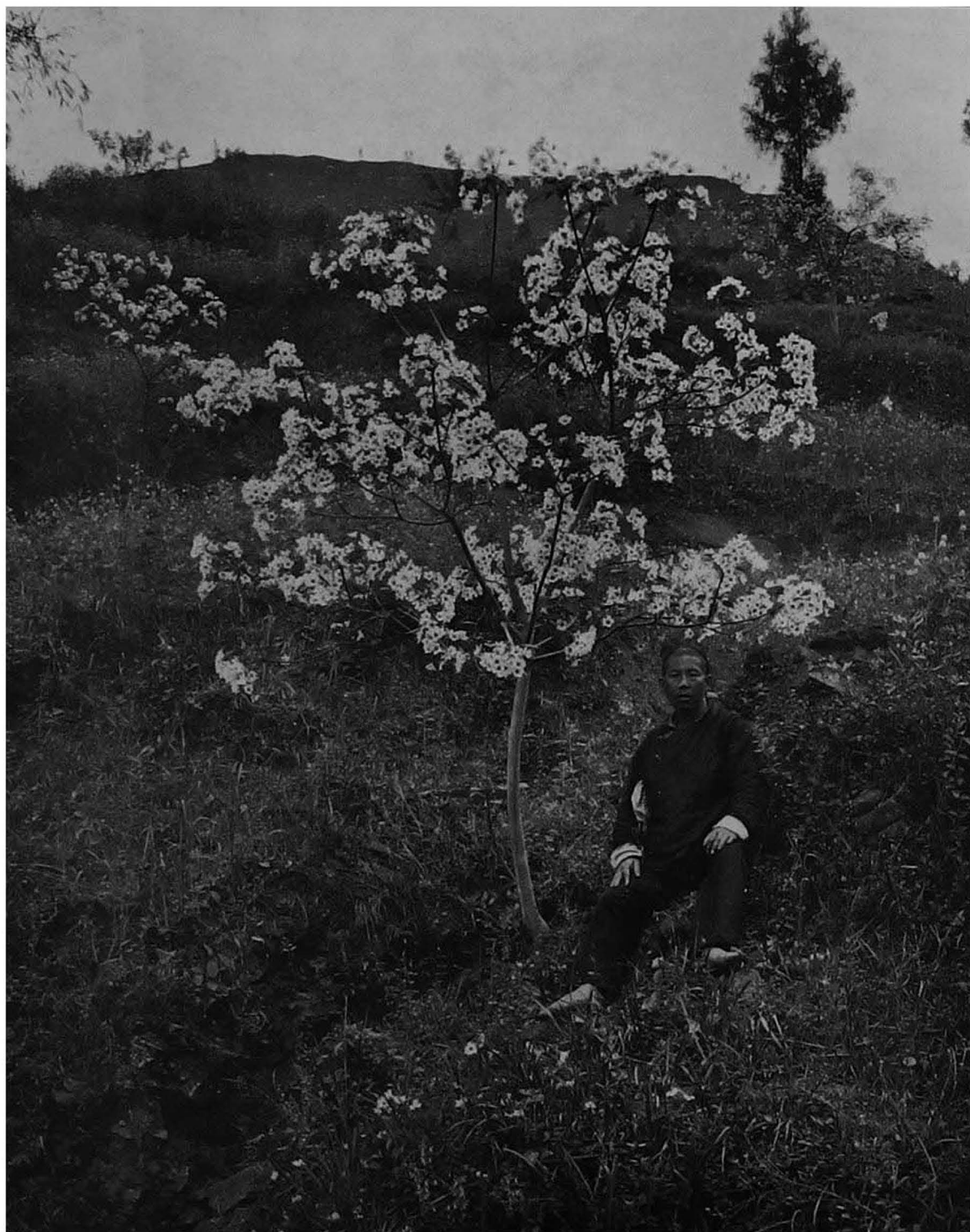
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INTRODUCTION

TUNG OIL, commonly called Chinese Wood Oil, is an essential raw material of present-day varnish manufacture, and its unique properties as a drying oil render it indispensable for certain types of varnish in which tough water-resistant films of high gloss are desired. It is also now widely used as an ingredient of certain types of paint media, and in the manufacture of electrical insulating varnishes. Other industries are also interested, for example, the linoleum industry.

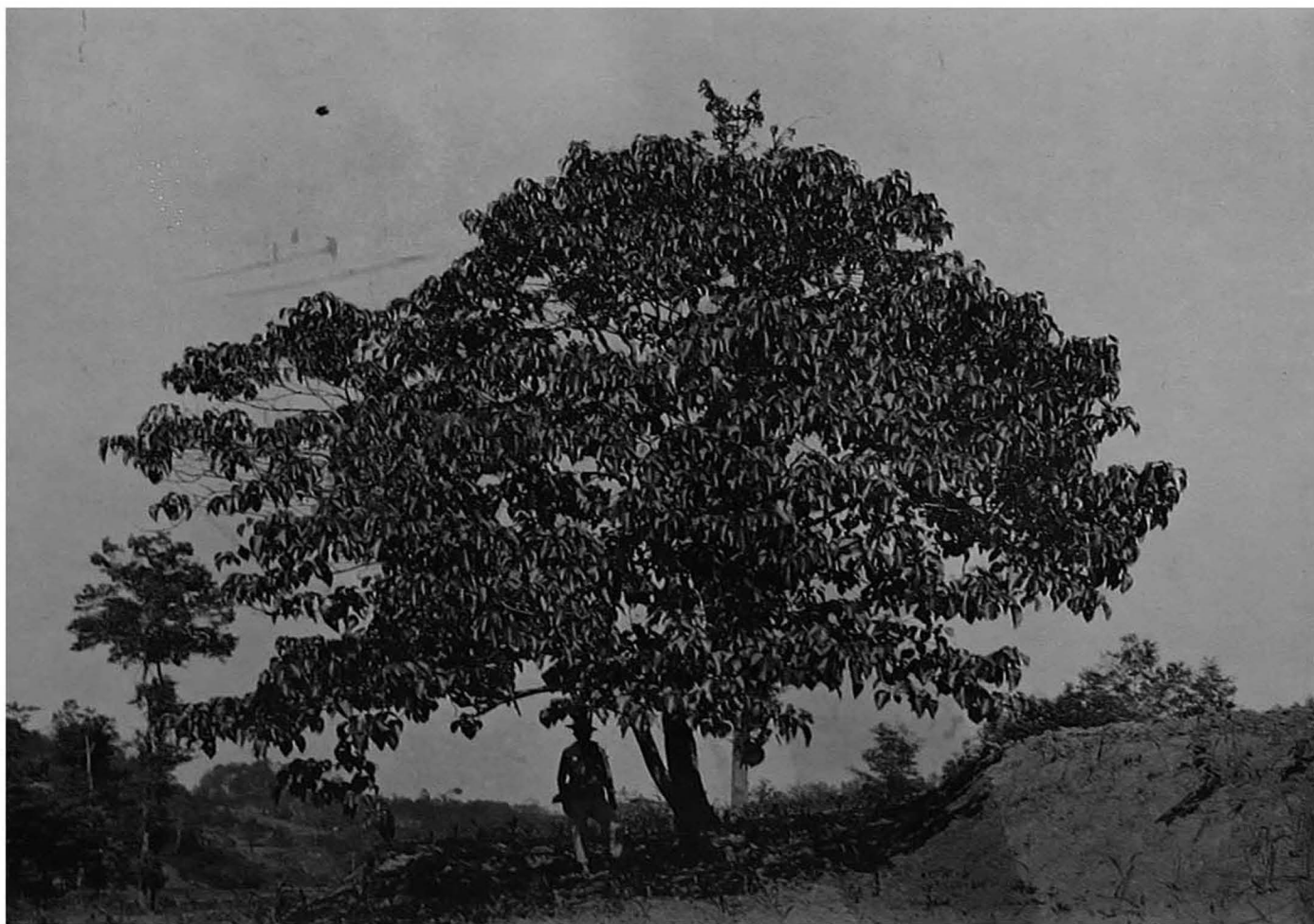
The oil was first introduced in the commercial sense into Western Europe over 30 years ago and reached its greatest development during the War, when it was an essential ingredient of aeroplane paints and varnishes. To-day this oil constitutes one of the chief exports of China, worth approximately three million pounds sterling per annum. There is keen competition for the oil and the price is maintained at a high level because all countries are dependent upon China for supplies, which are often of inferior quality and sometimes adulterated.

In view of the importance of this material to the paint and varnish industry, many have felt the need of freeing the industry from its sole dependence upon China for supplies of this oil. Plantations have already been started in the United States of America and are developing rapidly. The purpose of this pamphlet is to present a summary of available information upon the cultivation of Tung trees and the winning of the oil from the seed so that a proper judgment may be made as to the feasibility of supplying British needs for Tung oil by the cultivation of the trees within the Empire.



Photograph by E. H. Wilson.

No. 1.—Aleurites Fordii. In flower, 2 metres high ;
on banks of Yangtze River.



Photograph by E. H. Wilson.

No. 2.—Aleurites Fordii. A full-grown tree of average size in China ;
8 metres high ; head 6 metres across.

TUNG OIL

SOURCES AND PRODUCTION.

TUNG OIL is obtained from the seeds of *Aleurites Fordii* Hemsl., a tree which grows abundantly in central and western China. Another species, *Aleurites montana* E. H. Wilson, found in south-eastern China, yields "Mu-yu" oil, which is stated to possess similar properties to those of Tung oil. These two oils, sometimes indiscriminately mixed, are exported from China under the name of Chinese Wood oil.

Our knowledge of the distribution of these two species is limited but there seems to be no doubt that *A. Fordii* furnishes the bulk of the Tung oil exported from China. *A. Fordii* is a quick growing, small tree which occurs in the warm temperate parts of China, especially in the Yangtze valley, where the Chinese grow small plantations on hill-sides on land unsuitable for ordinary cultivation. Here the summers are warm enough for such crops as rice and giant millet, while wheat is grown in the cold weather when slight frost and snow may occur on high ground. *A. montana* extends from the Province of Chekiang in south-eastern China to Tonkin in French Indo-China and the Shan States of Burma. The presumption therefore is that *A. Fordii* is likely to thrive best in climates which are less tropical than those which favour *A. montana* and that the latter species may require a heavier hot-weather rainfall than the former. Trials with the two species on the American continent seem to support this. In size, habit, foliage and general appearance the two species are similar; both are deciduous and shed their leaves at the commencement of the cold weather. In both, the fruits are roughly spherical and about 5 cm. in diameter, but they may be readily distinguished because the outer surface of the fruit of *A. Fordii* is smooth while that of *A. montana* has wavy transverse ridges. The fruit of *A. Fordii* has from three to five one-seeded segments while that of *A. montana* usually has only three.

There are three other species of *Aleurites* which also bear oil-yielding seeds, namely, *A. cordata* Steud., the source of Japanese wood oil; *A. triloba* Forst. (= *A. moluccana* Willd.), yielding

candlenut or lumbang oil, and *A. trisperma* Blanco. Their oils have not the same special properties as those of *A. Fordii* or *A. montana* and cannot replace them in the paint and varnish trade.

CULTIVATION IN THE EMPIRE.

In view of the increasing demand for Tung oil in the United Kingdom and the fact that commercial supplies come solely from China, enquiries were made by the Imperial Institute in 1917 in India and a number of the Colonies as to the possibility of cultivation of Tung trees on a commercial scale being taken up with any prospect of success and in several cases supplies of seed were provided by the Institute for trials in suitable localities. Trees of *A. Fordii* grown in Kenya have fruited and a sample of the seed was recently examined at the Institute and found to give a normal yield of oil possessing the usual chemical and physical characteristics.

A few earlier attempts to cultivate Tung trees in the Empire are, however, on record. A year or two prior to 1904 the Superintendent of the Botanical and Afforestation Department in Hong Kong established a small plantation of *A. Fordii*, which in 1904 was in a flourishing condition and was in that year increased by a further 1,000 young plants raised from seed, obtained from the interior of China. No further particulars are on record and the plantation would appear to have been abandoned. In 1911 seed of *A. Fordii* was despatched from Kew to the Imperial Commissioner of the West Indies, but the conditions were unsuitable and the experiments were not successful; a few of these trees still survive in the Botanic Gardens in Dominica. In the same year seed was also sent by Kew to Australia. It was tried in the Botanic Gardens, Sydney, New South Wales, but only one seed germinated. This plant, however, developed well and at the end of four and a half years it produced a bushel of fruit, from which plantations have been made.

The question of the cultivation of Tung trees in the Empire was taken up again in 1927 by the Advisory Committee on Oils and Oilseeds of the Imperial Institute and this Committee, in collaboration with the Director of the Royal Botanic Gardens, Kew, and the Director of the Research Association of British Paint, Colour and Varnish Manufacturers, have distributed supplies of seed obtained from China and Florida to the following countries, where experimental cultivation trials are now in progress:—Australia, New Zealand, New Guinea, Fiji, India, Ceylon, British Malaya, Seychelles, Mauritius,

Union of South Africa, Kenya, Tanganyika, Nyasaland, Rhodesia, Sudan, Nigeria, St. Helena, Cyprus, Palestine, Bermuda, the West Indies and British Honduras. Although it is too early to say what the results of these trials may be, preliminary reports already received from some of these countries are distinctly encouraging, especially from North-East India.

Independently of these experiments, there are under plantation in New South Wales about 1,000 trees, many of which are now in bearing. This is the result of the distribution of seed from the Royal Botanic Gardens, Kew, to the Botanic Gardens, Sydney.

The production of Tung oil in the Empire is now considered of such importance that on the recommendation of an interdepartmental conference convened by the Department of Scientific and Industrial Research in March, 1929, a special Sub-Committee was appointed by the Imperial Institute Advisory Committee on Oils and Oilseeds to deal with this problem. This Sub-Committee, besides being engaged in encouraging the cultivation of Tung trees within the Empire by the distribution of seed and the dissemination of related information, have arranged for the investigation of cognate problems, the elucidation of which will contribute to the success of this Imperial production. Among these may be mentioned the comparison of the chemical and physical properties of the oils of *A. Fordii* and *A. montana* and the determination of the value of the cake or meal left after the removal of the oil from the seeds as a feeding stuff for animals and as a fertiliser. The widening of the industrial application of the oil by the finding of new uses is also engaging their attention.

The work of the Sub-Committee has been greatly assisted by the Empire Marketing Board who, besides undertaking the publication of this pamphlet, have also provided the necessary funds for the proposed investigations.

CULTIVATION IN THE UNITED STATES OF AMERICA.

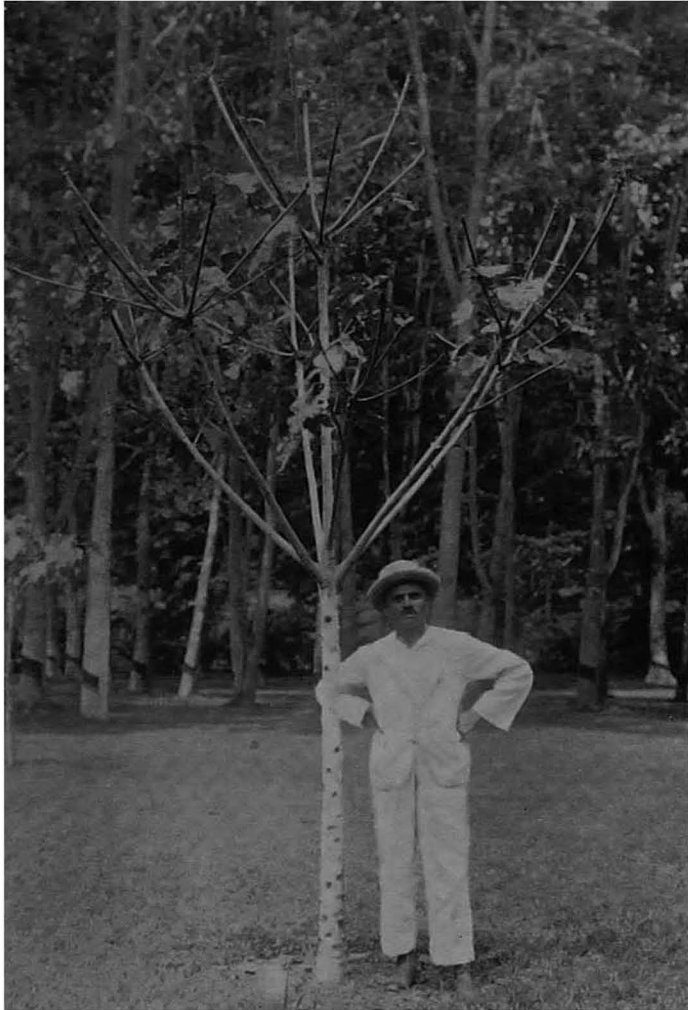
The first experimental distribution of Tung oil seeds was made in America by the United States Department of Agriculture in 1905. The trials showed that *A. Fordii* fruited well in certain of the Southern States and were considered so satisfactory that in 1923 the American Tung Oil Corporation was formed as a co-operative effort among the members of the American Paint and Varnish Manu-

facturers' Association. The object of the Corporation was primarily to prove the suitability of Tung trees as a crop in the hope of encouraging farmers to cultivate them on a large commercial scale. The first two plantations were established at Gainesville, Florida, and were 70 acres and 200 acres respectively in extent. In 1926, the area had increased to 2,500 acres, representing some 200,000 trees, and at the end of 1928 to 4,000 acres; another 1,000 acres were planted during 1929. The total area in Florida now represents 550,000 trees; in addition, 500 acres have been planted in States other than Florida. Some of the trees commenced to bear fruit in 1927, when a crop of about 16 tons was collected. No data are available as to subsequent crops. In January, 1929, an oil-mill was erected at Gainesville, Florida, the first complete plant to be assembled for crushing Tung oil seeds. It is understood that this plant is capable of treating up to approximately 1,000 lb. of seed per hour.

FURTHER DEVELOPMENTS IN THE EMPIRE.

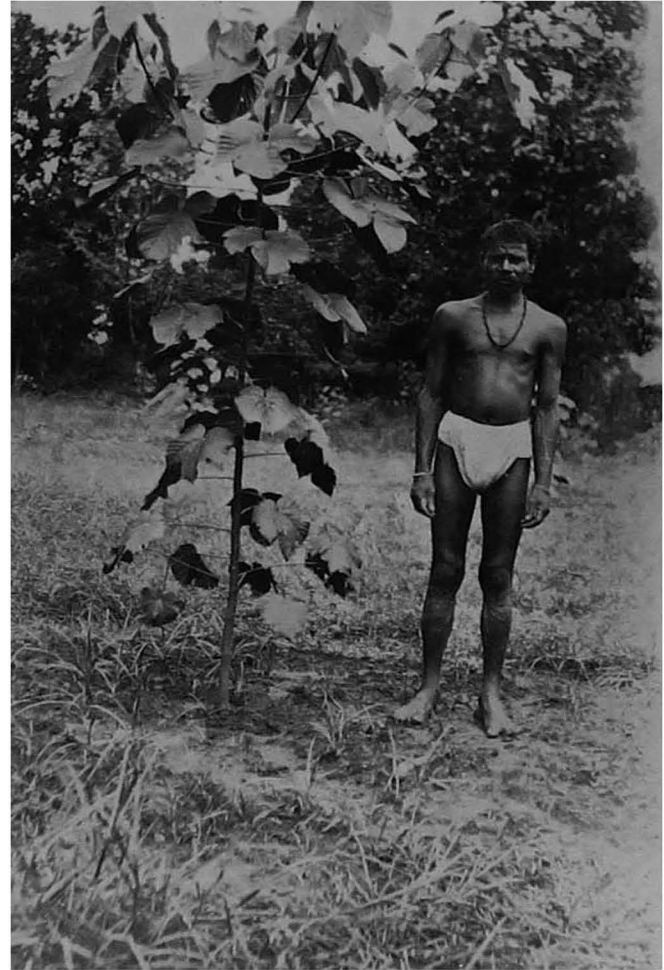
The results of trials made in the United States show that the Tung tree (*A. Fordii*) can be grown in countries other than China, and the expansion of the American enterprise suggests that it may prove a remunerative plantation crop. But so far as the British Empire is concerned, though there are records of individual trees that have reached the fruiting stage, the time has not yet arrived for the formation of a definite opinion as to the suitability of particular districts for the formation of plantations of either species. Close study of the conditions in areas in which the climate appears most suitable and experimental cultivation of the trees in these localities are essential. At first it would be advisable to carry out initial experiments with both species. It may be found that *A. montana* is the more suitable species where the climate is more tropical, the rainfall heavier and the seasons not so well defined. As a guide to those who may wish to undertake such trials the following details as to the methods of cultivation are given.

At the present time the only experience of Tung oil plantations is that gained in Florida and to a limited extent in New South Wales. In China, though the trees are privately owned and are planted on waste hillside land, there has been no attempt to grow them as a regular crop. Experience in the United States and Australia is, however, confined to the species, *A. Fordii*. *A. montana* has been tried in Florida but the climatic conditions there are not



Photograph by L. S. Bertus, Dept. of Agriculture, Ceylon.

No. 3.—*Aleurites montana*. Young tree, wintering, 12 feet high, Heneratgoda Botanic Gardens, Ceylon.



Reproduced by permission of the Director, Indian Lac Research Institute.

No. 4.—*Aleurites Fordii*. Young tree, 7 feet high 14 months old. Ranchi, Chota Nagpur, India.



Reproduced by permission of Mr. H. A. Gardner

No. 5.—Aleurites Fordii. In Fruit.

sufficiently tropical for this species to thrive. The information given below therefore refers only to *A. Fordii*. As regards nursery practice, a considerable body of information is being collected from Empire sources, which in the main bears out the experience of Florida.

METHODS OF CULTIVATION.

Rainfall and Temperature.—As the tree is deciduous and flowers before producing its leaves, it appears probable that it will succeed best under climatic conditions affording it a resting period. For successful cultivation the absence of much frost and a sufficient rainfall are essential. The rainfall should not be less than 30 inches, 50 or even 70 inches being preferable. In Ichang, China, where this tree flourishes, the average rainfall is 30 inches, most of which falls in April, July and August. Here the climate is rather one of extremes. The summer is tropical with a shade temperature ranging from 90° to 110° F. The winter is cold, snow often lying on the ground for days, but there are seldom more than 4 degrees of frost. In the mountains, at 2,600 feet altitude, the summer is somewhat cooler and the temperature may fall to 24° F. and occasionally as low as 20° F. Experience within the Empire indicates that this tree is very resistant to drought and can withstand very high summer temperatures.

Soil.—In China the tree appears to have no strong predilection in the matter of soil, and grows equally well on conglomerate, hard limestone, sandstone or sandy clay. It is essentially a hillside tree, thriving in the most rocky situations and in the poorest of soils. In America the tree has been tried on almost every type of soil, and has been found to grow on practically any well-drained soil which is slightly acid. The type of soil which is found most suitable in Florida is a sandy soil or sandy loam which is underlaid with clay 3 to 8 feet down.

Propagation.—The usual method of reproduction is by seed. Great variation in yield, however, occurs in trees raised from seed. This may have an important bearing on the future of the industry and attention has therefore been paid to vegetative methods of propagation so as to perpetuate the good qualities which may be found in individual trees. It has been established that the tree can be budded and grafted and also propagated by cuttings; that *A. Fordii* can be successfully grafted on to *A. montana*; and that

budded plants of the "cluster" type (see p. 12) have the flowering and fruiting characters of the parent plant and produce clusters of fruit.

Sowing.—In Florida the middle of February is the best time to sow, when the soil commences to warm up and growth can be expected. About 60 days are usually required for germination, but great variation is found in the germinating energy of the seed, particularly if the seed is old. When sowing, single seeds should be used and not the whole fruits. The seeds should be planted 3 or 4 inches deep and from 8 to 12 inches apart in the nursery row. The rows should not be less than 3 feet apart, to permit of ample cultivation between them.

The seeds should not be eaten as they cause vomiting and diarrhoea.

Site of Nursery.—A well-drained free working soil in a fairly moist position should be chosen. It has been found in the United States that the moisture content of the soil, particularly during the spring dry season, is of great importance, as if the seedlings are supplied with adequate moisture during this time they will not suffer from a setback in growth which would be caused by unduly dry conditions. At the same time, the soil should be sufficiently well drained to ensure that no water will stand between the rows for any length of time during the summer rainy season. Waterlogging is fatal to the young seedlings.

Nursery Cultivation.—Regular shallow cultivation should be given throughout the growing season, so as to keep down weeds and where necessary to form a surface soil mulch. Because of the shallow rooting habit of the plant, deep cultivation should be strictly avoided after the first few weeks.

Transplanting.—After one year in the nursery, the seedlings may be transplanted to the field. The methods commonly used in transplanting fruit trees are employed. The work should be done while the trees are dormant before spring growth commences, and care should be taken to prevent injury to the root system. Exposure to sun and wind should be avoided and at no time should the seedlings be allowed to become dry. They should be planted at the same depth as they stood in the nursery row. Deep planting is highly injurious. It is recommended that when the seedlings are transplanted they should be cut back leaving a shoot 12 to 14 inches

long. When established, no further pruning of young trees seems to be needed other than checking the growth of side branches by nipping out apical buds when necessary.

Planting at stake has been tried with some success but it must be borne in mind that this increases weeding charges and may result in an uneven stand. Neither uniform nor complete germination can be relied on.

Supplies.—American experience has shown that the mortality among transplants is from 1 to 3 per cent. and allowance must be made for the replacement of the failures. After the third year the mortality is negligible.

Plantation Distances.—Florida experience recommends that trees should be planted in parallel rows, $12\frac{1}{2}$ feet between trees in the row, and 30 feet between the rows. After the seventh year alternate trees should be removed, which will leave 25 feet between two trees in the same row and each tree will be $32\frac{1}{2}$ feet diagonally removed from its nearest neighbour in adjacent rows. It is calculated that the extra yield of fruit before the alternate trees are removed is sufficient to justify this practice. This arrangement finally leaves 60 trees per acre.

Manuring.—Sufficient information is not yet available as to the effect of manures and fertilisers on Tung trees and the need for such applications will have to be determined experimentally in particular cases. Trials carried out at the Florida Experiment Station indicate that on the poor sandy soils of that State up to 900 lb. per acre of a complete fertiliser, containing 4.1 per cent. nitrogen, 7 per cent. phosphoric acid and 2 per cent. potash can be used with profit on this crop. Nitrogen encourages vegetative growth; phosphates encourage root development and promote maturity and ripening of fruit; and potash increases the power of plants to resist disease and the attacks of pests.

Fencing.—It is recommended as being essential that the young plants should be protected by fencing from damage by animals, especially during the early stages of growth.

Harvesting.—In China the fruits are gathered before they are ripe by knocking them off the trees with poles. They are then collected in heaps, which are covered with straw or grass. Fermentation takes place and has the effect of loosening the outer husks, after which the seeds can be easily removed. Alternatively, the

husks may be removed by parching the fruits in iron pans over a fire. In Florida the fruits are allowed to ripen on the trees. When ripe they fall to the ground, and are left under the trees until thoroughly dry. On a commercial scale the seeds are separated from the fruits by means of mechanical decorticators. The seed, after removal from the outer husks of the fruits, can be stored in any dry place, but if the seed is to be used for planting purposes, it should only be removed from the husk immediately before sowing and should not be carried over from one season to another.

GROWTH OF TREES AND YIELD.

Size of Trees.—In China the trees seldom exceed 30 feet in height and are generally not so tall, and have a trunk of about 10 inches in diameter; the spread is from 15 to 30 feet. Tung trees have a low branching habit of growth, and, unless pruning is practised, they seem inclined to produce a straggling head rather than a uniformly developed crown. In Florida trees of the age of 8 years are nearly 30 feet high with a spread of 28 feet.

Leaves and Flowers.—The foliage is dense, the leaves being large, dark green and more or less heart-shaped; they are shed at the usual resting period for deciduous trees. The flowers are white with pink centres and are of two sexes. They are produced in clusters before the leaves. Each cluster is made up of one or more female flowers surrounded by male flowers, which are conspicuous with their yellow stamens. As a rule, only one female flower is found in a cluster, but occasionally two or more female flowers have been found in a cluster and it is hoped that selected seed of this type, known as "multiple cluster," will transmit this characteristic and lead to the development of a special variety which should produce a higher yield of fruit than the normal. The flowers are very sensitive to early spring frosts.

Fruits.—Both in China and Florida the fruits ripen at approximately the same time, that is, in October. When fully ripe they fall to the ground and eventually break open from the base upwards into from three to five segments each containing one seed. These seeds are composed of a fairly thick, woody shell, externally of a warty appearance, enclosing a creamy white kernel.

Yield.—Some young trees in Florida commence to bear fruit in the third year, though cropping on a commercial basis is not expected until the fifth year. In Florida it is generally held that the trees will

reach full bearing in their tenth year though records of individual trees seem to indicate that progressive production may continue after this age. The oldest trees in Florida are not more than 25 years old and they still appear to be vigorous.

Chinese trees are said to give a yield of from 1 to 5 or more bushels of fruit according to their age.

As regards the yields that may be expected from plantations the information is at present rather scanty as the American plantations have not been in existence sufficiently long to furnish very precise figures.

Records for a group of 109 trees nine years of age and over growing in Florida, showed that these trees yielded 5,000 lb. (approximately) of dried fruit, equivalent to over 1,000 lb. of oil, in each of two different years. On another plot of 1.9 acres, three-year-old trees produced 1,096 lb. of fruit or 576 lb. per acre, equivalent to 115 lb. of oil.

The latest information in respect of Tung oil yields from plantations in the United States is contained in a personal communication to the Director of the Research Association of British Paint, Colour and Varnish Manufacturers from the General Manager of the American Tung Oil Corporation, to whom acknowledgment is due. It is stated therein that the most interesting figures which can be properly authenticated are those of a company in the Gainesville area having 30 acres of well-cared-for trees, which range from five to six years of age. The yields on these 30 acres were as follows :—

1927	9,182 lb. dry fruit.
1928	16,421 lb. dry fruit.
1929	39,006 lb. dry fruit.

Thus, at the end of six years, the fruit yield was approximately 1,300 lb. per acre, equivalent to approximately 280 lb. of oil. Owing to various causes the yields on the larger groves of the American Tung Oil Corporation (220 acres) were less favourable. (The full text of the communication will be found in Appendix A.)

There are records in Florida of damage caused by late spring frosts occurring when the tree is in blossom and in such years the yield of fruit has been adversely affected. It is possible therefore that, in countries where this danger does not exist, higher yields may be obtained.

It must be pointed out that a great variation occurs in the yields of fruits from individual trees of the same age and maturity. For instance, observations made at the Experiment Station in Florida on ten trees showed that the least prolific of these trees yielded during the first ten years a total of 3½ lb. of fruit while the best one gave 180½ lb. These figures, however, cannot be taken as representing the full cropping capacity of the trees since they were planted in a row 10 feet apart. In reports from some places in the Empire where trials are now in progress mention is also made of the great variation that exists in the rate of growth of seedling trees. There is, therefore, a good possibility of increasing the estimated yields given above for plantations by means of suitable seed selection, by budding and grafting and by propagation by cuttings. For example, if seed selected from the "multiple cluster" type is found to transmit its characteristic, plantations stocked only with this type may be expected to give higher yields of fruit.

PLANTATION COSTS.

From the experience gained in Florida it is estimated that 200 dollars per acre is a safe figure to cover the cost of planting and of the necessary cultivation and fertilisation for the first five years. Of this sum a quarter is allowed for the cost of the land and of clearing it. Up to the fifth year there would be no appreciable income. During the next five years the returns will rise gradually until the tenth year is reached. Yield figures for trees over this age are very meagre but such as exist indicate that further increases in crop may be expected. The estimated figure given above of 200 dollars per acre for the first five years applies primarily to Florida and includes the cost of heavy manuring which is necessary on these light soils. It does not follow that it will be true for other countries, as the cost of land, labour and fertiliser will doubtless vary according to the local conditions. In India the cost of planting out, including the nursery expenses, has been estimated to be about 8 annas (9d.) per tree up to the end of the first year. This cost is based on actual expenses incurred in establishing a small plantation and does not include overhead charges.

UTILISATION OF NUTS.

Although in America the intention is to crush the nuts for oil near the point of production, as regards the produce of the British Empire it may be preferable in the early days of the cultivation to export

the nuts to the United Kingdom for the preparation of the oil. For this purpose the nuts would have to be separated from the fruits and after being dried in the air, if necessary, would be bagged for shipment. The outer husks yield only a very small amount of available ammonia, but their return to the soil would add appreciably to the humus content and this would be an important matter on sandy soil.

The nuts are composed of about 43 per cent. of shell and 57 per cent. of kernel. In the kernels there is about 56 per cent. of oil. The nuts on arrival in the United Kingdom would be crushed by oil-crushers in much the same way as is practised with other oilseeds. The expressed oil would be sold to the makers of paint and varnish and to other firms using Tung oil. It is considered that the English pressed oil would be of lighter colour and of better quality than the Chinese product and moreover it would be of guaranteed purity. The oil would be readily saleable in the United Kingdom and would fetch a price equal to, or possibly a premium over, that of the Chinese oil, which was quoted at £69 10s. per ton in London in January, 1930. The oilcake left after the expression of the oil contains useful amounts of nitrogen, phosphoric acid and potash and could be used, as is now being done in Florida, as a fertiliser.

In the case of many oilseeds the cake or meal left after crushing the seeds can be used as a feeding stuff for animals, but it is not known whether the cake from Tung nuts is suitable for this purpose. It is hoped to arrange for feeding trials with this product to be carried out and also for manurial trials in order to determine definitely the uses to which the cake can be put.

FUTURE OUTLOOK.

A point that arises is the influence the increased production will have upon the price of Tung oil. The question has been raised as to whether the larger quantities of oil resulting from the extension of the cultivation of Tung trees in America and the British Empire will have the effect of lowering the price of the oil to such an extent that the cultivation will become unprofitable. The general opinion is that with increased quantities of oil becoming available, new uses will be found for Tung oil and those industries already employing this material will absorb greater amounts. The increased production will naturally tend to reduce the price but it is considered that the reduction will not be so great as to render the cultivation unprofitable.

As far as can be seen, there will always be a demand for Tung oil, as it is a raw material which is essential in some industries. It should always command a price higher than that of linseed oil.

Statistics for the years 1924-29 are appended showing (1) exports of Tung oil from China, (2) imports of Tung oil into the United States, and (3) imports of Tung oil into the United Kingdom. A graph is also given showing the price of Hankow Tung oil in London during the years 1924-29.

It is hoped to revise this pamphlet in the future when more detailed knowledge of successful cultivation within the Empire becomes available.

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"Tung Oil," by L. A. Jordan, D.Sc., A.R.C.Sc., F.I.C., D.I.C. *Journal of the Oil and Colour Chemists' Association*, 1929, Vol. XII, No. 107. (This paper contains a complete bibliography of Tung oil.)

Circulars of the American Paint and Varnish Manufacturers' Association.

"Questions and Answers on Tung Oil Production in America." Published by the American Tung Oil Corporation, Washington, D.C. (Second Edition, February, 1930.)

Enquiries regarding the suitability of different climates for the growth of Tung trees, and for particulars as to supplies of seed, may be addressed to the Director, Royal Botanic Gardens, Kew, Surrey. Enquiries as to the uses of the oil, marketing and handling of the harvested crop may be sent to the Director, Imperial Institute, South Kensington, London, S.W.7.



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*No. 6.—Plantation of *Aleurites Fordii*. Osceola Grove, Florida.*



Photograph by Imperial Institute.

No. 7.—Aleurites Fordii. Fruits and seeds. (Natural size).



Photograph by Imperial Institute.

No. 8.—Aleurites montana. Fruits and seeds. (Slightly reduced).

APPENDIX A.

Copy of a Personal Communication to the Director of the Research Association of British Paint, Colour and Varnish Manufacturers from the General Manager of the American Tung Oil Corporation (dated 9th January, 1930).

Probably the most interesting and favourable figures on Tung oil yields in the Gainesville section during the last year are those from a local company having 30 acres of well-cared-for trees which range between five and six years of age. The yields, which, at present, should not be ordinarily counted upon, were as follows :—

1927	..	..	..	9,182 lb. dry fruit.
1928	..	..	..	16,421 lb. dry fruit.
1929	..	..	..	39,006 lb. dry fruit.

This would then suggest that in 1929, at the end of six years, there was available approximately 1,300 lb. of fruit per acre. 1,300 lb. of fruit would probably deliver in the neighbourhood of 280 lb. of oil. At the prevailing level of 15 cents per pound, this would set an outside return of 42 dollars per acre.

The yields on the larger groves of the American Tung Oil Corporation (about 220 acres) were less favourable, since these groves contained a large quantity of single fruiting trees. Moreover, the original American groves are on land that possibly was not well selected, the drainage being imperfect in many parts. However, as a result of our work, much information has been developed, upon which to base future plantings, and we believe that if the information outlined in our recent blue covered circular is followed, yields equivalent to those given above should obtain in all future plantings on well-drained, carefully selected land, if the trees are well cared for.

It would appear now that Tung oil trees will not come into their maximum bearing until they are at least ten years of age, and I am rather hopeful that at the end of ten years the trees referred to above will show double the yields which were shown in 1929.

On page 2 of the blue-covered booklet, "Questions and Answers on Tung Oil Production," you will find a picture of an individual Tung oil tree at Cairo, Georgia, which gave a yield in 1928 of 250 lb. of unhulled fruit. A mistake was made in printing the date of planting of this tree, which should have been 1908 instead of 1915. The tree was therefore twenty years old when it produced a crop of 250 lb. of fruit, which is equivalent to approximately 54 lb. of oil.* If we could get groves planted with trees of this character, the yields of Tung oil should be indeed very satisfactory.

* 7 dollars per tree, or 700 dollars per acre.

TABLE I.
Exports of Tung Oil from China.

Exported to	Long Tons.					Value in £.				
	1924.	1925.	1926.	1927.	1928.	1924.	1925.	1926.	1927.	1928.
Hong Kong ..	4,402	1,728	3,186	7,957	8,252	187,918	71,131	129,295	295,363	335,733
Great Britain ..	3,179	2,297	2,896	2,660	5,945	194,695	128,530	156,664	160,718	321,211
Denmark ..	249	156	144	202	333	15,443	9,120	7,694	12,191	18,024
Germany ..	4,719	3,778	2,738	3,238	2,553	291,157	215,278	148,407	195,792	138,024
Holland ..	474	619	927	3,429	1,537	29,336	35,586	50,261	206,895	83,471
France ..	978	847	1,193	815	1,024	60,204	47,475	64,658	49,231	55,697
Belgium ..	157	159	198	205	136	9,708	8,946	10,955	12,325	7,261
Japan ..	708	358	457	391	473	44,462	19,074	23,832	22,993	25,152
Singapore ..	26	55	53	47	66	1,669	3,040	2,564	2,537	3,439
Italy ..	365	265	225	327	335	22,779	15,079	12,059	20,001	18,038
Canada ..	515	619	2	—	—	32,358	36,406	107	—	—
United States of America ..	37,324	42,029	32,144	34,066	44,062	2,338,831	2,437,752	1,705,072	2,098,821	2,374,806
Australia and New Zealand ..	72	173	88	3	61	4,533	9,701	4,797	162	3,247
Other countries ..	168	136	234	308	360	10,171	7,743	13,850	18,342	20,165
Total ..	53,336	53,219	44,535	53,648	65,137	3,243,264	3,044,861	2,330,215	3,095,371	3,404,268

TABLE II.
Imports of Tung Oil into the United States.

Imported from	Long Tons.					Value in £.				
	1924.	1925.	1926.	1927.	1928.	1924.	1925.	1926.	1927.	1928.
China	34,128	43,806	35,863	33,502	43,653	2,329,793	2,268,382	1,813,352	1,989,324	2,471,931
Hong Kong ..	1,823	1,158	1,099	5,701	4,766	150,026	66,581	65,436	387,492	264,645
Japan	68	182	29	463	290	4,231	10,315	1,648	27,448	17,304
Kwantung ..	—	85	—	—	—	—	5,670	—	—	—
Philippine Islands	51	—	—	—	—	1,747	—	—	18	—
British Malaya ..	50	86	15	—	—	4,650	5,256	515	—	—
British India ..	—	—	—	29	18	—	—	—	1,509	632
United Kingdom	176	—	—	160	1	12,680	—	—	9,658	28
Germany.. ..	100	—	20	146	—	5,572	—	519	12,558	—
France	—	—	—	10	—	—	—	—	968	—
Denmark	—	15	—	—	—	—	1,262	—	—	—
Canada	—	—	28	—	32	—	—	1,153	—	2,039
Other countries ..	27	4	1	12	—	1,888	340	87	482	—
Total	36,423	45,336	37,055	40,023	48,760	2,510,587	2,357,806	1,882,710	2,429,457	2,756,579

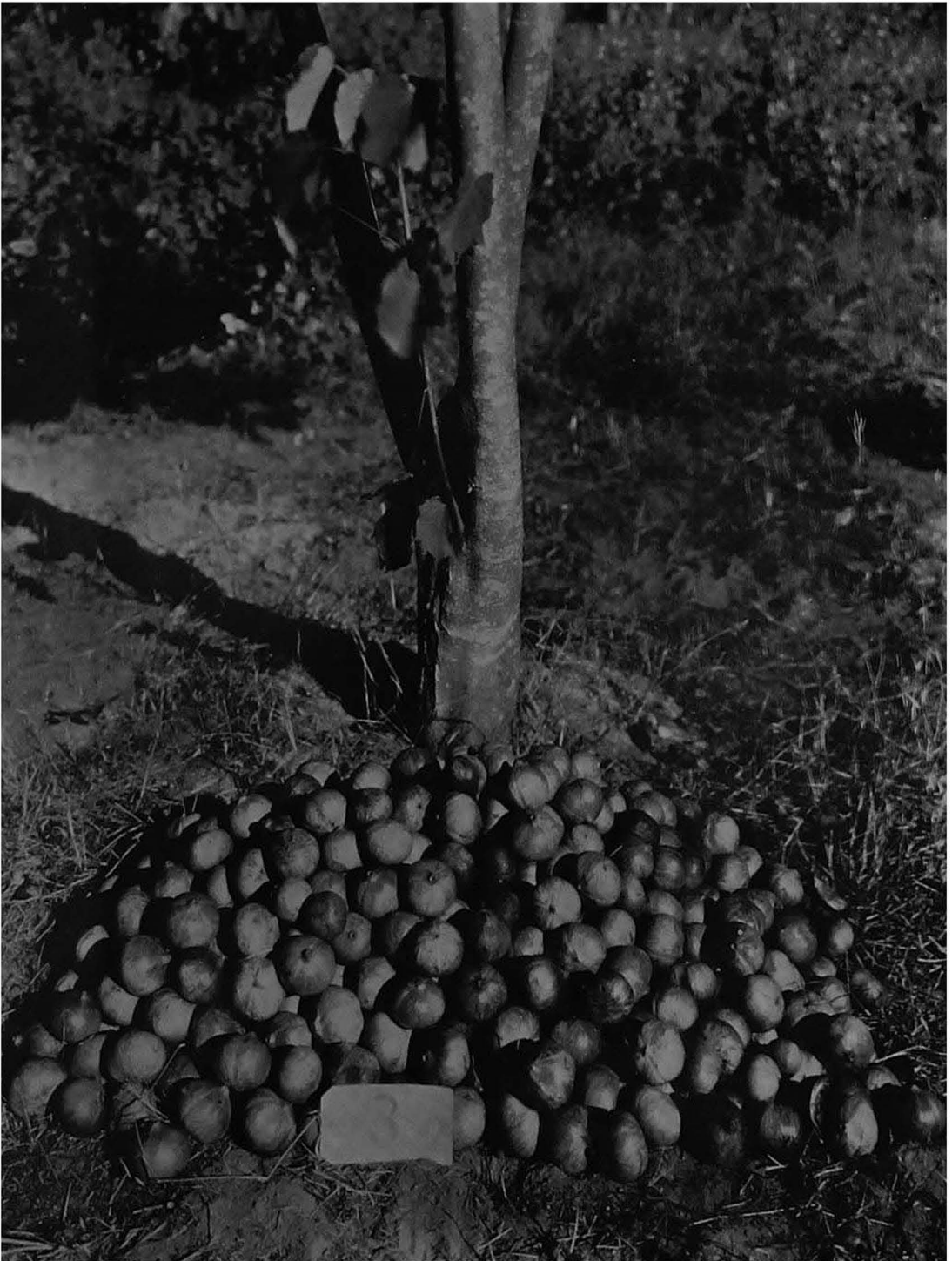
In 1929, the total imports into the United States were 53,428 long tons, valued at £3,082,578.

TABLE III.

Imports of Tung Oil into the United Kingdom.

Tung oil is not shown separately in the United Kingdom Trade Returns but is included in imports of "other vegetable oil, unrefined, not elsewhere specified." In the following table are given the imports of oils in this category received from China, 90 per cent. of which are stated by the Controller of the Statistical Office, H.M. Customs and Excise, to consist probably of Chinese wood oil.

				<i>Tons.</i>	<i>Value in £.</i>
1924	..	..	..	2,836	221,041
1925	3,057	205,252
1926	2,515	167,167
1927	2,833	241,220
1928	3,677	260,115
1929	4,154	273,350



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No. 9.—*Aleurites Fordii* with Fruits. Tree $4\frac{1}{2}$ years old.

E.M.B. 32.



REPORT ON THE CULTIVATION,
TREATMENT AND PROSPECTS OF
RICE IN BRITISH GUIANA.

By

Charles E. Douglas, M.I.Mech.E., A.M.I.Pet.T., M.I.Struct.E.



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CONTENTS.

	Page
Preface.. .. .	5
Author's covering letter	5
Introductory	7
General	7
Rice production	11
Rice varieties and experimental culture	12
Agricultural and milling conditions	17
Preparation of parboiled rice	31
Rice mills	38
Marketing	45
Conclusions	49

LIST OF ILLUSTRATIONS.

Fig.	TITLE	Page
1.	Diagram giving rice prices (1929-1930)	13
2.	Sketch map of British Guiana	17
3.	Rice mill in British Guiana	19
4.	Rice field ready for harvest	22
5.	Method of ploughing in British Guiana	24
6.	Light caterpillar tractor	26
7.	Threshing by hand on tables as in Essequibo district	27
8.	Mechanical thresher	27
9.	Dressing plant for cleaning dirty grain	34
10.	Steeping and parboiling tanks and drying floor	41
11.	Portable covers to protect paddy on drying floors during rain	41
12.	Rice huller	42
13.	Sheller for husking the paddy	42
14.	Self-contained pearling cone for whitening the shelled rice	43
15.	Sieve and winnower for dressing rice offals.. .. .	53
16.	Machine for separating shelled from unshelled rice	53
17.	Small rice mill	39
18.	Flow diagram of small rice mill	40
19.	Eight typical varieties of well known rices.. .. .	59

PREFACE.

Letter from Mr. Douglas covering his Report.

28th February, 1930.

The Secretary,
The Empire Marketing Board,
Dartmouth Street,
London, S.W.1.

Sir,

In accordance with the instructions contained in your letter of the 12th August, and my reply of the 28th August last, I proceeded to British Guiana during the second week in October in order to investigate and report upon the rice position in that Colony.

On the way thither, I visited Barbados and Trinidad. My object in doing so was to ascertain, as far as possible, the state of the Rice Market in Bridgetown and Port of Spain respectively ; to observe the extent to which rice cultivation was being carried out in Trinidad ; and to study the work done by the Imperial College of Tropical Agriculture in this connection.

I arrived in Georgetown, Demerara on Wednesday, the 30th October, and spent a clear month visiting nearly all the cultivated rice areas and the rice mills from the neighbourhood of the Pomeroon River, on the West Coast of Essequibo, right up to Skeldon, on the West Coast of the Corentyne River.

I also visited several of the Plantations and Mills on the Demerara, Essequibo and Mahaicony Rivers respectively.

By the courtesy of the Hon. Prof. S. Dash, Director of Agriculture, I was accompanied on all my visits by Mr. E. M. Peterkin and Mr. A. de K. Frampton of the Department of Agriculture.

In addition to these gentlemen, whose assistance was invaluable, I was accompanied on many occasions by Colonel H. M. Wallis, a well-known Canadian Rice Expert, who was visiting the Colony at the same time.

I was also privileged to meet, and on several occasions to confer with the West Indian Sugar Commission, presided over by the Right Honourable Lord Olivier, P.C., K.C.I.E., etc.

I was able to complete my investigations in time to leave Georgetown on the 30th November, and, after again visiting the Imperial College of Tropical Agriculture at Trinidad, where every courtesy was extended to me by the Principal, Mr. Geoffrey Evans, C.I.E., etc., and his Staff, whose work impressed me greatly, I arrived in London on the 20th December last.

I have pleasure to submit herewith a full Report of my visit.

I wish to take this opportunity of expressing my appreciation of the great courtesy and willing help extended to me by the Officer Administering the Government; by Members of the Legislative Council; by the Director of Agriculture and his assistants, and by many other well-known business gentlemen.

I have the honour to be,

Sir,

Your obedient Servant,

CHAS. E. DOUGLAS.

REPORT ON THE CULTIVATION, TREATMENT AND PROSPECTS OF RICE IN BRITISH GUIANA.

INTRODUCTORY.

This Report will deal with the problem concerned in three main sections. First, a general reference to physical conditions; second, a review of the agricultural and milling conditions met with during investigations; and finally, observations on and recommendations arising out of these investigations.

It has been deemed advisable to go into rather full detail in respect of the investigations made, so that the methods and processes at present in vogue, and the recommendations arising therefrom may be fully understood.

GENERAL.

Considerable attention has been devoted to British Guiana of recent years. Two or three excellent Reports have been published, notably the "Report of the British Guiana Commission," April, 1927, Cmd. 2841, which, incidentally, contains an excellent map of the Colony; and that by Mr. H. C. Sampson, C.I.E., "Report on Development of Agriculture in British Guiana."

Nevertheless, it is permissible to recall one or two facts regarding the geographical position and physical features of the Colony and its economic conditions, in order the better to appreciate the problems bound up with the question of its rice cultivation and treatment.

Although the Colony is of considerable extent, having an area of some 90,000 square miles, only a relatively small portion—being a narrow coastal belt of approximately 250 miles in length by some 10 to 15 miles in average depth—is at present cultivated.

This belt slopes in a south-easterly direction from the great mouth of the Orinoco River in Venezuela to the Corentyne River which forms the boundary between British and Dutch Guiana.

It may be noticed that this cultivated area lies principally within 6° and 8° of latitude ; in other words, bordering on that tropical belt which, in the Eastern hemisphere, provides the total rice production of the world.

When approaching British Guiana from the sea there is no indication of any land elevation. The whole cultivated coastal belt is, in fact, alluvial soil formed from the mud deposited through the ages, not only by the rivers flowing through the Colony itself, but, through the action of the South Equatorial current, by the River Amazon in the north-western corner of Brazil.

This soil is principally heavy clay, intersected here and there by sand reefs, and it is extremely fertile. It is low-lying being for the most part below ordinary high water sea level.

British Guiana is traversed by a considerable number of rivers, notably, from north-west to south-east, by the Waini and Pomeroon Rivers ; the Essequibo and Demerara Rivers ; the Mahaica, Mahaicony and Abary Rivers ; the Berbice with its tributary the Canje River ; and finally, the Corentyne River, which separates the Colony from Dutch Guiana. In addition to the foregoing there are several smaller and tributary streams.

It is important to realise the existence and position of these rivers, because not only do they provide the only means of access to the interior of the country—including, of course, the cultivated area—but they are also a source from which unlimited supplies could be obtained for irrigation purposes, were a co-ordinated irrigation system existent.

This Report is not concerned with any crop except that of rice ; an ample and, preferably, suitably controlled supply of water is essential for rice cultivation on efficient lines.

In addition to water from the rivers mentioned above, there is, throughout a considerable part of the cultivated area, a supply known locally as Conservancy Water. This supply originates in the flat swampy land behind the cultivated belt and is retained by the well-known system of back dams which, for many years now, have protected the sugar plantations from flooding, and which thus also constitute a natural reservoir of water.

This Conservancy Water Supply is distributed to the plantations and estates by means of navigation and irrigation canals known as

Middle Walks, while the water drained off the surface of the land is collected in what are called Side Lines, which ultimately discharge, or are discharged by pumping, to the sea.

In the Essequibo district there are two or three small lakes, the Tapacuma, Capoey and Ikuraka Lakes, as well as the Ituribisi and Supenaam Rivers, so that in this area at least, there is, or should be, little difficulty in providing an adequately controlled water supply.

British Guiana is favoured or otherwise with two rainy seasons, one from April to August, and a short one from November till the end of January.

The total annual mean rainfall varies within wide limits, and may in certain years and districts, be notably deficient. Usually, the wettest month is January, while the driest month is October when the bulk of the main rice crop is reaped.

As to temperature, this is tropical but not excessive, nor does it vary within wide limits at any season of the year.

It will be seen, therefore, that British Guiana possesses the three principal requisites for successful rice-growing, namely, an impervious sub-soil to retain on the land that depth of water necessary for rice ; an abundant amount of water ; and a suitable and reasonably constant temperature.

The coastal belt is, moreover, dead flat so that no expense is incurred in terracing the rice fields, as has to be done in many other important but hilly rice-growing countries such as Japan, Java, Ceylon, the Philippine Islands and Madagascar.

The fact that the area sown, and the amount of rice exported from British Guiana during the last few decades, have increased to the present extent is ample proof that conditions are all favourable.

The yield of paddy, or rice in the husk, is also remarkably high, comparing not unfavourably in different parts of the Colony—although by no means consistently—with such high-yielding countries as Japan, Spain and Egypt, and being well in excess of the yield per acre in British India.

It would serve no purpose to enquire into the origin of rice-growing in the Colony : clearly it has been grown, if in small quantities, for many years. Now it is an established fact of considerable agricultural and economic importance.

There is not and can never be any question of rice supplanting sugar as a major money crop ; but there are many reasons why the cultivation of rice, which has undoubtedly come to stay, should be encouraged as an important if subsidiary crop, provided such cultivation is taken in hand by responsible persons and wisely directed and controlled.

For some time now, and with the exception of some half-dozen Europeans and one Chinese planter, the cultivation of rice has been in the hands of East Indian cultivators, most of whom, or their forbears, no doubt originally entered the Colony as labourers on the sugar plantations.

The owners and managers of many plantations have allocated land—in some cases considerable tracts of land—to these East Indians, to whom rice cultivation is an art inherited from generations of ancestors and whose principal food was and still is rice.

It seems obvious that, under the favourable conditions obtaining as to soil and climate, and with the inherited knowledge or sense of rice culture which these people possess, the cultivation of this cereal is bound to be an important factor in the agricultural development of the Colony.

Broadly speaking, rice cultivation in British Guiana is conducted under the following systems :—

(1) Cultivation on sugar estates, with the consent and approval of the management, for the direct benefit of the East Indian labourers on these estates, most of the harvested rice being consumed locally by these labourers and their families : this may be termed a peasant crop. Perhaps no close estimate has been made as to the acreage so cultivated ; but as some individual estates have many hundred acres under rice, the aggregate throughout the Colony must be considerable. The estate management so arranges its own programme of work as to allow these labourers the necessary time to cultivate the land and sow the seed in early summer, and again, to harvest and thresh the rice in autumn.

(2) Cultivation in country and village districts respectively, where the land is usually rented by the local authority to a farmer or farmers, who in turn may let it out in small parcels of two or three acres to peasant cultivators. The production of such rice fields may be for local consumption or for export, according to quality.

(3) Cultivation on large estates, other than sugar plantations, where rice may or may not be the principal crop and where bananas, coconuts, and other produce may also be grown. The rice from such properties is largely intended for export.

In addition to these three main systems, there is spasmodic individual cultivation of larger and smaller areas throughout the Colony; but it may be accepted that the bulk of the rice grown is under one or other of these three systems.

RICE PRODUCTION.

It is not easy accurately to assess either the total area under cultivation, or yet the yield from that area. The figures for the year ending 31st December, 1928, are doubtless substantially correct, subject to an allowance for irregular cultivation here and there. They show a total reaped acreage of 55,560, yielding 61,144 tons of paddy, or rice in the husk, after threshing.

Taking the proportion of consumable rice to paddy in the fair ratio of 60 to 100, the rice production of the Colony for the year ending 31st December, 1928, was about 37,000 tons; of this amount 18,000 tons, or nearly 50 per cent. was exported.

(It is interesting to note that the years 1920 and 1921 showed almost exactly the same area under rice, *i.e.*, 55,246 and 55,910 acres respectively, but in those years the yield was below one ton per acre.)

The returns for the year ending 31st December, 1929, show that the estimated area under rice had increased to 59,000 acres with an estimated total yield of 71,000 tons. The exports of cleaned consumable rice for the same period amounted only to 14,000 tons as against 18,000 tons for the whole of 1928. Therefore, although the quantity from last year had increased by over 16 per cent., the amount exported had declined by no less than 22 per cent. The reasons for this will be considered later on.

It is desirable to make these figures clear in order to institute a comparison between the British Guiana crop and that of other rice-growing countries, and this in no way to belittle the importance of the former or to minimise its commercial value. Such comparison is important if the Colony desires to enter into competition with such countries in the export market.

The production of the big eastern countries, such as British India (including Burma), the Japanese Empire, the Dutch East Indies, French Indo-China, and Siam, runs *in each case* into millions of tons of *cleaned* rice per annum. Of these countries, British India heads the list with some 35,000,000 tons, while Siam is responsible for, say, 2,500,000 tons.

(China probably produces as much rice as British India does ; but China consumes locally and does not export outside its own borders.)

There is a considerable number of countries producing from 500,000 tons to 150,000 tons of cleaned rice per annum ; some of these countries, such as the United States of America, Italy, and Spain, export some of the world's choicest rices.

These three countries are specifically referred to because their labour is all highly paid Occidental labour and their efforts are devoted entirely to producing a high grade rice exclusively for Occidental consumption, whereas obviously the bulk of the production of the large Oriental rice-growing countries is for local use.

Returning now to British Guiana, we find that, extensive as the production of the Colony appears to be, it is spread along a relatively narrow coastal belt which so far presents no serious depth of cultivation back from the sea, and that the total production of cleaned rice, in the best years on record, is but a small fraction of the yield of those other countries in which rice is a staple article of food. In other words, what in an average year may be an easily exportable surplus either from Bengal or Burma would completely swamp the whole production of British Guiana. The figures just published for Burma alone show about 3 million tons of exportable surplus for the current season.

At first sight, this may not appear to be an encouraging fact to the rice-growers of the Colony ; but it is necessary to face such facts. From them we must endeavour to determine along what lines and by what methods the agriculture and milling industry of the Colony, both of which are established facts and assets of no mean value, can be developed and improved.

RICE VARIETIES AND EXPERIMENTAL CULTURE.

It is probably not generally known that there are literally thousands of varieties of rice, but the distinctions between the majority of these are only of academic interest.

FIG. 1.

RICE. (1929 - 1930.)

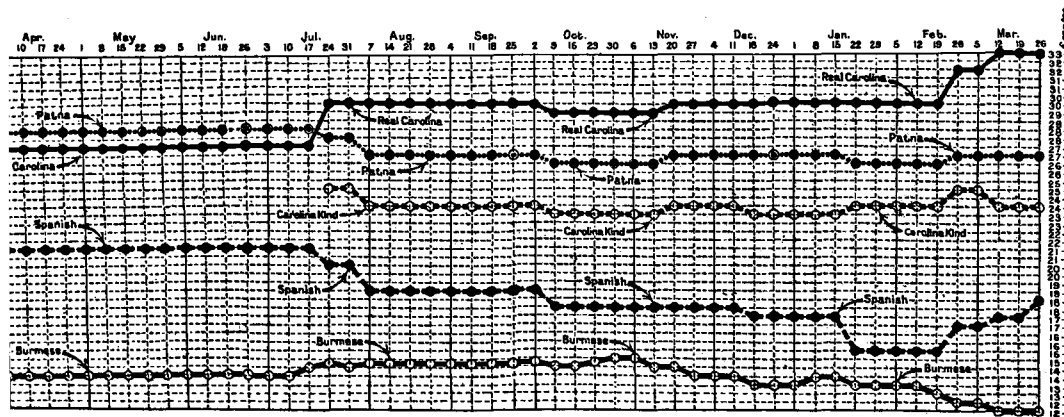


DIAGRAM GIVING RICE PRICES.

Compiled, by permission, from the graphs published weekly in the *Times Trade and Engineering Supplement*.

Commercial rice markets require roughly three standard types, if one excludes special rices and extra small grain grown in certain areas for specific purposes, or to meet purely local demands.

This broad commercial subdivision has no reference to the methods by, nor the extent to which the rice is treated.

These three types are :—

- (a) Long, thin, cylindrical grain of what is known as the Seeta-Patna type.
- (b) Medium long grain, broader and thicker than the above. This is known as Carolina type.
- (c) Short, round grain of the Japanese type. (In some places this is termed barley rice on account of its resemblance—in shape—to grains of that cereal.)

There are many intermediate varieties which approach these types so closely as to be commercially indistinguishable from them : and in practice many such rices are cultivated to be mixed and sold with the master type. There is no particular virtue in one type over another : their choice is only a matter of custom, perhaps even of fashion.

Burma rices, which themselves vary considerably in type, and which are known and appreciated and sold all over the world, compare favourably with the three types mentioned above.

The price ruling for Burma rices are usually much lower than those for choice Patna, Carolina or Japanese grains, although the food value of Burma rice is certainly no less than that of other kinds. (See Fig. 1 for chart of rice prices.)

To elucidate the foregoing, samples of Patna, Carolina and Japanese type rices, together with sample of typical Burma rice, accompany this Report.

Apart from the type of rice required in or by any market, there is a broad distinction which is important to bear in mind when considering present practice in British Guiana.

This distinction is one of preliminary treatment—between threshing and milling—and it only occurs in countries where East Indian purchasers are to be found in considerable numbers, as for example, in India proper, to some extent in Burma, in Malaya, in Ceylon, in British Guiana and perhaps in one or two other parts of the world.

This preliminary treatment is called *parboiling*; the process will be referred to later; but meantime the fact must be borne in mind that practically the total rice production of British Guiana is parboiled.

The rices grown in Japan, Java, Siam, French Indo-China, the Philippines, Egypt, Italy, Spain and the United States of America and the great bulk of the rice grown in Burma, are not parboiled, but are milled in their natural or raw condition.

Consequently—and this is important—there is at present practically no market for parboiled rice in the countries to which these producers of raw or natural milled white rice normally export their output.

In other words, the market for parboiled Guiana rice is strictly limited; India and Burma can easily supply all that is required in the East, at prices with which British Guiana cannot possibly compete, owing to the much lower rate of wages in India and Burma.

Dealing therefore with the matter of the most useful varieties to be grown, having regard to the number which one might attempt to grow with more or less success, the work of the Experimental Station in the Botanical Gardens, Georgetown, is of great importance.

A considerable number of varieties, from different parts of the world, have been tested over a number of years now and the results which are being obtained are most encouraging.

While it is obviously the function of such a station to continue to test out hitherto untried varieties, it is evident that discretion has to be exercised, careful observations made, and accurate records kept of the results actually obtained.

A new variety which may show great promise at the end of the first, or even of the second season's planting, may go off entirely in the following season.

Therefore, it is necessary to go patiently and try out such varieties over several consecutive seasons.

In some experimental stations it is not considered possible to arrive at definite conclusions as to how a recently imported variety will behave under seven years; in others, a period of five years is considered satisfactory.

This refers not only to the selection of pure strains but also, and equally, to hybridisation.

Thanks, however, to the experimental work already accomplished, there are now several reliable rices which have become established and found suitable for conditions in British Guiana.

An investigation of these varieties and of their records at the Botanic Gardens leads one to the conclusion that the following four or five rices may be included in this category.

1. *Demerara Creole* and variants thereof.

This is a good yielding rice with a tall, strong straw. It does not lodge (fall over) or shatter (part with its grain while still on the stem). It is a long, fine grain of the Seeta-Patna type, and has a white kernel without red cuticle. This grain mills freely when parboiled, but owing to its form, it will require more elaborate and careful treatment when being milled as raw white rice.

The average period of growth, from seed to harvest, is 146 days, say 21 weeks.

This rice is largely grown from Demerara to Corentyne.

2. *Blue Stick*.

This is a good up-standing plant with strong straw and excellent yield, but it shatters easily; in other words, the plants shed their grain while still in the stalk; this involves considerable loss of grain, to avoid which the rice is frequently reaped before it is sufficiently mature.

The grain is not quite so long as, and is plumper than, that of Demerara Creole; it is principally grown in Essequibo. The kernel is white, without red cuticle.

3. *Blue Rose Variant*.

This somewhat resembles Blue Stick. It has a good white kernel and strong straw; but unlike Blue Stick, it does not shatter, though it threshes easily.

4. *Blue Rose*.

This is a Carolina type rice, but the sample originally received as seed was not very satisfactory. Probably it was not fresh paddy, and as the germinative power declines rapidly with age, this no doubt accounts for the disappointing results recorded. A fresh supply

of 1929 Blue Rose Paddy seed had just arrived as this investigation was being concluded. The results from this new seed should be very carefully watched.

Normally this is about a 142-day variety from seed to harvest. This is a strong, upstanding grain with white kernel and, normally, does not shatter.

5. The last promising variety noted is that recorded at the Experimental Station as Hope Barley. This is about a 147-day variety; rounder than the other outstanding local varieties, it has a good stand and gives a good yield. It is said that it neither lodges nor shatters, and it mills well.

It should be noted that all rice tested at the Experimental Station was grown without manure.

The selected seed is soaked in submerged bags for some hours and then covered up to permit of incipient germination. This is common practice in many rice-growing countries.

The nursery plots are usually five square rods, or, say, $84\frac{1}{2}$ square yards, in extent. These are sown at the rate of 7 lb. per square rod, and the bed is usually one-sixtieth of the ultimate field, calculated as being equal to 300 square rods; therefore, the seed rate per transplanted field is 35 lb. per 300 rods.

It should be noted that here the old Dutch rod which is 12 feet 4 inches, is the unit of measurement. Three hundred square rods make one Dutch acre, which is therefore equal to 5,066 square yards, as against the English acre of 4,840 square yards.

This is a low economical seed rate which appears to give satisfactory results.

The young rice is left in the nursery for about four weeks. During this time it is carefully watched and may require to be swept periodically with a light drag net to remove destructive insects.

The average of a number of records taken at the Experimental Station shows that the nursery period was 29 days.

The young shoots are then transplanted to the field already prepared to receive them; they are planted in holes about 9 inches apart, two or three to each hole. The plants flower in about 70 days after transplanting, and the rice is usually ready for reaping about 50 days thereafter.

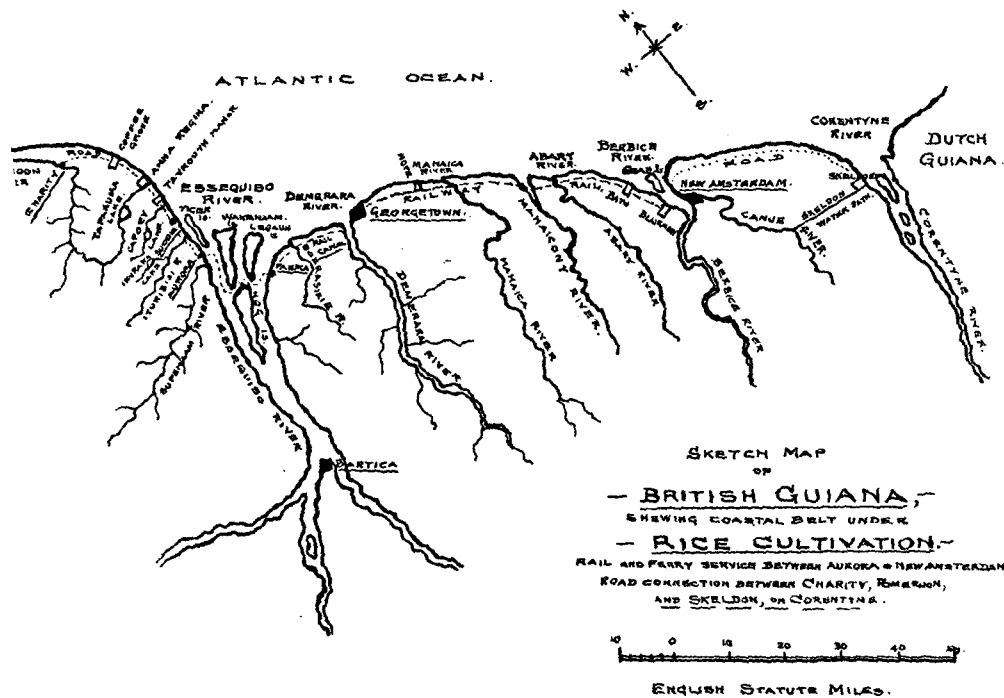


FIG. 2.

While probably the greater part of the crop in British Guiana is transplanted, there are areas where the rice is "shied" or broadcast.

Transplanting gives the best results; it is more economical as regards seed and water required; the yields are greater, and weeding is facilitated.

We can now proceed to consider the matter of bulk production.

AGRICULTURAL AND MILLING CONDITIONS INVESTIGATED.

Attached to this Report is a map showing the coastal belt and, marked by a dotted line thereon, the route followed in carrying out the investigations the subject of this Report. (Fig. 2)

The first of the visits paid to the different rice areas was along the east bank of the Demerara River. Here there are many closely grouped sugar plantations, not a few of which have gone out of sugar cultivation and are now being sown to rice.

It would lengthen this Report unduly to refer in detail to the rice properties visited in that area, but reference will be made to two typical examples.

Plantation Hope, at one time devoted to sugar, and on which the remains of the old sugar factory are still standing, is now being largely devoted to the production of first-class rice under the control of Mr. E. M. Walcott.

This is one of the cases of old cane land, broken down to rice and other cultivation, which, under able supervision and intelligent direction, is yielding excellent crops of two distinct varieties, a long-grained rice, and a rounder, shorter "barley" type of rice, both of which are in demand for export. In this case, the land is let out by the owner to small cultivators at a customary local rental, in assessing which surrounding circumstances are taken into account.

Although the tenant is responsible for cultivating the land, for sowing or planting out, and for harvesting, the owner exercises general supervision, and sees that his tenants cultivate their plots to the best advantage.

In this case, moreover, the owner of the estate has his own rice mill on the spot, and is therefore able to choose the most suitable varieties for milling and for export and to apply the most appropriate degree of preparation desired for any particular market.

A typical example of another kind is that of Clonbrook, a country district near the Mahaica River. Here a considerable strip of old cane land has been broken down, levelled, and put under rice.

A navigation and irrigation canal runs alongside this strip and is used, not only for irrigation, but for bringing the paddy, from the more distant fields, down to the mill, which, as in nearly every case, is situated near the main coastal road which runs through the Colony.

This is a case where the rice lands are let out to small tenant farmers who, in turn, sell their paddy to the miller, who ultimately sends it to Georgetown.

The general appearance of these particular fields was excellent, and there is little doubt but that, with suitable supervision and with properly selected seed, these country and village districts could produce a steady uniform supply of good grain. The contrast between Clonbrook and the neighbouring privately-owned property is most marked. The former is well cultivated and well kept ; the waterway is kept clear, and the whole place gives one a favourable impression.

The privately-owned property presents a most derelict appearance. The land, once broken down from cane, has run to bush. The waterway is overgrown with weed, and the whole place is in a bad state.

There is probably nothing to prevent the owner of a property from letting it go to ruin if he pleases ; but it is emphatically suggested that, in the interests of neighbouring communities, it may become possible to take action of some sort in the future to see that valuable agricultural land is subjected to reasonable agricultural development, and that waterways, drains, etc., are kept clean and free from weeds, dirt and rubbish.

In this case, for instance, the dam or road which divided the two former sugar estates, is bordered on each side by a waterway. It is a road common to both estates or properties, and to that extent it should be made within the power of the Local Government Board, or other competent authority to see that the road or dam, together with the waterways bordering it, are kept clean and sanitary.

The whole of this East Coast Demerara area is irrigated, as far as possible, from the Conservancy water impounded by the back dams behind the old sugar plantations.

To face page 19.



FIGURE 3.
Typical Rice Mill in B. Guiana.

All the rice along this coast is threshed by being trodden out or "bull-mashed" by oxen, an unsatisfactory, although convenient enough method, common to all Oriental countries.

The next visit paid was to the West Coast Demerara, where a considerable number of rice fields and rice mills were visited, from Windsor Forest, near the Demerara River, to Vergenoogen, towards Parika on the East Coast Essequibo River. (See Fig. 3.)

Practically the whole of this land was formerly under sugar cane ; and while there are still some notable sugar estates and large factories in this area, much of the old cane land has been broken down and put under rice.

Generally speaking, all along the coast, sugar has receded, as it were, from both road and railway, leaving the field to rice, which thus derives considerable advantage from its close proximity to both methods of transport.

There is one stream—the Boerasirie River—traversing this area, and the Boerasirie Canal runs eastward, about six miles inland, from that river, in the direction of the Demerara River. It is thus feasible to arrange for reasonable irrigation for this area.

Generally speaking, throughout this area, cultivation is carefully carried on ; but the treatment of the rice, as generally throughout the Colony, leaves much to be desired. This will be dealt with later.

While abandoned cane lands appear to give excellent rice yields, the cost of breaking down such land is considerable.

This will be apparent from consideration of the two following sketches, both purposely somewhat exaggerated ; one of these roughly indicates the transverse section of a cane bed, while the other shows the correct section for a typical rice bed.



The drains of the cane beds are necessary for collecting and running off surplus water in a country having such a heavy rainfall as British Guiana. The beds have to be levelled and the drains filled in before rice can be suitably grown. Even so, it may take several years for the soil in the old drains to attain a consistency similar to that in the old beds, with the result that the rice grown over the old drains does not reach maturity till after the main crop on the old beds is harvested, if then.

This was clearly noticeable in a number of places visited.

After breaking down and levelling the old beds and filling the drains, it is necessary to build up the bunds, levées, or "meres" as they are termed in the Colony, in order to ensure that the beds, planted to rice, will receive and retain the uniform depth of water required for the proper development of the plant.

Taken over a large area, all this land is generally level; but in converting old beds to new it may, for a time, be difficult to ensure sufficient accuracy of levelling within the bed to prevent over-submergence at one point, or deficiency of water at another.

Again, when once broken down, it is desirable to put the reformed land under rice cultivation as quickly as possible. It is remarkable how rapidly such land reverts to bush under the climatic conditions obtaining in the Colony. Once this happens, much money has again to be expended in clearing the land for cultivation.

Estimates given as to the cost of breaking down old cane beds vary considerably. In some cases the cost was stated as \$20, in others as \$30 per acre, in some cases as much as \$40 to \$45 per acre was given as the figure paid.

If the cane land is quickly converted to rice, and no bush has to be cleared, the lowest figure may be correct; but if some time elapses between breaking down and clearing, and again between these processes and the formation of good level rice beds, it is possible that the highest figure may not be so far out.

Samples of paddy from the fields and of rice from several of the mills were taken in this area, and have been examined. They indicate good average quality grain.

Here, as at other rice plantations and rice mills visited throughout the Colony, figures of cultivation and milling costs were freely given.

For obvious reasons, it is better not to connect these figures with any individual farmer or miller, but to tabulate them separately, under reference letters, at a later stage of this Report. (See pages 60-63.)

The impression conveyed by this visit was one of general activity in rice production without any apparent dislocation of labour for sugar cultivation. Threshing throughout this district is also effected by bull-mashing, or treading out by oxen.

Following on the visit to the west coast, the next district dealt with was Essequibo.

Our party went by rail to Parika, thence by ferry steamer to Aurora, on the West Coast Essequibo River ; thence by car to Colony House, Suddie, from which operations in this district were conducted.

Incidentally, all visits throughout the Colony were made by car, unless where recourse to river transport was necessary. By this means we were able to get out at any desired point and to examine any properties or mills which appeared to be of interest.

In respect of work already accomplished in mass rice cultivation in the Colony, Essequibo certainly presents the most advanced features.

Sugar has practically gone out of cultivation and the old beds have been broken down and planted to rice, of which good yields are obtained.

The soil is excellently adapted for rice, and there appears to be a reasonably good supply of water from the small rivers and lakes already mentioned on page 9 of this Report.

With the exception of one or two places on the coast such as near the point where the Capoey River enters the sea, and farther west near Anna Regina, the drains appear to clear the land easily of water.

It is stated that some of the Sea-Kokers, here and there, tend to silt up and, when they do, considerable expense is incurred in keeping them clean. This silting apparently occurs from the sea inwards and not from the land drains outward.

In so far as it is coastal silt the only thing to be done—in view of silting up on other parts of the coast—is to pay special attention to see that the flow through the Kokers is kept as unimpeded as possible.

While the middle walks and side lines in the Essequibo district appear to be kept in pretty good order, the periodic cleaning out of these should be insisted upon. There is not sufficient "fall" at any point on the coast where these Kokers are installed, to permit of any slackness or carelessness in keeping the waterways clear of weeds and rubbish from within.

In Essequibo, the rice lands are, generally speaking, well laid out and well maintained. Some of the fields behind Henrietta presented a particularly good appearance. (See Fig. 4.)

The standard of cultivation is reasonably high, and the milled rice is correspondingly good.

Taken in their order from Suddie in a north-westerly direction, the following estates or mills, as the case may be, were visited:—Johanna Cecilia, Zorg, Golden Fleece, Cullen, Taymouth Manor, Anna Regina (including Bush Lot and Henrietta), Lima and Coffee Grove.

The proprietors willingly gave all possible help and information as might conceivably be useful in forming conclusions.

The Hon. S. H. Seymour and Mr. J. A. Laing, as well as all proprietors, East Indian or otherwise, showed every consideration in this connection. Detailed costs of cultivation, production, milling and transport, were willingly produced and form most interesting reading, particularly when compared with similar figures from other districts. Here again, some of the figures obtained will be set forth later on. (See pages 60-63.)

The prevailing custom in Essequibo is for the owner of the land to let it out in blocks of from three to five acres each, to small tenant-farmers, the rent varying from \$6 to \$8 per acre, according to circumstances, such as proximity of water, access to transport facilities, and general cultural value.

Several of the estates run to five or six hundred acres, and may support a population of, say, seven hundred or seven hundred and fifty people, nearly all of whom are East Indians and appear to be happy, contented and comfortably housed.

The Hon. S. H. Seymour has built houses of his own for such of his tenants as care to take advantage of them.

If one has any criticism to make regarding the lay-out of some of the rice fields, it is in respect of the meres, or bunds, which sub-divide the various plots and retain water thereon. They are unnecessarily high

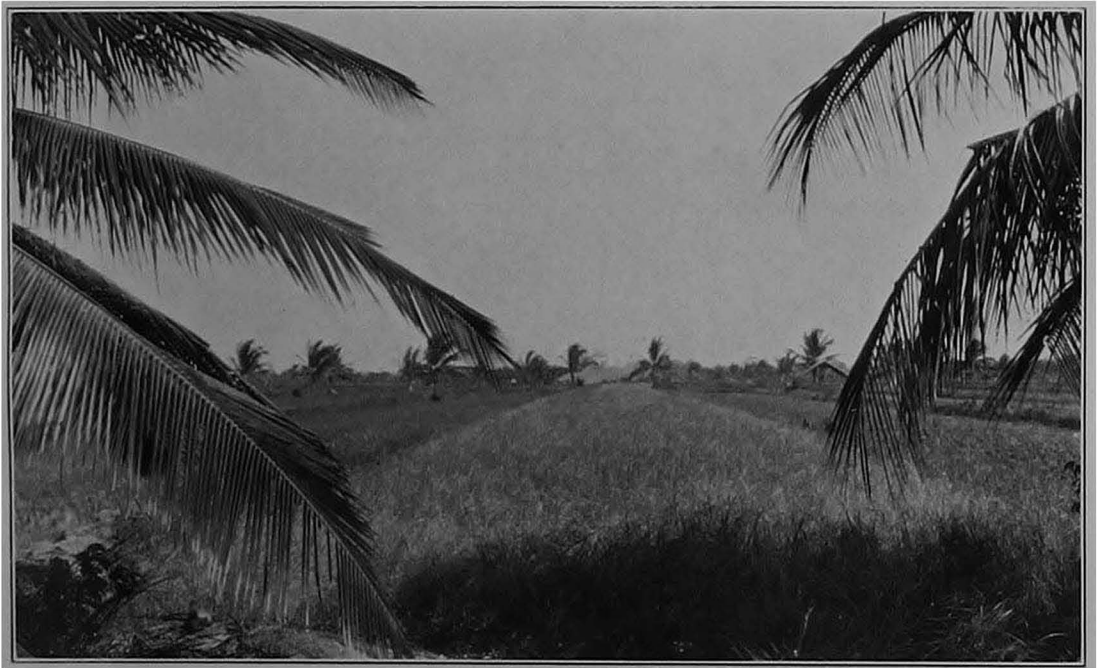


FIGURE 4.
Typical Rice Field ready for harvest.

and liable to crumble. They need not be higher than is required safely to retain the few inches of water which have to be maintained while the rice is growing. The usual, and better, custom is to keep these bunds as low as possible while broad enough to permit of using them for access footpaths to different parts of the cultivated area, to facilitate weeding, etc. They may even be sown to paddy.

Further, the number of these meres is excessive in some places. It is quite unnecessary to have so many, either for retaining water or for marking out tenants' plots; a reasonable reduction in the number of these would sensibly increase the area available for cultivation.

The rice chiefly grown in this area is known as "Blue Stick." This is a medium long grain which presents a sufficiently attractive appearance when milled. Its chief advantages are that it gives a good yield, is a good upstanding plant, has all-white grain, and threshes easily by hand.

It would appear to be this last characteristic which has largely induced the cultivation of Blue Stick in this district. The grain threshes easily because it has a marked tendency to "shatter"; in other words, to fall off the stem of its own accord when ripe.

This has two disadvantages, one of which is that there is a definite loss of valuable grain due to shattering; the other is that the fallen grain inopportunely sows itself.

In this connection, Essequibo is the only part of the Colony where two crops per annum are taken off the same land, and this without any rotation, fallow or manure.

It speaks well for the yield of this rice and for the fertility of the soil in this district that it has been possible to continue this system so long.

As already stated, most, but not all, of the rice throughout the Colony is sown in nurseries and transplanted at a suitable age into prepared fields. Although the summer rice crop had just been harvested at the time of our visit, the nurseries were already being prepared, if not already sown, for the winter crop. The yield from the summer crop is high, running to as much as 30 bags of 142 lb., or, say, 4,260 lb. per acre; the winter crop, reaped in spring, is said to yield about 2,850 lb.

It is always difficult to get correct records from small cultivators, unless these are carefully checked by responsible overseers or owners.

It was stated on page 11 that official returns for the year 1928 showed a total yield, over the whole Colony, of 61,144 tons of paddy from 55,560 acres, or 2,465 lb.; or about $17\frac{1}{2}$ bags per acre. 1929 indicates about 2,865 lb. of paddy per acre.

No doubt the lower-yielding areas bring down the general average throughout the Colony. Even so, however, it is instructive to compare these figures with those of, say, Lower Burma from which much of the rice which competes with British Guiana's exports to, say, Trinidad, comes.

The area under paddy in Lower Burma alone is $9\frac{1}{2}$ million acres; the normal yield per acre is 1,480 lb., or nearly 1,000 lb. per acre less than the average official yield for British Guiana.

In both cases the seed is germinated before sowing and, normally, transplanted after a few weeks. The bulk of the rice is rain irrigated, and the average annual rainfall is practically the same in both countries, but in Lower Burma the land lies fallow for six months and one crop only is reaped.

The reason given for this double-cropping in Essequibo is that there is no alternative winter crop and no cattle raising of sufficient importance to make the latter occupation more profitable than rice cultivation.

After all, if double cropping pays, and if the soil does not become unduly exhausted thereby, there is no reason why it should be discontinued at present.

All ploughing throughout the whole Colony—with one or two individual exceptions to be referred to later—is done by a simple light plough, drawn by a couple of oxen. (See Fig. 5.)

The possibility of using agricultural cultivating machinery and mechanical threshers was discussed while in this district. In one or two cases, tractors have been tried for operating ploughs, but so far only to a very limited extent.

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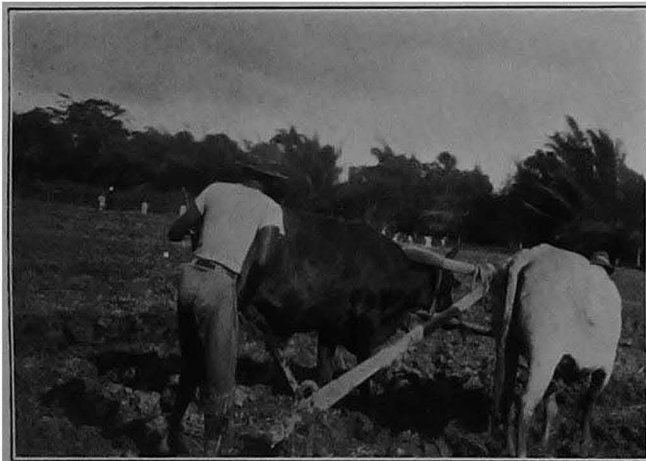


FIGURE 5.

Usual method of ploughing in British Guiana.

In the first place, it is impracticable to pass a tractor over land divided up by meres or bunds into such small plots. The height and contour of these meres at once precludes such a possibility.

The big rice fields in the Southern and South-Eastern States of the U.S.A. are all ploughed by mechanical cultivators and the rice is sown by drills, but the individual fields are of considerable extent, and the bunds, where they do exist, are relatively low, broad and ramped on either side so that a tractor or plough can conveniently pass right over them.

The following somewhat exaggerated sketches will indicate the difference between the arrangement of meres or bunds in British Guiana, and in, say, the United States.



MERES AS OFTEN BUILT IN BRITISH GUIANA



BUNDS AS MADE FOR TRACTOR PLOUGHING

One of the difficulties alleged in respect of mechanical tractors is the risk of these heavy machines getting bogged in the stiff clay. That will certainly happen if ploughing by tractors is undertaken without due regard to the dryness factor of the soil.

It is more than likely that, with two crops cultivated per annum, the land never has time to dry out sufficiently to carry the weight of mechanical ploughing tackle.

Later investigations, however, demonstrated that properly designed tractors, if not of excessive weight, do operate successfully in British Guiana on both rice and sugar estates.

The obvious points to watch are that the land be as well drained and as dry as possible ; that a tractor of moderate power and weight

only is employed ; and that such tractors are always equipped with broad caterpillar treads. (See Fig. 6.)

Ploughing by cable haulage across a field, with winches and engines carried in punts moored on the navigation canals, becomes equally difficult on account of the number of high meres. Apart from this, it is a costly method of dealing with the problem on a relatively restricted rice acreage.

Mechanical thrashing is on quite a different footing, and should be encouraged in the interests of labour saving if for no other reason.

We are at present dealing with Essequibo where all paddy is beaten out by hand on tables placed over mats in the open. (See Fig. 7.)

Judging from many examples noted of such threshing, a considerable number of people seem to be employed, either as operatives or on-lookers. The grain can be handled much more rapidly, with far greater overall efficiency and much less waste, by machinery.

This may be of the stationary or of the portable type, the latter being most convenient, though the installation of stationary machines, complete with driving engine, in punts, is perfectly sound. The unthreshed grain can be conveyed to the machine by land or by water, and the threshed-out paddy can then be quickly transported again by water to the nearest market.

Care should be taken to select a machine specifically designed for rice, which requires different treatment, and therefore different mechanical action from that provided by the standard types of threshers used for other cereals. (See Fig. 8.)

When rice fields, or the acreage under rice are relatively small as in British Guiana, it may be appropriate to employ small threshing machines geared down to be driven by bullocks.

Reference has already been made to the practice known as "bull-mashing," *i.e.* treading out the paddy by three or four bullocks or oxen yoked side by side and circling round a central pole. This is not done in Essequibo, although it is universal throughout the rest of the Colony.

Although it is supposed to be customary to prepare a specially hard mud "floor" on which the grain in the straw is laid, this is not always done. If the ground is naturally soft, or if rain falls just before or during bull-mashing, the threshed-out grain is often exceedingly dirty, while the loss must be considerable.

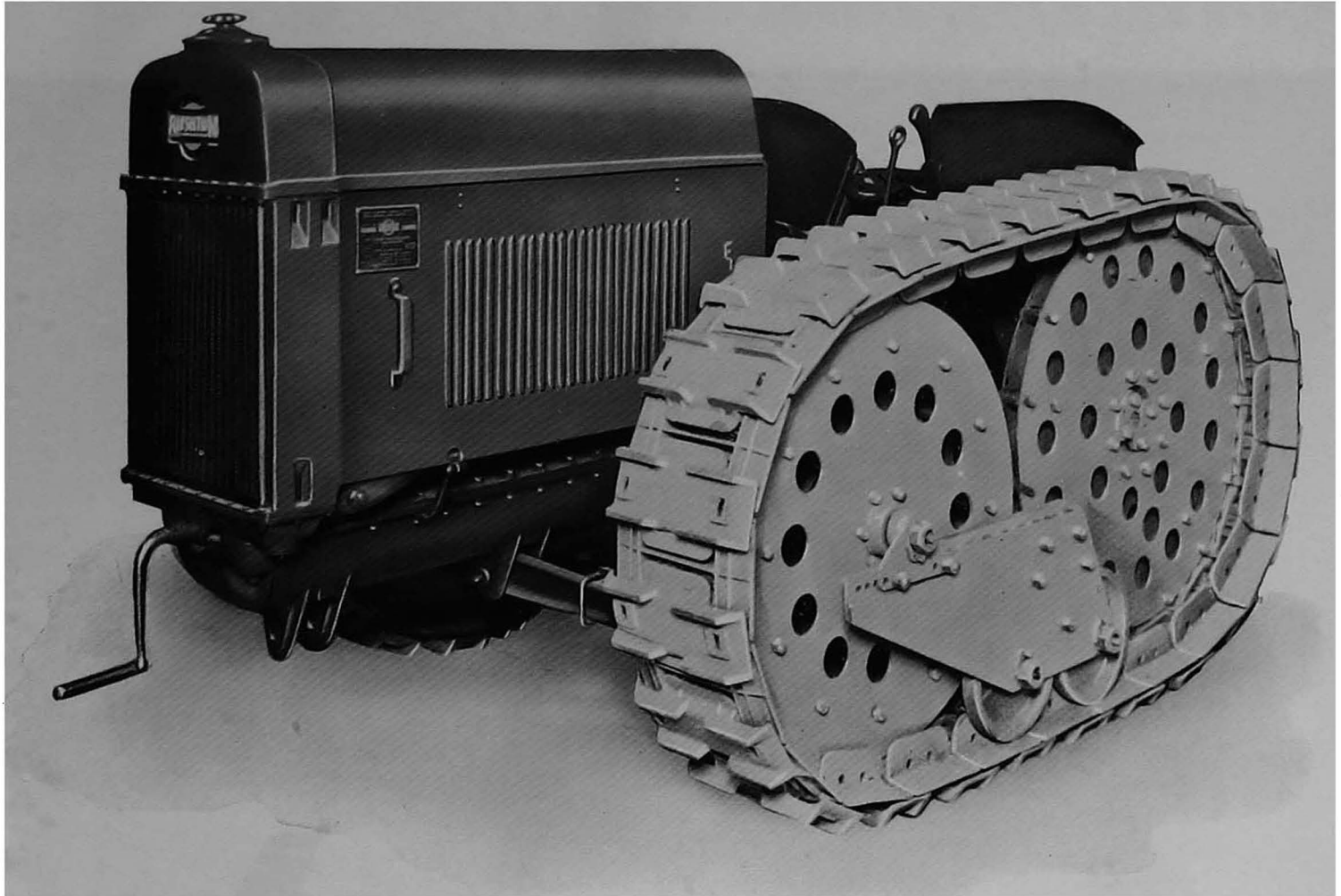


FIGURE 6.
Typical Light Caterpillar Tractor.

To face page 27.



FIGURE 7.
Threshing by hand on Tables, as in Essequibo District.

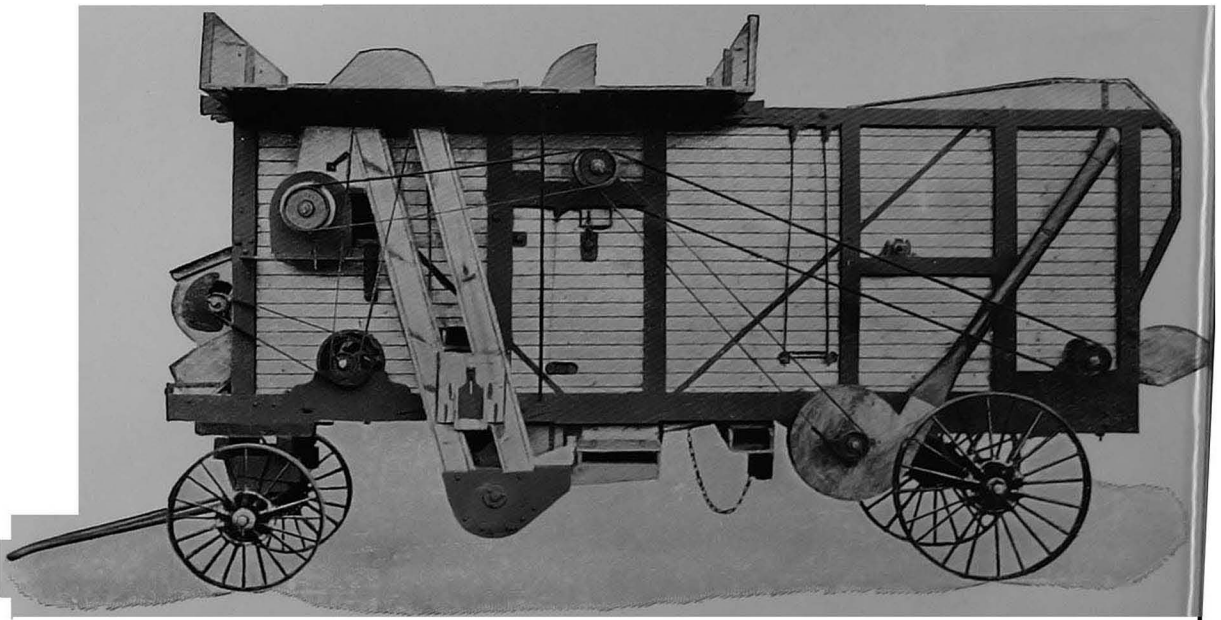


FIGURE 8.
Typical Mechanical Thresher.

The fact that this or some analogous method is adopted almost universally throughout the world does not lessen its disadvantages.

The argument advanced in Egypt against deviating from treading out the rice by oxen is merely that the oxen are there and may as well be employed in this way as in any other.

Satisfactory development of the bullock-operated thresher would, no doubt, contribute a good deal to improvement of product.

It is proposed to deal later with the preparation and treatment of the paddy from the threshing ground. It is fitting to state here, however, that with perhaps only one exception on the East Coast Demerara, the average standard of the treatment of the rice is of a higher order in Essequibo than elsewhere.

A day was spent at Bush Lot, Anna Regina and Henrietta, inspecting the work accomplished in connection with the Government Land Settlement Scheme. We had the pleasure of being accompanied on this occasion by Mr. H. Nightingale, Land Settlement Officer, who showed us round the estate and gave us much useful and valuable information.

It is hardly within the scope of this Report to dwell on this particular settlement problem.

This is of great interest and most promising ; it is to be hoped that the excellent housing scheme already laid down will be made full use of and be fully justified by the early occupation of all the houses, with a corresponding increase in agricultural development and efficiency in this district.

As already noted, the rice lands at Henrietta are decidedly attractive. There are wide expanses of well cultivated grain, apparently without the necessity for a large number of intervening meres. (*See Fig. 4.*)

There were two uncommon features noted along this coast—uncommon, that is to say, as far as the generally accepted system of rice treatment goes throughout the Colony.

One of these is the installation of machines to dry wet paddy by mechanical or artificial means, as against drying the wet grain by spreading it out on special concrete floors in the sun. The latter method is excellent—in the sun ; but if rain comes, as it well may, the whole effect is spoiled and measures must be hastily taken to cover the paddy. For this reason, efforts have been made, from time to time, in many countries, to design a reliable dryer. One may

perhaps be excused from being somewhat pessimistic concerning the dryers seen in British Guiana. Judging by the freely expressed opinions of the users, they are not unduly satisfied.

The other interesting feature is an attempt to separate and purify the offal from the small rice mills.

In shelling the paddy by the methods universally adopted at present in British Guiana—and these to a large extent reproduce the system in vogue in Bengal—there is considerable loss, not only in broken rice which has a definite market value, but also in rice bran, or meal, which is a valuable foodstuff for animals. In only one mill visited, and that in Essequibo, was any sustained effort being made to recover this broken rice, and none at all to recover the bran. (Incidentally, the recovery of the bran is impossible under the milling system referred to.) This will be discussed in detail later; but it is fitting to suggest here that the rice mill installed in the abandoned sugar factory at Anna Regina could, at a very moderate expenditure, be converted to a more modern and up-to-date installation which, under reasonable care, would not only give better milling results, but would also be an object lesson to those millers who desire to adopt more efficient methods.

Generally speaking, the impression left on our minds by the Essequibo visit was one of distinct encouragement in respect of the desire to adopt, whenever possible, improved methods both of cultivation, and treatment after harvesting.

* * * * *

On returning to Georgetown we stopped for several hours at Tiger Island in the Essequibo River, and had an opportunity of discussion with the son of the owner who also has a rice mill, which was visited later, at Houston, East Coast Demerara.

Tiger Island is now practically given over to rice cultivation which, from reports received, is doing well and giving excellent yields.

We also stopped at Wakenaam Island, also in the Essequibo Estuary, where rice was being loaded on to the steamer. Once an important sugar centre, this Island is being gradually given over to rice.

* * * * *

The next visit of importance was to the South Eastern end of the Coastal Belt.

Here, the Rice Mission went right through to Lot 63, on the West Coast, Corentyne River, which was examined as far as Skeldon and Springlands, from whence the return journey to Georgetown was made by easy stages, in order to investigate the rice situation between the Corentyne and Mahaicony Rivers.

This area is extremely interesting and seems to offer every opportunity for considerable rice development. Although there are, here and there, patches of coastal belt which seem more or less derelict or entirely given over to cattle grazing, there are great stretches of land which are eminently suited to first-class rice cultivation on an extended scale, provided that water supply were available in case of deficient rainfall.

We were informed that, on a 35 mile frontage—roughly from Springlands to Bloomfield—4,000 additional acres had been sown to rice during 1929. As it is, official returns up to the end of 1928 showed nearly 21,000 acres under rice in Berbice area, as against 17,500 acres for the larger area of Essequibo Mainland and Islands, and 17,000 acres for Demerara.

Attention could well be directed to the land lying between the coast line and the Canje River, the maximum distance of which, from the coast, is only some 14 or 15 miles. The present system of irrigation, where any system does exist, is by conservancy water as in other parts of the Colony. An exception is the Pumping Station on the Canje River, from which water is supplied through a water path to Skeldon.

There appear to be similar water paths lower down the Canje River, connecting that source of supply with conservancy water at the new back dams running behind Bush Lot and Whim.

Much of the land at present under rice is held by small tenant farmers in lots not exceeding five acres, of which three to three-and-a-half acres may be under rice, the balance being under ground provisions.

Behind this again is more or less virgin savannah which has not been under sugar. It is level and, what is important, it appears to be appreciably higher above sea level than the remainder of the cultivated belt of the Colony. This, of course, permits of better and easier drainage than in Demerara and Essequibo.

While the average yield of Berbice county is stated to be as high as 23 bags of 140 lb. each, or, say, 3,200 lb. or nearly 1½ tons per acre, we were informed that yields in this area have been certified up to as high as 45 bags, or 6,300 lb.—over 2¾ tons per acre.

This yield was questioned, the more so as it is extremely difficult to obtain reliable statistics from small cultivators; but in this case the figure was vouched for by the Resident Acting District Commissioner.

Even allowing a margin for errors of observation, there appears to be no doubt that big yields and excellent crops of good rice are obtained, and obtainable on an extended scale in this district.

There is relatively deep water at Springlands Jetty on the Corentyne River, and the Colonial Transport Department has, it is understood, taken this Jetty over. At the time of our visit there were two vessels taking in rice cargoes for conveyance to Georgetown, although the cost of conveyance by sea, including all handling charges, appears to be identical with that of land transport, *i.e.* 36 to 38 cents per bag of rice weighing 180 lb.

It is stated that most of the small cultivator-proprietors are old sugar estate labourers who are not now so employed permanently, but offer their services for such labour when in need of money, and when their rice fields do not claim their personal attention.

Only one crop of rice is grown in this district which, for the remaining six months of the year is given over to cattle raising. This, of course, is an important alternative occupation for the farmers and their land during the winter months. The cattle tread down the rice straw and stubble, and puddle it well into the soil, besides incidentally manuring the latter.

This combined action is the very best treatment to which rice land can be subjected during six months' fallow. There must, however, be as strict control as possible of the cattle, which may work considerable, indeed almost irreparable, damage to the banks of the side lines and drains when watering, if not kept under proper control.

Most of the rice grown in this area is of the variety known locally as Demerara Creole—undoubtedly of Bengal origin. It is a long thin grain of the same type as what is known in the world market as Patna Rice. It is also very similar to Siam Rice. Incidentally, first grade white Patna Rice usually commands a high price in that market.

A good deal of the rice seed is "shied" or broadcast here, in contradistinction to the planting out common throughout the rest of the Colony. It would be interesting if a careful comparison were made, over one season or more, of the actual results of broadcasting only as against sowing followed by transplanting. This comparison should extend not only to the seed rate employed, but also to the yield per acre.

Such tests would require to be made on adjacent ground and under the same supervision, so that conditions should be as alike as possible in each case.

As is customary throughout the Colony, except in Essequibo, all the Berbice paddy is bull-mashed. Whether it is due to less careful cultivation, to soil conditions, or perhaps to the incidence of rain when the grain was harvested, much of the paddy laid out on the drying ground along this coast was dirty and badly discoloured.

While in other areas, the drying grounds showed grain of golden yellow colour, not a few of the mills along the south eastern coast exhibited paddy of a definitely muddy aspect.

The colour of the husk itself means nothing ; but if it connotes a damp, discoloured or musty condition of the rice kernel inside the husk, then the matter requires attention.

As a matter of fact, speaking generally and not particularising as to any one mill or rice property, one would say that the average appearance of the milled rice here was below that of the Demerara area and notably below that of Essequibo, but there does not appear to be any justifiable reason for this difference.

PREPARATION OF PARBOILED RICE.

With one or two rare exceptions, all the rice in British Guiana is prepared by being steeped, parboiled and dried before milling. This custom is almost universal in India and is found wherever East Indians congregate, whether in their own country or out of it.

This process, not only toughens the rice, permitting of more severe milling, but it also loosens the husk which is therefore the more easily shelled from the kernel. Parboiled rice, moreover, has the faculty of keeping better, both after milling and after domestic cooking: Careful experiments have shown that milled parboiled rice definitely

contains more anti-neuritic " B " vitamin than milled raw rice. The explanation usually given is that as the parboiled process renders the grain itself tougher, the outer layers of the endosperm or kernel, which are rich in this vitamin, are not removed by milling to the same extent as in the case of raw rice.

This special Indian process demands that the paddy be steeped in warm water for a number of hours, varying from 15 or 18 to 24 according to circumstances.

It may well be that the cause of discolouration referred to above is due to dirty water being used for steeping, or to the same water being used over and over again. In several cases the steeped paddy had a most offensive odour, and in certain places there was evidence of fermentation.

The use of unclean or doubtful water is by no means confined to Berbice ; it is too common in other parts of the Colony as well. There is no doubt that side lines and field drains are not kept sufficiently clean and that, most regrettably, they are consistently used as latrines. That under such conditions the rice itself does not become contaminated is probably due to the fact that the parboiling process, which follows that of steeping, the prolonged drying in the hot sun, and the subsequent milling of the rice during which process considerable heat is generated, counteract any evil effects arising from using impure water.

Working along the coast, a considerable number of rice plantations and rice mills were visited and samples of both paddy and rice were taken. The Department of Agriculture maintains in this area an agricultural instructor who keeps in close touch with the cultivators and does whatever he can to guide and help them on right lines. This is entirely good and should be reinforced by more frequent visits from experienced European Inspectors who can still further direct the cultivators to better ends.

It appears that some form of award has been instituted, for good yields of good quality rice, between the Corentyne and Berbice Rivers ; this also is eminently worth developing, the ultimate Referee being preferably a European Inspector from Headquarters in Georgetown.

It is unnecessary to enumerate all the properties and mills visited. We are concerned solely with the results of these visits. Real interest was shown by everyone with whom the visitors came into touch and

there was marked evidence of keenness to improve existing conditions if it were possible to do so without the expenditure of much money.

The market value of paddy and similarly of rice in this area was definitely below that in other parts of the Colony. To what extent this difference in price was due to an all-round drop, rather than to poorer quality, it is difficult to determine; but whereas the price of paddy varied from 7s. to 8s. per bag of 142 lb. in Essequibo, the price in Berbice had dropped to as low as 4s. per bag in some places on the Berbice-Corentyne coast.

At quite a number of mills visited in this district, there were considerable stocks of unmilled paddy, varying from as much as 10,000 to 20,000 bags according to the importance of the area served. The millers stated that at the low prices prevailing, it did not pay them to mill the paddy which is much less liable to deterioration in store than milled rice is.

Whether due to deficient rainfall or to other causes which could not be ascertained on account of lack of knowledge, there seemed to be an unduly high percentage of malformed, as well as of dead grain along this stretch of coast. So much is this the case that many of the millers here have the paddy crudely winnowed before they purchase it, in order to remove the dead grain, or "wind rice" as it is called.

This crude winnowing process, which is also sometimes adopted for the crude separation of broken rice from the mill offal, consists in filling old kerosene tins with the grain, raising the tin above the head and pouring the stream of grain (or offal as the case may be) over mats spread on the ground. This is done when there is a breeze blowing; the wind carries away the dead grain and dust, odd bits of husk, and the bran, while the denser grain falls to the ground and is collected on the mats spread out to receive it.

Reference has been made to the steeping of the paddy in all these mills: the good heavy grain falls to the bottom of the steeping tanks, while "wind" rice, dead grain, and light, loose husks float on the surface.

At a moderate estimate, one may safely place the loss due to dead grain at ten per cent. If added to this, one considers the amount of dirt and dust caused by bull-mashing, it will readily be appreciated that preliminary cleaning of some sort is necessary.

The farmer is unlikely to go to this trouble and expense if he can sell his paddy direct from the "Caryan" or threshing floor. It remains for the miller to accept the grain and to bargain for a lower price if it be of poor quality. It, however, as is often the case, the miller is milling paddy for hire only, returning the resultant rice to the farmer or dealer who brought in the paddy, he will probably not be greatly concerned with the condition of the grain, but will simply fix his milling charges accordingly.

There is ample room here for simple grain cleaning machinery. (See Fig. 9.)

As matters stand at present, there is every chance of the steeping tanks becoming receptacles for dirt, mud and other unnecessary rubbish, with the result that unless these are thoroughly cleaned out from time to time, the grain suffers both in colour and quality.

There were some fine stretches of rice along this coast, some of it grown on savannah and some on old cotton land. The fields presented a uniform well-kept appearance, without the irritating intervention of unnecessary meres which, where needed, were of a practical and unobtrusive kind. In big areas, the line of demarcation between one tenant's land and that of another is indicated by a line of light posts which offer no obstacle to ordinary agricultural operations.

To sum up, as regards the Corentyne-Berbice area, while the quality of the threshed paddy and of the milled rice is not so attractive as that examined in Essequibo, one is inclined to the view that this is due to entirely preventable causes. Cultivation is on a relatively extensive scale; land is eminently suitable, and there is plenty available; and the variety of rice grown is of a type in demand in outside markets. If a controlled water supply were available, there would appear to be no reason why this part of the Colony should not develop, under proper supervision, as to seed selection, cultivation and milling, into a first-class rice proposition.

As to labour, it is common knowledge that this has always been a difficult problem in British Guiana; sugar has prior rights, but one is not convinced that the development which has so far taken place in rice cultivation has, in fact, seriously affected the sugar labour problem. Indeed, it appears possible that development of rice cultivation on sound lines might even attract more outside labour, some of which might become available, periodically at least, for sugar.

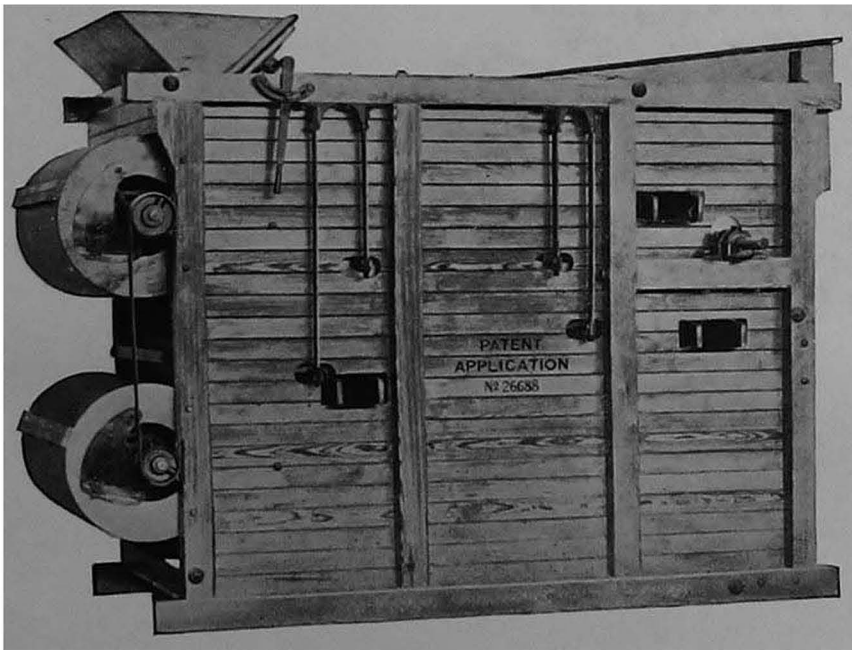


FIGURE 9.

Dressing Plant for Cleaning Dirty Grain.

Apart from a period of two or three weeks in early Summer and a similar period during harvest time in Autumn, there is not, after all, a great deal of labour required for rice cultivation. With the gradual adoption of more modern methods of threshing, grain cleaning and milling, even some of that labour could be released.

The wages earned by agricultural workers in British Guiana are markedly higher than in India. Living may be more costly also ; but the needs of the East Indian labourer are of a simple kind and he is a steady and conscientious worker when engaged in a familiar and congenial occupation, as rice cultivation is in his case.

Enquiries made during the course of this Corentyne-Berbice visit elicited the reply that there was no lack of labour either for cultivating or planting in the Spring or for harvesting in the Autumn. To what extent these operations may have affected the sugar estates it is difficult to say ; but on the other hand, the Managers of the sugar plantations visited indicated that it was feasible so to arrange their work that the temporary withdrawal at stated times of a certain amount of labour for rice cultivation, did not in effect seriously interfere with sugar.

West Indian labour is not much interested in rice, and East Indian labour is said to be unsuited for, for example, the heavy work of cane cutting.

It looks, therefore, as though the labour problem may not be so serious as anticipated in certain quarters, particularly as some areas have gone out of sugar altogether.

This particular trip terminated with New Amsterdam as its centre, and visits were paid to two or three of the principal sugar plantations.

In each case interesting rice developments were noted. Pln. Albion is reputed to have a total of over 1,100 acres of land sown to rice, simply for the benefit of the many East Indians employed on the estate.

At Port Mourant and Rosehall, everything is done to assist East Indians to cultivate their rice fields on the best possible lines, little or practically no rent being charged, irrigation water being provided and facilities afforded for bringing in the paddy.

At Blairmont and Bath a similar state of affairs was noted ; at the latter there were some 500 acres under rice, and another 300 waiting to be taken up. Much of this is old cotton land which has

long been out of cultivation ; it has not been under sugar, but is good level pasture land with a gentle declination towards the coast, again ideal rice land.

Not only do the estate managers assist their East Indian labour in every reasonable way to cultivate rice for their own requirements, but in several cases simple mills are provided so that the locally grown paddy can be milled to meet local demands.

It may be mentioned here that, at the estate of Lusignan, East Coast Demerara, there are said to be over 1,000 acres under rice, again for the benefit of the estate labourers.

It will be seen, therefore, that sugar interests place no obstacle whatsoever, but very much the reverse, in the way of rice cultivation, and this appears to be susceptible of development on the soundest possible lines.

Obviously the management of the big estates commands a wide range of technical knowledge, skill and experience, not only in agricultural methods, but also in engineering practice. They have the land and control of water, and they are in a position, if so inclined, to command the selection of pure seed and to encourage, if not actually to insist upon, proper attention to cultivation.

It is not necessary to labour this point ; it appears to be one of the greatest importance.

The area surrounding the mouth of the Berbice River offers facilities in other directions as well. From the point of view of deep water traffic, Crab Island is a serious stumbling block, but conveyance by shallow draft vessels need not be ruled out. The nearness of the relatively deep Canje River on the one hand, and the vicinity of the upper reaches of the Abary River on the other, with their possibilities in the way of waterpaths for irrigation, are important.

Apart from developments at Bath where Messrs. Davson have very kindly placed land at the disposal of the Department of Agriculture for rice experiments, several rice estates of no little interest lie along the coast watered by the Abary, Mahaica and Mahaicony Rivers. In addition there is a 40-ton-per-minute Government Pumping Station at Bush Lot. In this particular property alone there are said to be some 2,000 acres of good paddy land going under cultivation, and although much of the seed sown here is broadcast, it is averred that yields up to 40 bags—5,600 lb. or two-and-a-half tons per acre—are obtained.

It was in this neighbourhood that the ill-fated and unsuccessful Abary Rice Scheme was started in or about 1911-12. That scheme went on the rocks, not because local conditions were unfavourable, but because its originators and administrators appear to have completely failed to appreciate these same conditions, and to have launched out on a sea of adventure for which they were entirely unsuitably equipped.

Their failure does not alter the fact that the land through which these rivers flow seems well suited to the cultivation of rice on an extensive scale, subject to appropriate recognition of local conditions, to the provision of suitable seed and to adequate supervision. Much of this is not, and never has been, cane land.

It was stated by some cultivators in other areas that the rice grown in the neighbourhood of the Abary and Mahaicony Rivers is discoloured and of poor quality; but provided the "pegasse" or peat lands are avoided and mechanical threshers adopted, there seems to be no reason why a properly conceived and managed rice scheme should not succeed.

A most interesting visit was paid to the property owned by Jugdio Bros., on the Mahaicony River, on both sides of which considerable areas are sown to rice.

It is interesting to note that this enterprising family have, among themselves, cut a navigation and irrigation canal between the Mahaicony and the Abary Rivers, a distance of certainly not less than four miles. This venture occupied two years; but by means of this canal, coupled with pumping plant installed on the banks of the river, it is possible to irrigate a considerable area of land in times of deficient rainfall. Here also the maximum development was observed in the application of cultivating machinery consisting of tractor-operated ploughs and harrows, mechanical threshers, and reapers and binders—all, be it noted, of American origin.

The Abary River rice scheme was, incidentally, promoted by Americans, and it is rather more than probable that the Mahaicony idea of mechanical tillage, harvesting and threshing, together even with some of the earlier tractors themselves, was derived from that ill-starred venture.

Here again the rice is sowed, or broadcast. The little Colony is a self-contained family party and there is presumably insufficient labour available to undertake the somewhat arduous process of

transplanting over a considerable area. Here the yield is not particularly good, nor were the rice samples attractive, but this may be accounted for in part by sowing poorly selected seed.

The individual fields are well laid out and are rarely under 30 acres in extent; and here again there is no unnecessary breaking up of the land by excessive bunding or meres.

On this property there is a number of caterpillar tractors of two, five and seven tons respectively. The latter is too heavy for clay ground in a wet condition; even the usefulness of the five-ton tractor, is restricted; but with the two-ton tractor and a three-disc plough five to six acres can easily be cultivated per day.

A further advantage of the small two-ton tractor is that it can be advantageously employed for driving mechanical threshing machinery which can be conveniently transported in punts, by canal, to different points on the estate.

Other independent visits were paid to rice plantations and mills at Houston, at Vreedenhoep and other places; also to Pln. Diamond where tractors are extensively used.

There is ample evidence that this method of cultivating is entirely practicable in the Colony, if due consideration be given to the type and weight of the machinery used, the time and circumstances of use, and adequate cleaning and housing after use.

Obviously such appliances are too expensive for the small cultivator, but they are not beyond the reach of the owner of a 500-acre estate, nor even perhaps of a village or country district, or other group of cultivators, working under a co-partnership arrangement.

This concludes what may be termed a general review of the situation at the time these visits were paid. It remains now to go more fully into the important question of rice milling, following which the matter of marketing can be dealt with.

RICE MILLS.

An attempt was made, but with little success, to find or compile a list of all the rice millers in the Colony, but their name is legion, and the activities of some at least are surrounded by appropriate obscurity.

As has already been stated, the whole commercial rice output of the Colony, with the exception of one or two cases, consists of what is known in the World's Rice Markets as Parboiled Rice. In British

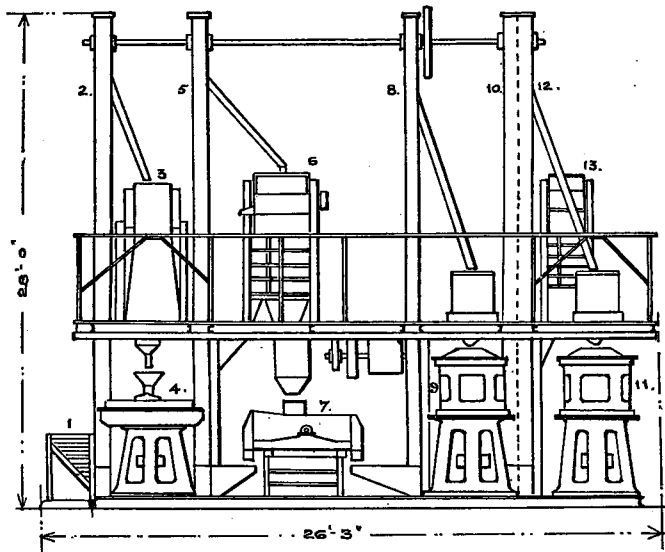


FIGURE 17.

TYPICAL SMALL RICE MILL.

TO TREAT 10 TO 15 CWT. OF PADDY PER HOUR.

(For key flow diagram, see Fig. 18.)

PADDY CLEANING

PREPARATION OF CARGO RICE

PREPARATION OF WHITE RICE

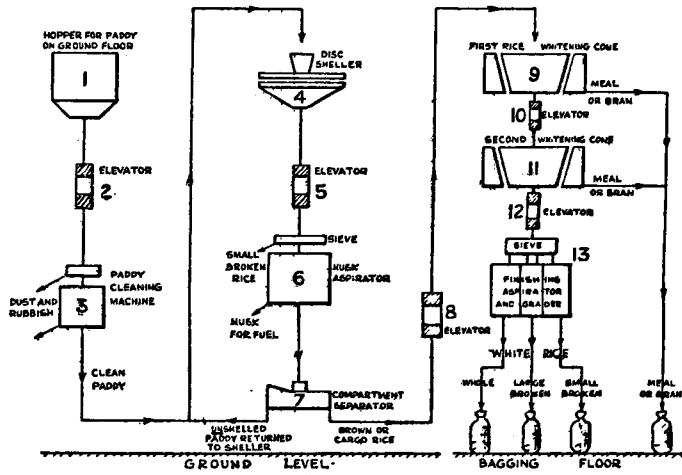


FIGURE 18.

FLOW DIAGRAM OF RICE MILL.
 TO TREAT 10 TO 15 CWTs. OF PADDY PER HOUR.
 (See also figure 17.)

To face page 41.



FIGURE 10.
Steeping and Parboiling Tanks and Drying Floor.



FIGURE 11.
Portable Covers.
To protect Paddy on Drying Floors during rain.

Guiana this is termed Brown Rice, but it would be advisable to try to alter this title, because in the World Markets, the term "Brown Rice" connotes something quite different.

The process and its object have already been touched on; to recapitulate the former briefly, the paddy is brought in from the fields by the farmer who either sells it to the miller, or hands it over for milling and takes it back as rice. This paddy is put into steeping tanks, preferably of iron or cement, but frequently mere empty wooden barrels. In these it is allowed to soak at a temperature which varies from 100° to 125° F., according to circumstances. After 18 or 24 hours of steeping, the sodden paddy may be removed to other tanks or barrels containing no water, or the liquor contents of the steeping tanks are run off and the paddy left for a short time to drain. By means of small perforated pipes inside the tanks or barrels, the drained paddy is now subjected to the passage of low pressure steam for a period of ten or fifteen minutes, after which steam is shut off and the now parboiled hot paddy is tipped out and spread over a cement floor or drying ground exposed to the rays of the sun.

It is customary to allow two days for this sun-drying process as it is considered inadvisable to expose the grain too long at one time. In the event of rain occurring, as it unfortunately frequently does, the paddy must either be hastily collected in heaps and covered over with mats, tarpaulins or such coverings, or ridged wooden roofs are run out on wheels and placed over the heaps to protect them. Photographs of these parboiling tanks, drying floors and portable covers are appended. (See Figs. 10, 11.)

It is in order to obviate the disadvantage arising from unwelcome showers that the idea arose of using mechanical hot-air dryers within the mill. As already remarked, the few examples noted in the Colony cannot be termed successful, nor indeed is this an easy problem to solve except at the expenditure of time and money. The paddy becomes so completely sodden after 18 or 20 hours' steeping that dryers such as are used, for example, in Italy, to counteract the effects of even heavy rain during harvesting, would probably be of little avail.

The paddy is raked over on the cement floor, or it is turned over by women and children shuffling through it with bare feet. When considered to be sufficiently dry, it is collected and brought into the mill where, only occasionally in the Colony, it may be subjected to

the action of a fan to blow away excess dust, dried mud and dead grain. It is then passed to a machine which shells and brushes (so-called polishing) the rice, and from that machine it is bagged off and handed over to the owner or merchant.

The majority of the mills in the Colony are fitted out with one such rice huller (*see* Fig. 12) the output of which may be taken, on the average, as about 550 lb. of shelled rice per hour. Some mills have two of these machines, a very few have three of them, in perhaps one or two cases the miller may even possess four.

In some cases two machines are installed so that the miller may use one for the paddy which he himself has purchased to convert into rice for direct sale ; while the other machine is reserved for milling paddy which a customer may bring in to be converted into rice on his own account. In the latter case, the almost invariable custom is to return one bag of rice, weighing 180 lb. from two bags of paddy, each weighing, say, 140 lb. This, it will be noticed, means a yield of 180 lb. of rice from 280 lb. of paddy, or say, 64 per cent. only. In Essequibo, a bag of paddy weighs 150 lb. so that there the ratio of rice to paddy is only 60 per cent. It is on this latter percentage that the conversion of paddy into rice is usually calculated in the Colony.

Now the average weight of the husk shelled from the paddy is 20 per cent. of its weight. This is an accepted average figure throughout the world ; therefore, according as we take the outturn—of rice to paddy—as 64 per cent. or, as usually accepted, 60 per cent., there is an additional loss of from 16 per cent. to 20 per cent. Under the system in vogue in British Guiana, this is a net irrecoverable loss.

The design of rice huller used is such as to render such loss inevitable unless some sort of auxiliary machinery is installed to try to recover at least a portion of the broken rice which passes away with the husk and bran. These rice hullers have the merit of being cheap in relation to their output, and they are easily and cheaply installed ; but they require a considerable amount of power in relation to their output and they produce a considerable proportion of broken rice. Were it not that the steeping, parboiling and subsequent drying processes toughen the individual grains in a remarkable manner, the breakage would be considerably greater.

It has been stated, not only in respect of British Guiana rice, but also of Patna rice in Bengal, that it can only be milled in this parboiled state (on account of this toughening) and that it cannot be milled into the *white* rice with which we are familiar in Europe. That, in a

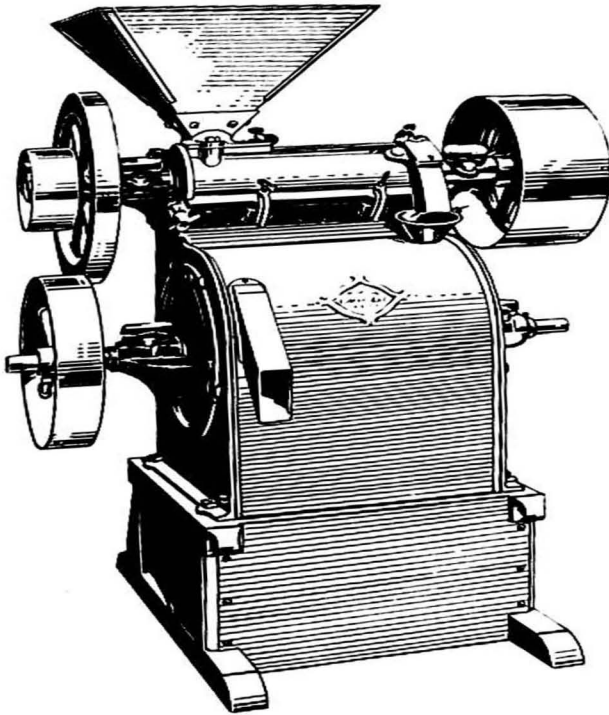


FIGURE 12.
Typical Rice Huller.



FIGURE 13.
Sheller.
For Husking the Paddy.

To face page 43.



FIGURE 14.
Self-Contained Pearling Cone.
For whitening the shelled Rice.

measure, is true if this particular type of rice huller is adhered to, because it is bound to break and damage a considerable proportion of the long-grained white (unparboiled and therefore untoughened) rice.

That is not to say, however, that this high grade white rice cannot be prepared from long-grained Demerara Creole paddy provided appropriate machinery is employed for the purpose.

Inevitably, the long-grained rice is bound to suffer more breakage than a shorter, stouter variety ; and to that extent much more care and better appliances are required in milling the former into European quality white rice ; but it can be done, and is done regularly in other countries. Moreover, by the use of modern machinery designed for the purpose, the inevitable broken white rice is not discarded with the husk and offal, but is all recovered, graded, and sold, at remunerative prices, for a variety of purposes such as the manufacture of alcohol, of starch, of rice flour, for brewing and for pharmaceutical and toilet purposes.

Even in the manufacture of high-grade parboiled rice, considerable saving can be effected by simply shelling the rice in appropriate disc shellers (*see* Fig. 13), winnowing out the resultant husk which can thus be recovered and used as a valuable fuel ; brushing or pearling the subsequent rice in a separate machine termed a " pearling cone " (*see* Fig. 14) or even in the existing rice hullers in use in the Colony. The bran and broken rice can then be recovered and treated so as to separate them for subsequent profitable disposal.

In no modern mill in any civilised part of the world would the loss and waste inseparable from the methods adopted in British Guiana be tolerated. In such modern mills—and there are very many treating literally hundreds, in some cases thousands—of tons of paddy per mill *per day*, it may be said that almost every particle of the paddy entering the mill is recovered, in one form or another, and utilised, or sold as a marketable product. It is important to note that practically every mill in Burma, Siam and French Indo-China is operated entirely by burning the recovered paddy husk, as fuel, under boilers thus generating ample steam to supply a steam engine to drive the complete mill, including auxiliary machinery.

Now it is a debatable point as to the extent to which it might be desirable to attempt to produce what may be termed Europe quality *white* rice in the Colony. There is a market for such rice at British Guiana's door ; in Jamaica, in Hayti, in British Honduras ; in Cuba, Venezuela and Colombia, and, of course, in Canada. There is,

however, an intermediate stage of preparation which is well worthy of consideration.

It was stated on page 41 that to call parboiled rice *brown* rice is to confuse accepted terms. If a grain of paddy is plucked and the husk is split open, it will be found that, beneath the husk and adhering to the white inner kernel or endosperm, there is a fine skin or cuticle which may vary in colour from cream to dark red. In the mass, raw rice, merely shelled or husked, has a rather dirty brownish appearance, and it is this merely shelled raw rice which is termed "brown" rice or, commercially, cargo rice.

There is an increasing demand in many markets for such rice. Into highly protected countries, Europe quality white rice can only enter after paying a substantial duty, whereas there is usually little or no duty on paddy or on "brown" or "cargo" rice. By purchasing this brown rice, however, the buyer is not called on to pay freight on twenty per cent. by weight of husk; and moreover, he can proceed to treat the brown rice in his own mill if he has one, or send it to a white rice mill, to be treated in precisely the same manner, and exactly to the finish and quality which his local market demands. It is therefore also to the preparation of this brown or cargo rice that attention may be well directed, apart from the continuance of the preparation of high-class *parboiled* rice for export to Trinidad, Barbados, and other islands where the latter is largely consumed.

It is well worth consideration whether the best quality of parboiled rice could not be introduced into Great Britain. As a domestic rice it is entirely unknown at home, and yet it presents many excellent features. It keeps well; it seems practically as white as our white rice does when cooked; it has an agreeable flavour and it is undoubtedly more nourishing than the highly finished and artificially glazed and coated rices of commerce.

Done up in special cartons and suitably presented to the buyers' attention, it is possible that a favourable market could be created. It is, after all, in universal use among the white or European population of the West Indies in general; and not only so, it is actually preferred by them to the less nourishing and more expensively milled white rice.

It is recommended that special consideration be given to this point. A sample of high-grade parboiled rice from British Guiana accompanies this Report, together with one of "brown" or cargo rice, though the latter is not from British Guiana.

MARKETING.

Turning to "The Commercial Review," the official organ of the Georgetown Chamber of Commerce, particularly to pp. 424-5 of that Review for December, 1929, and comparing the figures set forth therein with those given on page 11 of this Report, it will be seen that roughly half the rice crop of the Colony is retained in the Colony and half is exported. The proportion retained in the Colony during 1929 is considerably greater than in 1928. (Reference was made on page 33 to the considerable quantity of paddy stored on the Berbice-Corentyne coast owing to the big drop in price.)

The Commercial Review shows that, out of 18,000 tons exported in 1928, British purchasers outside the United Kingdom and Canada took 17,500 tons. During 1929, out of 14,000 tons exported, "other British Possessions" (*i.e.* excluding the United Kingdom and Canada) took over 12,600 tons. In 1928 foreign countries, outside the United States of America, took 556 tons; in 1929 this had been multiplied nearly two-and-a-half times, to 1,332 tons. Purchases by Great Britain and Canada were entirely negligible in each year.

It is recognised that the bulk of the rice sold is parboiled rice which is sent to Trinidad as the largest, and to Barbados as second consumer.

Now British Guiana's chief competitors in parboiled rice are Burma and Bengal. It is a far cry from either to Trinidad and the freight is from 50s. to 55s. a ton. It is a matter of a few hours only from Georgetown to Port of Spain, and the freight is of course very much lower than it is from Calcutta or Rangoon.

From figures kindly given to me by Importers in Trinidad and Barbados, it appears that the former Island took, in 1928, 22,500,000 lb. of rice from British Guiana, and about 7,750,000 lb. from all other sources. In 1929, however, up to the end of September, the figures were completely reversed. British Guiana supplied some 8,500,000 lb. while other countries shipped 17,500,000 lb. to Port of Spain.

In 1927, Barbados imported over 10,000,000 lb. from British Guiana, and 7,250,000 lb. from India; in 1928 Barbados improved her purchases by 10 per cent., taking 11,500,000 lb. from Georgetown, and only 2,500,000 lb. from India. The corresponding figures for 1929 are not yet available.

From enquiries made in Trinidad as to the drop of imported rice into Port of Spain, the reason given in every case was that a steady uniform supply of good quality rice from British Guiana could not be relied upon.

Rice comes from India in new bags and, owing to the large quantity available, the importer can buy for his requirements several months ahead, while being sure of receiving a standard uniform quality when the time comes. As things are at present he cannot depend on doing this in respect of Demerara rice, because the supply is too uncertain, and the quality—except in the case of what, in the world rice market are but small parcels—is insufficiently uniform and attractive.

I have made most careful examinations on several occasions of the imported East Indian and of the Demerara rices, and have no hesitation in stating that, on sample, Demerara rice is every bit as attractive as—in some cases much more so than—the East Indian rice samples imported into the West Indies. The difficulty appears to be simply that there is not enough of the good quality Demerara rice available; that if there is such quality available at one time, it may not be so available at another and, finally, it is, quality for quality, at least as expensive as the imported East Indian.

Again, there is no doubt whatever that the efforts of the first-class merchant in Georgetown to sell good rice in either Trinidad or Barbados are stultified to a considerable extent by the promiscuous shipment by small traders of thoroughly unsatisfactory rice in small parcels. Such parcels are hawked round the market until at length they have to be disposed of at prices which must obviously re-act on the prices of the better quality product; moreover, the lower grade stuff tends to reflect on the credit of the better milled, better quality, though higher priced grain.

In addition to the question of quality and quantity, there is little doubt that the price asked for Demerara rice is undoubtedly high.

The wages paid to agricultural labourers in British Guiana are considerably higher than the corresponding rates paid in either Bengal or Burma. On the other hand, the yields per acre in Demerara are much higher than in British India, so that, per unit of crop harvested, the difference should not be so markedly in favour of British India.

It is suggested that, by the adoption of more up-to-date methods, permitting the recovery of by-products which, in British Guiana, are

merely wasted, the cost of milling, anyhow, might be perceptibly reduced. There is no doubt at all that rice should only be shipped under a sworn weight certificate, and then shipped in new bags, carefully sewn.

In some shipments noticed, the sewing was definitely unsatisfactory and a number of bags burst open at the corner on handling.

There has been little or no organisation of the rice industry in British Guiana, and without some such organisation it seems difficult to predict a rosy future for that industry. It is too scattered and spasmodic and, one might even suggest with all due deference, carried on in too many almost water-tight compartments.

The sugar industry has always been under the control of European firms of repute, among whom it was not difficult to arrange a periodic exchange of views and a common understanding as to the benefits to be derived from this or that procedure.

Hitherto the rice industry has been on a very different footing and has been largely, as it still in point of fact is, in the hands of relatively small cultivators, the great majority of whom are of East Indian origin.

It is always difficult, under such conditions, to arrive at a common denominator, and to formulate a mutually satisfactory policy. Again, and with all respect to those concerned, there has been an undue amount of talk, in relation to solid foundation work done, regarding the possibilities of the rice industry in the Colony.

Having regard to favourable soil and climatic conditions, with resultant good yields, the temptation to increase rice cultivation and to multiply small mills is intelligible enough. Much has been said and written as to the potentialities of this market or of that, as well as of the productive capacity of the Colony; but it would have been better to hasten slowly.

The promiscuous and haphazard sowing of mixed seed; the crude methods of threshing, cleaning and milling; and the unregulated system of shipping and selling hitherto in vogue, have definitely retarded the progress of the Industry where they have not actually brought it into disrepute. There can be little doubt that this is the reason for the stocks of paddy which have accumulated along the coast. (See page 33.)

The whole matter is one which can only be dealt with by the local producers and millers themselves, working always, and this is important, hand-in-hand with the Department of Agriculture, to ensure adequate supplies of reliable seed of uniform quality and type. There is usually somewhere a market for a really good product if continuity of supply and quality can be relied on, assuming of course that prices, having regard to quality, are competitive.

Further, it may doubtless safely be left to the enterprising merchant, or to a combination of such merchants, to ascertain for themselves where that market lies. British Guiana is, in fact, most favourably situated geographically in respect of markets at her very door. Certain of the West Indian Islands as far as parboiled (or erroneously termed "brown") rice is concerned; Central America and the North-Western territory of South America; Jamaica, Hayti, Cuba and Canada in respect of unparboiled rice, whether completely or partially milled. Let it be noted that even if British Guiana secured the whole of the parboiled rice trade with Trinidad and Barbados, based on the average total imports by these islands during the last three years, she would only find an outlet for some 20,000 tons out of a total production of some 40,000 tons of milled rice per annum.

As against parboiled rice, however, there is a market at the Colony's door for ten times the quantity of *white* rice which they could at present ship as parboiled rice to these two islands.

The first and absolute condition, however, is the sustained production of adequate supplies of uniform reliable quality, of types appropriate to these respective markets.

How far Great Britain or Europe may become a purchaser will depend entirely on this question of sustained quantity, quality and type. Hitherto as previously stated, parboiled rice, however inherently attractive or valuable as food, has held no place at all outside the tropics. Whether education and advertisement can effect any change in this respect, remains to be seen. London and Canada, Holland and Hamburg are close bargainers and critical purchasers of good quality grain, to be milled up locally to suit high-class markets; but unless the supply is uniform and dependable and reasonable in price, they will certainly refuse to buy.

CONCLUSIONS.

To sum the matter up, I suggest that attention be concentrated on the points summarised below.

1. *Irrigation and Drainage.*

For the sure production of regular crops of good quality, these are of primary importance. A properly co-ordinated irrigation and drainage scheme will of necessity be costly. So, also, will be the appointment of reliable trustworthy irrigation officers.

This is a matter with which the Government only is competent to deal. Moreover, it will require not only careful consideration, but a considerable measure of altruism to decide where, if agreed on, such a scheme should commence. The view of the Reporter is that the first steps should be taken either between the Canje River and the Corentyne coast, or between the Abary and Berbice Rivers.

Growers in other areas will be disappointed ; but the scheme, if proceeded with, should be started where the need is greatest and where there is most scope for big future development. Interest and Sinking Fund would have to be met out of an agreed water rate to be levied, and continuance of water supply should be absolutely conditional on proper cultivation.

2. *Mechanical Cultivating Machinery.*

As stated in the body of the Report on page 25 the adoption of light tractors for ploughing and harrowing is entirely feasible provided due regard is paid to—

- (a) condition of soil at time of use ; and
- (b) proper disposition of meres to permit of most effective use.

It is obvious that the use of such tractors on small fields would be ruled out as impracticable. It is equally obvious that their maximum efficiency will be obtained on fields of as uninterrupted a contour as possible. At present any tractors in use are of American origin. Can great Britain not meet the demand ?

3. *Seed Selection.*

This is of primary importance. It cannot be over-emphasised. With a few exceptions, the seed usually sown is badly mixed, resulting in an equally mixed product which may not only lead to undue loss alike in the field and in the mill, but may also spoil the market.

There is, so far, comparatively little red kernel rice in the Colony, but if and when it appears it should be rogued out and burnt.

In dealing with seed selection, regard must be had to the type, *i.e.* length, breadth, thickness, density and general appearance of the finished grain; while experimental work in different varieties is of great value, the selection and propagation in bulk of a few—two or three—standard *types* is the object to be aimed at. Their selection will clearly depend largely on the markets in view.

The Department of Agriculture should take this up at once by way of demonstration; large cultivators could follow, grading their own seed later on. Plant specially designed for this purpose is already on the market, and in operation in French Indo-China, Egypt and other countries. Not only would yields be increased, but buyers of rice would be attracted, as the result of sowing uniform seed.

In this connection, the viability of the seed must be borne in mind: seed stored for over a year soon begins to lose its germinative power. A point of great importance is that paddy stored for seed, should not contain more than from fourteen to sixteen per cent. of moisture.

Seed rate, per acre, is important, particularly where specially selected seed is being sown. The Department of Agriculture, through its Inspectors, and Sub-Inspectors, has no doubt got this clearly in view.

4. *Manures.*

So far little has been said or done in connection with rice in the Colony, but it is a matter which should not be lost sight of. The Department of Agriculture has no doubt got this also in mind.

5. *Weeds and Pests.*

So far, British Guiana seems relatively free from these; compared with some other more important rice-growing countries, the Colony cannot be said to suffer. Shied seed and double-cropping are apt to induce weed and "volunteer" rice, but generally speaking the fields were clean. Birds will always do a certain amount of damage, notably ducks and pigeons. The cultivator may have the remedy for this in his own hands. As to insect pests, if the seed beds are swept regularly, these will be kept down. As to disease, one saw little or no evidence of this.

6. *Harvesting.*

This is done by hand and the straw is left on the ground, to be ploughed in later. The preceding remarks on tractor ploughing apply here also. In one case only was a mechanical reaper seen in the Colony and that not in operation. There is no particular reason for departing from the usual practice at present.

7. *Threshing.*

Bull-mashing and the threshing table are alike wasteful and unsatisfactory, though almost universal. There are thoroughly satisfactory specially designed rice threshers of British manufacture on the market at moderate prices. Identical machines have been supplied to the Departments of Agriculture in Egypt, Ceylon, Bombay, Bengal, Central Provinces, Raipur and other big rice-growing centres. For the relatively limited present conditions in British Guiana it is not necessary to employ heavy big-capacity machines. The farmer who has a light tractor can easily operate a thresher, moving the latter, if of portable type, conveniently enough from centre to centre by means of the former. For small estates, or for country districts, a Communal Thresher may well be employed, but if used as a communal machine it should be thoroughly cleaned out after each complete threshing of one farmer's grain, so that, in case of different varieties of rice, the chance of mixing seed (retained out of the threshed paddy) is reduced to a minimum.

8. *Grain Cleaning or Dressing.*

The properly designed modern rice thresher dresses the threshed grain to a certain extent, in other words, it will remove a fair proportion of dead grain, wind grain and rubbish, but where mechanical threshing is not adopted, the use of a suitably designed grain cleaner, to treat the paddy prior to milling, will often be of great value. Particularly will this be the case with bull-mashed paddy which is inevitably mixed with small particles of mud and even of animal excreta, husk, straw and other rubbish.

Excellent machines of British manufacture are available for this purpose. (See Fig. 9.)

9. *Steeping, Parboiling and Drying.*

Present methods are with some exceptions crude but apparently reasonably effective. The use of a combined elevated steeping and parboiling tank has obvious advantages. It saves handling and permits of steeping at a regulated temperature. The elevated tank can be more readily drained, and therefore cleaned, than a tank on the ground. Some of the tanks, pans and barrels at present in use are noticeably foul. By adopting the grain cleaner referred to under 8 (*supra*) a good deal of nuisance and labour in connection with steeping could be avoided.

It would be well to point out here that the greatest possible care is required if it is proposed to dry damp—apart from steeped and parboiled—paddy for storage as seed. Careless treatment and over-heating may seriously impair the germinative capacity of the seed.

As pointed out in the body of this Report, mechanical drying is not an easy problem. Steam drying is apt to damage or discolour the grain. Hot air drying involves the use of fans requiring not inconsiderable power. Drying by hot water elements seems to offer a reasonable solution and there are such dryers on the market; but as all artificial dryers must dry the grain slowly, they require to be of considerable size, if they are to deal with any quantity of material, and this, of course, costs money. Sun drying is excellent, but it cannot be undertaken during the rainy season.

10. *Milling.*

The present method of milling by means of what is known as the Engleberg Huller is undoubtedly effective, up to a point, when treating parboiled rice. It is, however, unsuited to milling anything but parboiled, and therefore toughened and easily shelled grain. Moreover, the loss of husk, valuable bran, and broken rice is considerable.

Feeding stuffs are being imported into the Colony now. There is valuable feeding stuff in the rice bran, although its value at present is discounted by its inevitable admixture with broken husk which is a dangerous food stuff. The paddy should be shelled in disc shellers, which require very little power. (*See Fig. 13.*) The resultant mixture of husk and shelled grain (with the bran still on it) can then be winnowed, the grain being thereafter milled in the Engleberg

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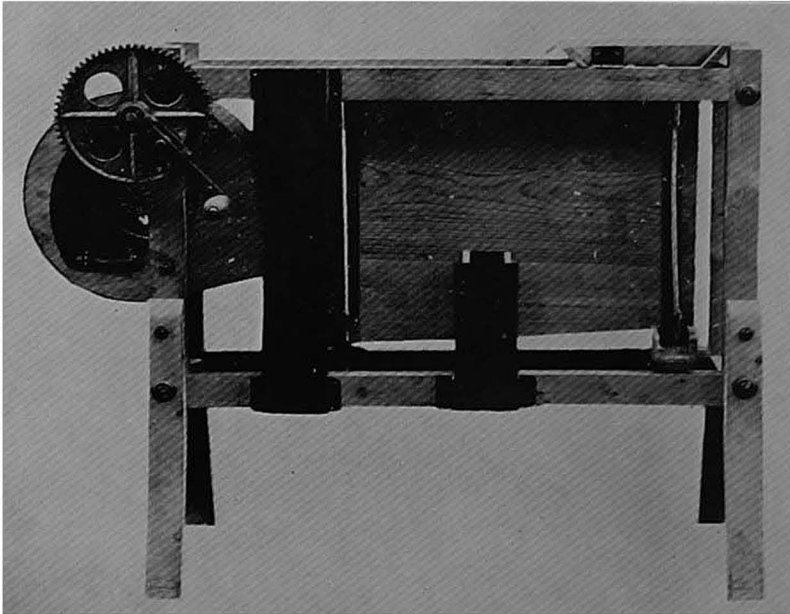


FIGURE 15.
Sieve and Winnower.
Suitable either for Hand or Power Operation.
For Dressing Rice Offals.

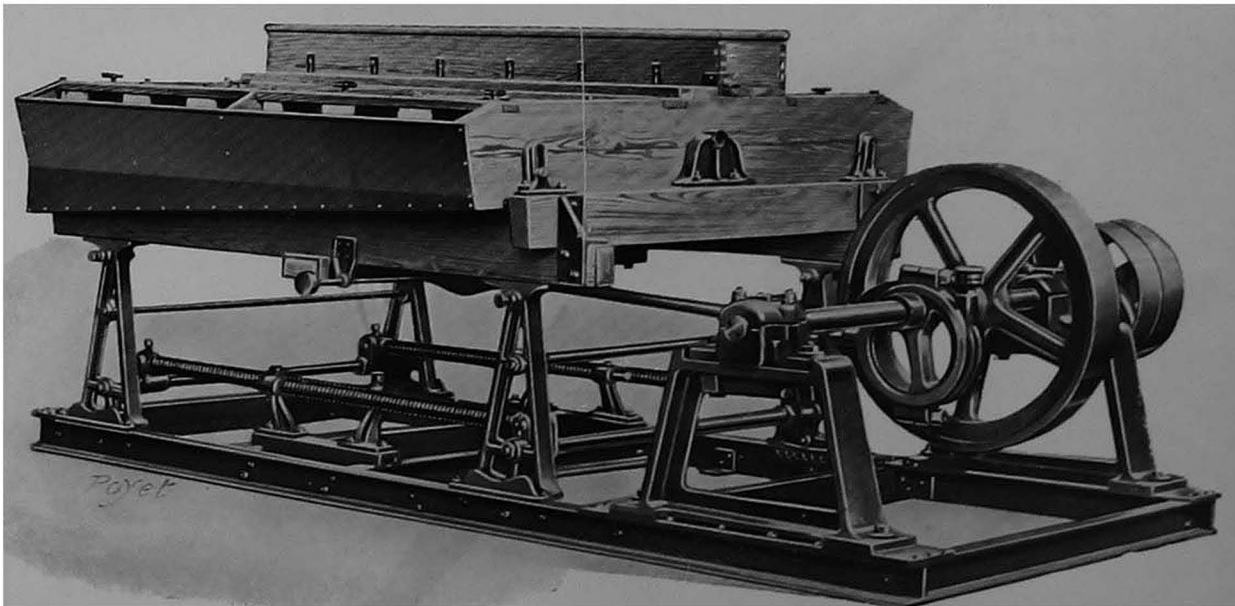


FIGURE 16.
Machine for separating shelled from unshelled Rice.

machine. The husk is a valuable fuel and can be used as such, while the offal from the Engleberg, being free from husk, can be passed through a simple machine to separate the bran from the broken rice. Both have a definite food and money value. (See Fig. 15.)

For the preparation of true brown rice, *i.e.* not parboiled, but merely raw shelled rice, the Engleberg machine is not required at all. The disc sheller is used, followed by a winnower to remove the husk, and by a special machine to separate the shelled rice from such grain as may still remain unshelled. (See Fig. 16.) (It must be borne in mind that unparboiled rice does not shell nearly so readily as parboiled grain does.)

There is a definite market for this real brown rice, not parboiled, containing not more than two per cent. of paddy and not more than ten per cent. of broken grain. As already stated, this brown rice is sold in many parts of the world to be milled up into white rice to suit local markets.

As to the milling of white rice itself, this has hardly been touched in the Colony. The usual methods at present in vogue are entirely unsuitable: properly designed machines, each proportioned to the requirements of the process, must be employed: *i.e.* to clean, shell, winnow, separate, whiten and finally purify the ultimate product. In this system, the whole of the original grain is accounted for and recovered in the form of a product of greater or less commercial value.

When dealing with long thin rices of the Demerara or Seeta-Patna type, a properly designed mill is essential.

Incidentally, while the Engleberg type of mill is of little use for milling white rice, a mill designed specifically for producing white rice will equally produce parboiled rice if desired. (See Figs. 17 and 18 for typical small white rice mills.)

It is common knowledge that, at one time, there were several moderately important Mills in the Colony, other than merely simple installations of Engleberg Hullers. These mills were installed at Berbice, Corentyne, Mahaicony, Georgetown and perhaps other centres as well. Not one of these mills now exists.

Various explanations were advanced for the non-success and subsequent dismantling of these mills. It would be injudicious to re-open a discussion on these causes now, but it is possible that the

mills were too large for the supply of uniform grain available at that time ; moreover, their operation may have been unduly burdened with overhead charges which absolutely precluded their commercial success in face of competition from the cheaply installed and cheaply operated small mills.

In fact these ventures were perhaps over ambitious in relation to the general condition of the industry at that time. There seems no reason, however, why judiciously selected mills of moderate capacity should not be a commercial success, having regard to the more established condition of the whole industry, and the expansion which may be legitimately anticipated, if patience, a broad outlook and community of interests are brought to bear on the problem.

11. *Milled Rice Surveys.*

This is a critical point deserving special consideration, the more so because the total production of the Colony is relatively small (compared with that of its competitors) and yet that production is represented by the combined output of a large number of very small mills.

Taking the average mill in the Colony as having two Engleberg machines giving a combined output of half a ton an hour, we get from such a mill about five tons per working day.

The average mill in Burma, Siam or French Indo-China, milling for export, has a capacity at least fifty times as great. The mill producing this greater quantity does so under the supervision of one skilled mill manager. The machinery works continuously at this output and therefore under the most favourable conditions. There is at least no chance of any parcel of five tons differing in any appreciable degree from the remaining 245 tons milled during the day.

In British Guiana, on the other hand, the character of the five-ton output from B's mill may well be essentially different from that of A's ; while C's may differ from both.

It is thus that, apart from variations which arise in the paddy itself, due to lack of uniform seed or to careless cultivation and threshing, variations in the quality of the finished rice are bound to arise. Under existing conditions, the paddy supplied to these small mills may itself be derived from a number of small tenant farmers whose product *may* differ materially. Yet it is precisely the united

product of a number of these quite small rice fields and not very efficient small mills which goes to make the total of a reasonable shipment.

Now this is where supervision is badly wanted, and where it is impossible under existing conditions to apply it as it should be applied. It may be argued that it is up to the merchant to see that what the miller sells to him is equal to requirements. Is the merchant necessarily competent to determine this, or if he is, has he the time necessary to examine all these contributory supplies? If he has grounds for rejection and does reject, how is he going to be placed with regard to fulfilment of his contract with his customer?

In an old established industry where there are definitely understood and accepted standards of milling which do not vary from month to month, or even from year to year, and where vast areas of more or less uniform paddy are available, no difficulty need arise. It is otherwise in a relatively new and comparatively small industry such as that under consideration; that the difficulty does frequently arise, is admitted on all sides.

It would appear that the only way in which it can be overcome is to have a Board of Control consisting of representatives of farmers, millers and merchants respectively, with one or two non-party members affiliated, together with a representative of the Department of Agriculture, whose province it would be to examine, approve or reject paddy delivered to and rice prepared by these many small mills. Central depots should be provided in each county and both paddy and rice graded according to a mutually agreed specification, both as to type and quality.

At present the millers speak of their super, No. 1 and No. 2 qualities, but these qualities from one mill may bear little relation to the super, No. 1 and No. 2 from another mill farther along the coast.

Grading, therefore, is essential, and any scheme introduced must include all responsible growers and millers interested in providing rice for shipment from Georgetown. If rice so shipped passed through such an organisation, and bore, on the bags, the stamp of that organisation and of the grade, it should materially help to raise and maintain the standard, and obviate many, if not all, of the complaints which, rightly or wrongly, are made from time to time by purchasers of Demerara rice.

In addition, such rice should be sold on a sworn weight certificate, the bags being marked accordingly.

While this would never prevent the pirate miller from running small consignments of uncertified and indifferent quality over to Port of Spain or Bridgetown, the purchaser thereof would at least know what he was not getting.

A properly constituted body acting in this way under Government sanction, could do a great deal to abolish existing abuses and irregularities, and to establish the rice trade on a satisfactory footing. While the quality of rice produced for internal consumption is of relatively little importance, it would be one of the functions of the Board of Control to see that such low grade rice was not incorporated with higher grade products for export.

12. *Supervision of Mills.*

While it would rightly be deemed unfair to make any proposal which might be construed as interfering with the liberty of the subject, there is no doubt that some sort of supervision should be effected, either under the authority of the Local Government Board or under that of the Medical Officer of Health, in respect of general cleanliness, hygiene and safety of workers.

Not a few of the mills visited were in an extremely dirty condition, badly lighted and ill-ventilated. The water supply to many of these, whether the water was converted into steam to drive a steam engine operating the mill or used for steeping and steaming paddy, was fouled and unpleasant.

At present it appears necessary for any person desiring to erect a new mill, to make application to the Local Government Board to do so. The application is published in the local Press and objections within fourteen days are invited. If no such objections are raised or, if raised, are not substantiated to the satisfaction of the Board, the application is granted.

Without the least suggestion as to acting harshly or unconscionably, it should be in order for the Local Government Board, either on its own responsibility or in conjunction with the Medical Officer of Health, to refuse the application if they have reasonable grounds for so doing; or if, having been granted permission to build, the miller does not conform to such regulations as may be laid down from time

to time by the Governor in Council, it would be within the power of the competent authority to compel him either to put matters right or to shut down his mill by a given date. Here again the opinion of the suggested Board of Control could be of considerable value. Stated baldly, the wiping out of some of the existing mills could hardly fail to raise the present standard of rice in the Colony.

13. *The Department of Agriculture.*

The work already done by this Department on rice is admirable and will no doubt be developed more and more as time goes on.

There is a relatively long coast line broken at three points by the Essequibo, Demerara and Berbice rivers respectively. In the case of an old-established industry like that of sugar the reaction of the Department is probably academic rather than otherwise. In the case of what after all is a new industry like rice, the co-operation of this Department is essential and can be of the very greatest possible value.

Apart from the work at the experimental station in Georgetown, a great deal has yet to be done in providing farms for bulk propagation of suitable seed in selected areas at appropriate points on the coast, together with dry well-ventilated depots for such seed.

This must be done under the Department's supervision, and it is for the Department also to follow up the distribution of such seed by watching the resultant crop and aiding the farmer in turn to select his own seed from the best of his crop.

Likewise, to advise him as to his sowing and planting out ; as to keeping his fields clean ; as to manures, if such be required ; and as to the threshing and cleaning of his grain.

There is plenty of work to keep such of the staff as are earmarked for rice developments, working up to the collar for some time to come, both on outdoor work and on records within the office ; expenditure on this account can be fully justified.

14. *Financial Assistance to Farmers and Millers.*

It is a moot point as to how much, and in what direction, if any, and by whom, assistance could be rendered to deserving farmers or millers as the case may be.

There appears to be little doubt that a not inconsiderable number of small but entirely trustworthy men may be unduly handicapped for lack of what may seem a relatively small amount of capital.

Rents may or may not be unduly high, but the rate of interest charged by certain owners, or by money-lenders, appears unduly harsh. Owners and merchants at present advance money, tools or machinery on the security or on the prospective security of the crop ; while it would obviously be improper and erroneous to impute any but the best motives to any individual owner or firm, the impression remains fixed in one's mind that the present system might become liable to abuse and is far from being in the best interests of the industry.

One can hardly, perhaps, under present conditions, expect the Banks to take a hand ; but if, through the intervention of a properly constituted Board of Control, the standard of British Guiana rice were raised, and certificates of quality were issued by such Board, it would not appear to be too speculative a suggestion that the Banks might then advance money direct to the cultivator and also to the miller, on appropriate terms and under suitable conditions as to security.

The enormous rice crops of the East and of the Far East are in many cases financed by the Banks in this way ; so also are many of the mills.

A solution of this problem can only be arrived at by those directly connected with the rice industry on the spot. Tentative suggestions have already been made on somewhat similar lines, but it would seem that the time has now come for these suggestions to be hammered into a concrete workable proposition.

One can only conclude by stating again that the essentials of a successful industry exist ; that the industry is capable of considerable expansion, not only by increasing the quantity and improving the standard of the paddy for the production of first-class parboiled rice, but also by taking up seriously and with due forethought under suitable direction, the production for export of both brown (or cargo) rice and white rice.

Once more, however, a word of warning as to undue haste. There is little doubt that the publicity given to British Guiana rice within the Colony has raised hopes incapable of immediate fulfilment, with



FIGURE 19.

Eight Typical Varieties of well-known Rices.

The top and the third rows are Paddy, the second and fourth are shelled Rice. The varieties are :—
1. Seeta (India); 2. Uganda; 3. Lower Burma;
4. Java; 5. Egyptian; 6. Spanish; 7. Manchuria;
8. Upper Burma.

the result that far too much mixed and low grade paddy has been sown with results which must only be disappointing to cultivator, miller and exporter alike.

Illustrations pertaining to this report are appended, together with certain examples of the actual cost of agricultural and milling operations. Samples of various types and grades of rices are also submitted by way of explanation. Fig. 19 shows eight typical varieties of well known rices.

CHAS. E. DOUGLAS.

28th February, 1930.



COST OF CULTIVATION ON
EAST COAST, DEMERARA RIVER.

Owner's Land.

	\$
Ploughing per acre	8·00
Planting	4·00
Cutting	4·32
Transporting	2·16
Threshing.. .. .	1·68
Winnowing	0·56
Making a total of	\$21·72
Add to this Rent, say	7·00
Grand Total per acre.. .	\$28·72
In this area Owner takes the yield per acre as 28 Bags of first quality paddy, valued at about \$1·43, making a total of	
The above charges work out at	28·72
There is thus a return per acre of	\$11·60

COST OF CULTIVATION ON
WEST COAST, DEMERARA RIVER.

	\$
Preparing the land per acre	6.00
Preparing the seed	1.00
Planting	3.00
Cleaning	1.00
Reaping and Threshing.. .. .	6.00
Rent for one crop	6.00
Transport to mill	1.00
Wear and tear of bags	1.50
Total per acre	<u>\$25.50</u>

COST OF CULTIVATION ON
ESSEQUIBO COAST.

<i>Labour Account.</i>	\$
Making nursery : 1 man for 1 day at 48 cts	0·48
Setting seed and attending nursery	0·48
Ploughing : 3 days at 60 cts. per day	1·80
Levelling and preparing for planting	0·60
Weeding meres	1·60
Taking out plants : 1 man for 1 day	0·48
Planting : 7 women for 1 day at 28 cts. each	1·96
Weeding during crop growth	0·80
Changing water and attending bed during crop growth	0·64
 <i>Cutting Paddy.</i>	
7 women for 1 day at 28 cts.	1·96
Beating out (hand threshing) paddy and transporting : 5 men for 2 days at 48 cts.	4·80
Attending oxen during ploughing period	1·28
	\$16·88
 <i>Expenses Account.</i>	
Paddy for seed 64 lb. at 1 ct.	0·64
Land rent per acre	4·00
" Agistment " fees for 2 oxen for 5 months at 24 cts. per ox per month	2·40
(One month free " Agistment " is allowed for oxen each crop)	7·04
	16·88
Total expenditure per acre	\$23·92

COMPARISON BETWEEN
Dollars per 160 lb. bag and Shillings per cwt.

160 lb. at \$4.25	..	..	..	..	=	s. d. 12 5 per cwt.
160 lb. at \$4.50	..	..	..	..	=	13 1½ per cwt.
160 lb. at \$4.75	..	..	..	..	=	13 9¼ per cwt.
160 lb. at \$5.00	..	..	..	..	=	14 6¼ per cwt.
160 lb. at \$5.25	..	..	..	..	=	15 3½ per cwt.
160 lb. at \$5.50	..	..	..	..	=	16 0¼ per cwt.
160 lb. at \$5.75	..	..	..	..	=	16 9¼ per cwt.
160 lb. at \$6.00	..	..	..	..	=	17 6½ per cwt.