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INDIAN
CENTRAL COTTON
COMMITTEE

FIRST CONFERENCE
OF
SCIENTIFIC RESEARCH WORKERS
ON
COTTON IN INDIA

MARCH 1937

PAPERS READ

AND

SUMMARY OF PROCEEDINGS

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1938

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INDIAN CENTRAL COTTON COMMITTEE.

First Conference of Scientific Research Workers on
Cotton in India.

March 4th, 5th and 6th, 1937.

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Present:—

Members of Indian Central Cotton Committee.

Sir Bryce Burt, C.I.E., M.B.E., I.A.S., (*President*)—*Chairman on the first day,*
 Dr. W. Burns, D.Sc., I.A.S., Agricultural Expert, Imperial Council of Agricultural Research, *Chairman on the second and third days,*
 Mr. V. Ramanatha Ayyar, Cotton Specialist, Coimbatore,
 Mr. T. R. Low, I.A.S., Director, Institute of Plant Industry, Indore,
 Dr. V. K. Badami, Deputy Director of Agriculture, Mysore, Bangalore,
 Mr. P. B. Richards, I.A.S., Offg. Director of Agriculture, United Provinces,
 Rao Bahadur S. S. Salimath, Deputy Director of Agriculture, Southern Division,
 Dharwar.

Research Officers working on the various schemes financed by the Committee and others.

Mr. J. B. Hutchinson, Geneticist & Botanist, Institute of Plant Industry, Indore,
 Mr. K. Ramiah, do do (designate) Institute of Plant Industry, Indore,
 Rai Sahib Kalidas Sawhney, Cotton Research Botanist, Parbhani, Deccan,
 Mr. M. Mohammad Afzal, Cotton Research Botanist, Lyallpur,
 Khan Bahadur M. Afzal Husain, Entomologist to Government, Punjab,
 Mr. R. H. Dastur, Plant Physiologist, Lyallpur,
 Rao Bahadur M. Vaidyanathan, Statistician, Imperial Council of Agricultural Research,
 Mr. B. M. Dabral, Cotton Physiologist, Sakrand,
 Rao Saheb S. H. Prayag, Cotton Breeder, Jalgaon,
 Mr. M. L. Patel, Cotton Breeder, South Gujarat, Surat,
 Mr. G. B. Patel, ,, ,, North Gujarat, Viramgam,
 Mr. P. L. Patel, ,, ,, Broach,
 Rao Saheb G. L. Kottur, Cotton Breeder, S. M. C., Dharwar,
 Dr. B. N. Uppal, Plant Pathologist to Bombay Government, Poona,
 Mr. B. P. Deshpande, Assistant Marketing Officer, Poona,
 Prof. L. S. S. Kumar, Economic Botanist to Bombay Government, Poona,
 Dr. V. N. Likhite, Plant Physiologist, Baroda State,
 Mr. A. F. Patel, Economic Botanist, Baroda State,
 Rai Sahib Thakur Ram Prasad Singh, Economic Botanist for cotton, United Provinces, Cawnpore,
 Mr. K. V. Joshi, Deputy Director of Agriculture, N. C. D., Nasik,
 Mr. Mazhar Husain, Director of Statistics, Hyderabad State,

Members of the staff of Arts and Science Colleges in Bombay.

Prof. M. J. Antia, Sydenham College of Commerce & Economics, Bombay,
 Prof. R. E. Cooper, Royal Institute of Science, Bombay,
 Mrs. Ella Gonzalves ,, ,, ,, ,,
 Prof. C. J. George, Wilson College, Bombay,

Research Assistants working in the Committee's various Schemes,

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Dr. R. Sankaran,		
Mr. Y. D. Wad,	}	Indore.
Mr. R. L. M. Ghosh,		
Mr. P. D. Gadkari,		
Mr. V. G. Panse,		
Mr. M. A. A. Ansari,		
Mr. Shamsher Singh,		
Mr. G. K. Govande,		
Mr. Maya Prakash Singh,	}	Mysore State.
Mr. K. Gopala Iyengar,		
Mr. T. J. Chellaramani,	}	Sind.
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Mr. N. T. Nadkarni,		

Assistants from the Technological Laboratory, Matunga.

Mr. D. L. Sen,
 Mr. N. Hari Rao Navkal,
 Mr. Ram Saran Koshal,
 Mr. Amar Nath Gulati,
 Mr. C. Nanjundayya,
 Dr. K. R. Sen,
 Mr. V. Venkataraman,
 Mr. V. V. Gupte,
 Mr. G. Rama Rao,
 Mr. M. U. Parmar,
Visitor, Mr. F. W. Andrews, Plant Pathologist, Anglo-Sudan Government,
Secretary (Mr. P. H. Rama Reddi, I. A. S.), and
Director, Technological Laboratory, Matunga, (Dr. Nazir Ahmad).

Subject 1—President's (Sir Bryce Burt's) Speech.

Gentlemen,

It is a great pleasure to me to welcome this large and distinguished gathering to the first Conference of Scientific Workers on cotton problems. Though it has an Agricultural Research Sub-Committee which meets regularly at least twice a year, the Indian Central Cotton Committee has felt for sometime past that there should be an opportunity for the discussion of purely scientific and technical matters in an atmosphere free from those administrative and financial considerations which are always in our minds at Central Cotton Committee meetings. It is obvious that the many technical and scientific questions connected with cotton improvement should from time to time be discussed in a purely objective manner and from the scientific aspect. This meeting also gives us an opportunity of bringing together many of the junior cotton research workers who would otherwise have no opportunity of meeting each other. We are also glad to see amongst us professors from local Colleges and I trust that they will find some matters of interest in the Central Cotton Committee's work. Conferences such as this do much to defeat distance and to mitigate that intellectual isolation which unfortunately is so often the lot of the scientific worker in India.

Though we owe allegiance to several different branches of science we all have this in common that we are all interested in the application of science to the improvement of cotton production. Indeed one may safely say that there is more scientific work in progress on cotton in India than on any other commodity. As we are all workers in applied science it may be as well to remind ourselves that the distinction between pure and applied science is purely one of objective. There are not two kinds of research; much less is there any room for slipshod methods in applied science. Where applied research does perhaps differ from a more academic research is in the wider outlook and more all-round equipment which is demanded of the worker in applied science. We need the help of all branches of science in the solving of most problems of economic importance. In pure science very intense specialisation is becoming the custom—not always to the advantage of either the worker or his science. In applied science team work by specialists is demanded but every team needs a leader. One of the objects of this Conference is to bring specialists together to discuss their own subjects with their confreres. Another of equal importance is to broaden the outlook of a very cotton research worker by bringing him in touch with those working in other branches of science. One need go no further than our agenda for evidence of the number of sciences contributing to cotton improvement.

Recent developments in pure science should constantly enable us to attack agricultural problems from a new angle. But it is no small task in the present to

keep up even a nodding acquaintance with the important literature in even a single science. I should like to take this opportunity of drawing your attention to the abstracts and technical communications issued by the various Imperial agricultural Bureaux particularly those of Plant Genetics and Soil Science and to the fact that those bureaux will gladly answer enquiries regarding recent work in special subjects. They have also been able to lend us translations or full summaries of many important papers in other languages which are not readily accessible. I will not burden you with details but the Imperial Council of Agricultural Research will at all times be glad to help in this matter.

The arrangements for our business are shown in the papers before you. We shall devote to-day to papers and a discussion on pests and diseases. To-morrow we shall discuss Cotton Technology and visit the Laboratory at Matunga. The third day will be devoted to Botany, Genetics and Plant Breeding.

Subject 2—Reading of Scientific Papers.

The President suggested that in order to go through the agenda according to the programme, scientific papers should not be read but the respective authors should give the gist of their papers within a period of 5 to 7 minutes. This would allow more time for discussion and replies to questions.

COTTON ENTOMOLOGY

Paper No. 5.

THE CONTROL OF PINK BOLLWORM (PLATYEDRA GOSSYPIELLA SAUND.)

BY

P. B. RICHARDS,

DIRECTOR OF AGRICULTURE, UNITED PROVINCES.

The pink bollworm is distributed throughout the whole of the cotton growing areas of India. It appears to be an indigenous insect as it was first described from Bombay early in the 19th century and was not known to occur in other cotton growing countries of the world until the early years of the 20th century. Its appearance in Egypt has been traced fairly certainly to its introduction in cotton from India, used as packing material. It has since spread to most, if not all, of the important cotton growing countries of the world. The pest is eminently suited to world wide distribution by modern transport. In countries with a marked cold weather or a lengthy hot weather during which cotton plants are not available the caterpillars tide over the unfavourable season inside the empty cotton seed in which they are well protected and remain alive for many months. In rare instances both in Egypt and in India survival for 18 months has been recorded with subsequent emergence of the adult moth. That this insect is highly adaptable to different climatic conditions, is evident from its Indian distribution from Madras to the northern limits of the cotton area in the Punjab.

It is strange that if the pink bollworm is indigenous to North India, it should have failed to have been observed as a serious pest of cotton until comparatively recently. Lefroy regarded it as a minor pest in comparison to the spotted bollworms. Bainbrigge Fletcher was the first entomologist to draw attention to its true status as a major pest in India. It is possible, although it does not appear likely, that this is due to a fairly recent adaptation of habit. However that may be, there could be

no uncertainty upon its importance both actually and relatively to the spotted bollworms in the United Provinces, when the standing and harvested crop was first examined by myself in 1921. It was quite clear that the attack of the pest in the United Provinces was at least as important as it was by then known to be in Egypt. More detailed examination in 1922 fully confirmed the importance of the pink bollworm as a major pest in the United Provinces cotton crop.

Ballard had previously investigated the pest in South India and discovered that under the Madras climate the habit of the pest would permit of control, if all cotton plants were removed for a given period. A pest control enactment was passed providing for such a close season but appears never to have been put into really effective action. Under North India conditions, the behaviour of the pest was found to be so markedly different that methods applicable to Madras were obviously not suited to the control of the pest in a colder climate.

LIFE HISTORY AND BEHAVIOUR.

It is in the caterpillar stages only that the pest damages the cotton crop, destroying in turn the flower buds, flowers, young bolls and the developing seeds in larger bolls. The incidence of the pest was observed to increase as the cotton crop developed from flowering to maturing of bolls. The extent of the damage was estimated to be between 20-25%. This was obviously of such importance in a Province then growing approximately a million acres of cotton as to warrant a full investigation of the status of the pest, of its life history and behaviour under local conditions, and of ways and means of preventing or reducing the tremendous annual loss which it inflicted upon the cotton growers. A scheme of enquiry was therefore drawn up. The United Provinces Government provided considerable staff and funds for the purpose and in 1923 the Indian Central Cotton Committee assisted by provision of funds for 10 wire gauze experimental cages, and subsequently by providing a research assistant and contingent expenditure for laboratory investigations. This assistance continued from 1925-32 and was augmented by funds for the purchase of a Simon cotton seed heating machine in 1926. From 1925, as a result of the earlier small scale experiments, the work was carried on to field scale trial operations, starting modestly with about 300 acres in an isolated area. The results obtained were so promising that in 1929 the field experiments and demonstration were expanded to about 25,000 acres; and further extension has since resulted in bringing the area under experimental control to nearly 60,000 acres of cultivators' cotton in 1936. During the past 10 years the U.P. Government has provided about Rs. 40,000 annually for the cost of this work. As will be seen later, the increased value of the crop obtained from the areas under pink bollworm control is estimated to have averaged over 5½ lacs rupees per annum in this period.

For those less familiar with insects and their behaviour a brief account of the life history of the pest may be of service before considering the enquiry and its results. A convenient point at which to commence this is the cotton sowing time.

It is well-known that the pink bollworm hibernates as a fully fed caterpillar during the cold weather and until rain and warmth combine to produce conditions favourable to its further development into a moth. In the United Provinces it has been demonstrated that the survival of the pest from one season to the next is almost entirely from hibernating caterpillars inside the hollowed out seeds of cotton. The small seed of Bengal cottons is individually not big enough to accommodate the resting pink bollworm. The hibernating caterpillar therefore spins together two or more emptied seeds, lining the cavity with silk. Such double seeds are typical of infected cotton seed in the Bengal areas. In larger seeded types such as Americans and Egyptians a single seed is adequate to accommodate the caterpillar and double seeds are unusual. The entrance hole of such single seeded hibernacula is closed with silk and it is not easy even on careful examination to distinguish the sound seed from those carrying the resting caterpillars.

The hibernacula containing live caterpillars are sown with the sound seed. The caterpillar shortly makes its way out from the hibernaculum and works upwards through the soil, making a silk lined tunnel as it proceeds. Having carried the tunnel up to the surface it goes down again to pupate. The moth on emergence from the pupa has thus a means of egress already prepared for it.

The moths are small insignificant looking, cryptically coloured insects, which remain concealed throughout the day under leaves or lumps of soil. If disturbed they quickly seek fresh shelter. Late in the cotton season there may be many thousands to the acre and yet they are rarely seen by day unless carefully looked for. The moths become active in the late dusk, and occasionally are attracted to artificial light.

The number at the commencement of the season is small, possibly a few dozen to the acre. It is therefore hardly surprising that the ryot does not know of their existence. With his almost total ignorance of the relation between a small moth and the 'Lal Kira' in his cotton it is understandable that he explains its presence as from the air brought by the moist winds.

The moths which emerge from the resting caterpillars are relatively long lived. Females have survived for 56 days and males for 20 days. The transformation (pupal) period occupies nine or ten days, and a few days may elapse between sowing time and pupation. There is thus a period of several weeks over which the female adults can survive, awaiting the development of fruiting bodies on the young cotton plants.

About the time the plants are ready to produce flower buds, the females lay their small white eggs. A large number of eggs is laid, the maximum recorded during the United Provinces investigations being 220. The average number recorded per female was about 125. The eggs are laid singly although several may be found fairly near together. Favourite situations are the hairy under side of young leaves, the stems of young shoots and leaves, and on young flower buds, the bracts of flowers, and the stalks of cotton bolls. The eggs are invariably laid in the dark mostly before midnight. The females of this generation have been observed in the Laboratory to lay eggs over a period of 23 days. In the field it appears that egg-laying is conditioned by the development of the plant, all the females laying their eggs within a few days when flower buds are developing. This accounts for the periodicity in subsequent generations which is often a marked feature of pink bollworm incidence in the crop.

The development of the caterpillar inside the egg takes four or five days in the monsoon. The young caterpillars are very minute, white with a small dark head. They wander searching for buds or bolls, sometimes feeding to a small extent on the leaf tissue, and occasionally entering a young shoot, the pith of which may be bored for about $\frac{1}{2}$ "— $\frac{3}{4}$ ". No pink bollworm caterpillar has yet been reared on shoots and it is assumed that shoots are attacked as a final resort. The real food of the caterpillar is the contents of buds, flowers and bolls. The first pink bollworm brood in the cotton season develops mainly at the expense of buds and flowers as the bolls have not yet developed. The young caterpillars attack flower buds of all sizes except the very smallest, feeding upon the developing anthers and style and occasionally on the ovary. As the food material becomes exhausted they move from one bud to another. Small buds thus attacked are shed. Larger buds may develop into flowers but the petals rarely open. Open flowers are also attacked, the caterpillars feeding down the column into the ovary. Attacked flowers are thus seldom fertilized, the young bolls being shed a few days after the falling of the corolla.

Developing bolls are attacked at all ages. Of young bolls the entire content is eaten but in older bolls the caterpillars confine themselves to the young shoots. Bolls attacked when small are invariably shed. The larger bolls mostly remain adherent to the plant. In either case the fully fed caterpillars leave the fruiting bodies before pupation, most of them entering the soil to pupate, but occasionally a cocoon is spun on a bract or against fallen leaves, or inside a fallen flower.

During its development the caterpillar undergoes three moults before pupating. It generally assumes the characteristic pink colour in its third instar, this, however, depending upon the nature of food. The caterpillars found in flowers are often a dirty purple until the final instar.

Under favourable conditions during the monsoon season the complete life cycle occupies between 23 and 31 days. Typical examples for July and October are as under.

Eggs laid	..	July	18th		October	2nd	
Hatched	..	"	22nd	4 days	"	6th	4 days.
1st moult	..	"	24th	2 "	"	8th	2 days.
2nd moult	..	"	27th	3 "	"	11th	3 days.
3rd moult	..	"	29th	2 "	"	14th	3 days.
Pupated	..	August	1st	3 "	"	17th	3 days.
Emerged as moth	..	"	10th	9 "	"	28th	11 days.
				23 days.			26 days.

Coupling usually takes place the night after emergence and egg laying commences from the second to fourth night. The adults of this and the succeeding generations are short lived; seven to nine days. The females die very shortly after the completion of egg laying.

If the monsoon sets in early there is thus time for four complete life cycles from July to October and if the weather remains mild and humid a fifth generation may be completed in November or early December. Under favourable climatic conditions multiplication can thus be very rapid. From a few moths per acre before the first flowering of the cotton crop the population may increase to hundreds of thousands to the acre by the end of October or early November. Judging from the population records in the field over a series of years, the conditions which lead to rapid multiplication are warm but not excessively hot weather, cloudiness, and frequent but not excessive rain. Long spells of dry hot weather are associated with a lower pink bollworm incidence in the field, and less damage to the crop.

The generations which thus succeed one another without a diapause are commonly called short cycle generations. There is generally a periodicity in the generations which tends to become masked late in the season owing to overlapping of broods. It thus becomes necessary to make frequent counts of the bollworm population in the field to arrive at any approximate estimate of the total population, as counts coinciding with pupation of the majority of the insects would indicate either a very low infection or none at all. This may possibly account for the failure of early observers to recognize the importance of this pest.

If growing bolls are still available on the plant, the short cycle habit may be persisted in during the cold weather but the life cycle is greatly lengthened. Thus in December the eggs may take 23 days to hatch, the normal stages occupying about

two months, and the pupal period 16 days or more, the whole cold weather life cycle occupying about $3\frac{1}{2}$ months. The proportion of the insects which continue to develop without true hibernation is however very small. With the fall in temperature and in humidity at the close of the monsoon the hibernating habit is induced, and the majority of the caterpillars which become full fed after the middle of November either prepare hibernacula in the seeds or make their way into the soil and remain quiescent for 6 or 7 months until the break of the succeeding monsoon. This generation in which there is a more or less prolonged diapause in the full fed caterpillar is spoken of as the long cycle generation.

This, then is the pest insect with which we were concerned; one capable of rapid increase during the cotton growing period and of survival in large numbers from one season to the next certainly in the seed, and possibly in the soil, on perennial cotton plants and on other cultivated or wild host plants; a pest, moreover, which appeared to be destroying a quarter or more of the cotton crop. The question set us by the problems were, what was the real extent of the loss—as this naturally determines what can profitably be spent to prevent it; could the loss be prevented or effectively reduced; if so by what means; and finally were those means practicable and economic?

ECONOMIC STATUS OF THE PEST

The gross effect of pink bollworm attack upon the cotton plants was first examined by growing the crop in large wire gauze cages provided from the Indian Central Cotton Committee grant. Of these there were 10 each of $\frac{1}{40}$ th of an acre, divisible into four separate compartments of $\frac{1}{160}$ th of an acre. Within these it was possible to grow the crop under pest free conditions in comparison with deliberately infected cages and with normal pest damage in outdoor controls. A fairly typical picture of the effect of pink bollworm attack may be obtained from an inspection of the data from infected and uninfected cages and outdoor controls of 1925 and 1926.

Average yield in maunds per acre. 1925.

	Uninfected cage. Mds.	Infected cage. 30 female moths.	Outdoor controls
Clean ..	4.04	2.0	0.03
Damaged ..	.60	2.30	2.05
Total saleable ..	4.64	4.30	2.08
Useless ..	....	.60	1.78
Total ..	4.64	4.90	3.86

Average yield in maunds per acre.
1926.

	Uninfected cage. Mds.	Infected cage. 30 female moths.	Outdoor controls.
Clean ..	10.02	4.3	1.91
Damaged ..	1.18	4.1	5.19
Total saleable ..	11.20	8.4	7.10
Useless ...	....	0.5	0.94
Total ..	11.20	8.9	8.04

To infect the cages 30 female moths were released at the time of flowering. Infection was naturally considerably higher in the open controls which were also subject to attack by all other cotton pests. Growth outdoors was however more vigorous than in cages, to some extent offsetting the protective effect of caging. Little significance attaches to the recorded gross weight of the crop, as the experiment was not on a scale to give statistically significant total yield data. What is of importance is the proportion of clean, damaged and totally useless and unsaleable lots under the different treatments. The attack of the pest in 1925 was specially heavy. The 1926 uninfected cage crop would have been better but for the fact that casual infection took place late in the season.

These and similar cage experiments clearly showed that, apart from the increased total crop which might be expected from pink bollworm control, the harvested saleable crop would be increased by 25% upwards, as the useless locks are not worth harvesting. Moreover the majority of the damaged locks are more or less heavily stained resulting in lowering of class, and of value.

Endeavours to reproduce the conditions of the experiment in the open on a small scale proved futile as the moths fly to the pest free fields and reinfest them. To ensure reasonable freedom from reinfestation it was necessary either to find an isolated cotton area on which to carry out the experiment, or to organise control on a wide scale, so that the centre of the area remained free. These became possible in turn. That the cage experiment results have been amply confirmed is evident from the sample analysis yield figures given below.

Average yield in maunds per acre.
1930.

<i>Submontane tract, Bijnor District.</i>		Analysis of crop by weight %.		
Treated. Average of four plots.		Clean.	Damaged.	Damaged by
Yield per acre.				Pink Boll- worm.
Mds. Srs.				
12—24		94.2	5.8	1.0
Uncontrolled area. Two plots.				
8—27		79.8	20.2	14.0
<hr/>				
<i>Doab tract, Aligarh district.</i>				
Treated. Average of seven plots.				
13—4		86.9	12.9	6.8
Untreated area. Average of three plots				
6—21		59.4	40.6	28.2

The Bijnor treated block of about 1,200 acres of cotton was isolated by river beds and jungle. The Aligarh area was a whole tahsil with about 20,000 acres of cotton. There were not natural boundaries and the check fields were mostly subject to infection by flight. The central plots in this area produced over 90% clean *kapas*, pink bollworm damage being some 3%.

Further evidence of the serious status of the bollworm is found in the following consolidated statement which combines the results of check plot observations in Aligarh District for the years 1929-35 during which data were obtained from 176 plots in the experimentally controlled areas and 99 in similar fields outside the controlled areas.

1929-35 Aligarh District.
Average yields—percentage analysis.

	P. B. W.		Controlled	Uncontrolled area.	
	176		area.	99	
	Mds.	Srs.	%.	Mds.	Srs.
Clean	5	8	71.4	1	31
Damaged	1	34	28.2	2	9
<hr/>					
Total saleable	7	2		4	0
Useless	0	1	0.3	0	6
<hr/>					
Total	7	3		4	6

Average increased yield, over uncontrolled crop.	Mds.	Śrs.	%
Clean <i>kapas</i> per acre.	3	17	193%
Total <i>kapas</i>	2	37	70.5%

It must be emphasized that these figures of the controlled area are derived from fields many of which are reinfected by flight from beyond the borders of the areas under control. If the central plots only are taken into account the actual yields obtained indicate an increase in total yield per acre of over 97%.

It may have been observed that the differences in yields are not necessarily proportional to the extent of damage as derived from examination of the harvested crop. This is due to the fact that the reduction in crop is the result of the cumulative effect of a number of factors. The occasional boring of the main shoot by the pink bollworm results in a check in growth followed by production of monopodial branches, late flowering, and a high ratio of vegetative development to crop. The first pink bollworm brood attacks mainly the young flower buds, the caterpillar eating out a considerable number in the course of its development. The early buds are thus largely destroyed, and of the remainder which develop into flowers, many are also attacked and fail to set bolls. The young bolls also, if attacked, fail to develop and are shed. It is only the larger of the attacked bolls which persist with varying degrees of damage caused by the presence and feeding of the insect.

CAGE EXPERIMENT. BOLL ATTACK AND SHEDDING PER PLANT.

Caterpillars per cage.	Bolls attacked and shed.	Bolls attacked and matured.	Unattacked.
70	17.4	29.7	.....
280	41.7	56	20.3
Open control	83.2	45.5	4.4

The proportion of larger bolls in the sheddings increases with the intensity of the attack, and this increases as the season develops. Early in the season it is unusual to find more than one caterpillar per attacked boll. As the pest increases in numbers and particularly after the flowering has passed the peak point, multiple infection becomes common, and towards the end of the season several pink bollworms may be found in one boll. Such heavily attacked bolls either shed or open prematurely and remain attached to the plant. In no case do they produce pickable cotton. These sheddings and failures are responsible for heavy loss of crop. Attacked bolls producing pickable cotton ripen in from one to five days less time than the unattacked bolls. Very heavily attacked bolls open frequently in much shorter

time, but produce no useful cotton. This shortening in the period in which the boll develops has an adverse effect upon the development of the seeds and lint.

Following the shedding of attacked buds and young bolls, vegetative development is stimulated to enable the production of more buds. An attempt to measure the effect of this by preserving all the vegetative material and fruiting bodies in pink bollworm free and pink bollworm attacked plants, and taking their dry weight as an indication of the energy expended, shows that, with comparatively light infection of pink bollworm the weight of the stem increases by from 15% to 30%, and that of the sheddings and leaves increases in somewhat similar proportions; while the weight of the seed cotton produced per plant decreases by 16% to 33%. Taking the ratio weight of seed cotton dry weight of sheddings, stem and leaves=1 in the pink bollworm free plants, this ratio was reduced to 0.565 in plants infected at the rate of 160 young caterpillars per plant, a reduction by nearly half in the efficiency of the plant.

Locks which are attacked very young or which suffer from a multiple attack are usually rendered useless. In such locks the majority of the seeds are eaten and the remainder fail to mature.

Locks attacked less severely or at a later stage in growth when the seed has attained considerable size, may have two or more of the seeds completely destroyed, but the remainder develop, producing pickable though generally stained and weak lint.

The effect of pink bollworm attack on one lock appears to be transmitted to adjoining locks, possibly by interference with the food supply. Such locks may have the seeds only partly developed and lint of a yellowish brown colour.

A less obvious but very important result of pink bollworm attack in one lock is a reduction in number and weight of seeds and of quantity of lint in the remaining locks of the boll.

The unattacked locks in attacked bolls suffer diminution in number and size of the seed produced, and in the quantity of lint per seed. In the clean locks of bolls in which one lock was attacked and two locks remained free from direct pink bollworm damage, the number of seeds per lock was reduced by 5.03 %; lint weight per seed by 4.35%; seed weight per seed by 3.15% and the ginning percentage was reduced from 34.7% to 34.4%.

Where two out of the three locks are attacked the effect upon the remaining free lock is more marked. The number of seeds per lock is reduced by 8.15%; the

lint weight per seed by 8.3%; seed weight per seed by 5.06%, and the ginning percentage was 33.9% only.

In the unsorted crop, which contained all categories of clean and pink bollworm damaged locks the number of seeds per lock was reduced by 10.24 % as compared with the average unattacked boll; lint weight per seed was reduced by 26.08%; and seed weight per seed by 23.29%; while the ginning percentage was reduced to 32.6%.

Expressed in terms of locks the indirect reduction in crop may be summarised as follows :—

	% seed per lock.	% lint weight per seed	% seed weight per lock.	Ginning percent- age.
All locks clean ..	100	100	100	34.7
One lock attacked, two locks clean ..	94.97	91.15	91.97	34.4
Two locks attacked, one lock clean ..	91.85	84.37	87.37	33.9
Unsorted crop ..	89.76	66.67	73.13	32.6

As, in a bad pink bollworm year, the number of bolls which escape attack is small, it is obvious that this indirect effect of pink bollworm attack is a serious factor in the reduction of the crop.

Bazar samples of seed examined in 1931 for insect damage showed that this varied between 17.5 and 36.3%. Most of this damage is ascribable to pink bollworm attack; and the seeds so damaged are useless for germination, and almost entirely so for oil crushing or cattle food.

Cotton seed from check plots in treated and untreated areas was examined or comparison with bazar seed. Results are tabulated below :—

Treated Areas.

Damaged seed per cent, average
for season.

Chamuan. ..	9.8
Chhabilpore ..	8.2

Untreated Areas.

Harduaganj ..	26.1
Kheria ..	23.2

The seed from the treated area thus appears to be better than from the untreated area by approximately 20%, there being roughly 75% of sound seed in the produce of the untreated area compared with 90% in that of the treated area.

The combined effect of these contributions to the reduction in crop, most of which are incapable of individual estimation, is very diminished outturn which has been demonstrated both in cage and field observations. The illustrations given are sufficiently conclusive to indicate the status of the insect as a major pest the control of which would be definitely worth while.

To revert to the problems presented by the enquiry, and to their solution, the next question to be answered is: Can the pest be controlled? It was known from the result of Gough and Storeys' work in Egypt that the hibernating caterpillars in the seed could be destroyed by heating the cotton seed to a temperature of 140°F. This would, however, be insufficient if there were other effective means available to the pest for survival in sufficient quantity from one season to the next. The obvious possible sources were alternative wild or cultivated host plants, survival on cotton plants standing in the fields or cut and stored, and survival in the soil.

SOURCES OF SURVIVAL BETWEEN SEASONS.

A number of alternative host plants was discovered. Of the cultivated alternative hosts, under intensive artificial infection, *Hibiscus esculentus* (*Bhindi*) was most important showing up to 21% attack in the pods, followed by *Hibiscus cannabinus* with one per cent attack, and *H. subdarifa* and hollyhock with traces. Of these *Bhindi* is of some importance, but is usually not grown extensively during the hot months, and is unlikely to play any serious part in carrying over the pest in rural areas. The others are negligible. Of the wild hosts, *Abutilon indicum* carried the maximum attack of 2 per cent in the green pods. This weed, although common, is not regarded as important as it is dormant during the hot weather, and hibernating caterpillars have not been traced in it. Other wild hosts although capable of serving as a food for the pink bollworm caterpillar are not generally attacked. No appreciable reinfection of treated areas has so far been traced to any of these sources and there is no evidence that they would materially vitiate control measures.

Cotton plants left standing in the field were found to be so effectively browsed by cattle and goats that there was no possibility of survival of the pest on developing fruiting bodies. Occasionally the worthless bolls remaining attached to these were found to contain living hibernating caterpillars early in the cold weather but not during the hot months.

It was feared that a more serious source of reinfection might be found in cut cotton sticks. Bundles of these kept under shelter produced 82 living moths between May 20th and August 2nd. A detailed examination was therefore made of the stocks of cotton stalks retained in villages of five districts, the census being made through the courtesy of the revenue staff. Careful examination of the attacked dry bolls disclosed an average number of caterpillars and pupae per maund as follows :—

Up to April 17th	..	11.6
„ May 21st	..	10.
„ June 11th	..	5.7
„ July 18th	..	2.17

The quantity of the cotton sticks disclosed by the census, and the calculated pink bollworm survival per acre on the 11th of June are as follows :—

District.	Area under cotton acres.	Maunds of cotton sticks June 15, 1928.	Maunds per acre.	Pink bollworm per acre. June 11th.
Muttra	.. 58,120	11,266	0.19	1.08
Aligarh	.. 1,07,695	13,890	0.13	0.74
Bulandshahr	.. 82,310	3,926	0.048	0.31
Meerut	.. 48,085	1,830	0.037	0.24
Muzaffarnagar	.. 25,900	341	0.013	0.08

While this survival is sufficient to preclude the possibility of complete extermination of the pest it is insufficient to have any serious results upon the cotton crop.

The possibilities of survival in the soil appeared to be very great in view of the fact that large numbers of the hibernating larvae were found to enter the soil and to rest there at varying depths. It was first attempted to obtain a measure of this by replanting infected cages in successive years and observing the extent of reinfection in the cotton plants. Even in cages in which very large numbers of full fed caterpillars had been introduced to ensure a heavy population of hibernating larvae in the soil, the evidence that any emerged to attack the succeeding crop was completely negative.

Two other methods were widely adopted. Double seeds containing live pink bollworms were buried in perforated zinc cylinders so that the seeds were at depths of $1\frac{1}{2}$ ", $2\frac{1}{2}$ ", $3\frac{1}{2}$ ", 5 ", $6\frac{1}{2}$ ", and 8 " in the soil. This experiment was conducted in Bundelkhand, at Cawnpore, in Muttra and in the submontane area, thus covering the different types of soils and climatic conditions of the U. P. cotton tract. At Cawnpore one set was buried in fallow soil and another under a crop of field pea. In March many living larvae were recovered at all depths, the percentage of survival decreasing with depth. Mortality was great in the field pea crop and in deeper levels where the soil moisture content was high. By the end of April the mortality was almost total in the field pea plot, and in the submontane soil at all depths, but there was little further mortality in the other sets. By the end of May no living larvae remained in the shallow series except in the Bundelkhand experiment, though fair numbers of caterpillars were still alive at deeper levels. By this time the soil temperature at $1\frac{1}{2}$ " had reached 150° F in the submontane soil, and 130° F. elsewhere, just before the break of the monsoon mortality was found to be complete at all levels except for a small survival in the Bundelkhand experiments at $3\frac{1}{2}$ " and below.

The experiment was repeated in Cawnpore and Muttra districts with irrigated and fallow soil. Under irrigated conditions the mortality was complete by May, while in unirrigated plots there was no survival beyond the beginning of June in Cawnpore and almost negligible survival at the middle of June at 6 "— 8 " depth in Muttra district.

The indication that pink bollworm larvae were unlikely to survive in any number through the hot weather in the soils of the United Provinces was supported by extensive and careful examination of infected soil both in the cages and in the field. Soil from two deliberately and heavily infected cages each $1/40$ th of an acre at Cawnpore was carefully removed and sifted in sections fortnightly from January. Approximately one live caterpillar per square yard was found until the middle of March. At the end of April two larvae only were obtained, and thereafter none but dead caterpillars were recovered approximately one per four square yards. The soil was examined to the depth of 8 ".

Similar examination was made of a heavily attacked cotton field in the College farm. Up to the middle of March live larvae were recovered at about the rate of 5000 to the acre. By the middle of April this had decreased to about 500 per acre. Thereafter no living caterpillar could be obtained in about 200 sq. yards dug and sifted to a depth of 8 ".

The soil in the submontane tract was extensively examined to the depth of 5 " only. In the first week in April, eight living caterpillars were obtained from $1/6$ th of an acre. None was obtained from over $1/4$ th acre examined in early May and early June.

Further soil examinations were conducted in the succeeding year in Bundelkhand and in Cawnpore District. The results are tabulated below. In all cases the fields had suffered a heavy attack of pink bollworm and the cotton sticks were left standing in the field, no cleaning up of any sort having been done.

Location.	Area.	Date.	Depths.	Bollworms found.
<i>Bundelkhand</i>				
Atara	30 sq. yds.	Feb.	9"	30
"	1,300 "	Late April.	8"	Nil.
Kervi	250 "	Late May.	6"	Nil.
<i>Cawnpore.</i>				
Katra	250 "	Late April.	8"	Nil.
Pukhrayan	300 "	Early May.	8"	Nil.

It thus appears that soil carry over is not a serious factor in pink bollworm control in the U. P. Mortality is associated with high soil temperature and is accelerated by high moisture content.

CONTROL PROBLEMS.

While determining the status and important means of carry over of the pest, various possibilities of control were also examined. Concentrated and detailed studies upon a wide range of cotton varieties indicated that while there was a considerable degree of difference in the intensity of the attack with varieties this was inadequate to afford any satisfactory protection. All were seriously attacked, some more so than others. The possibility of employing host resistance as a defence against pink bollworm attack therefore appeared out of the question.

Biological control by means of indigenous parasites was also examined. A number of parasites were recorded from caterpillars feeding in flowers, and from the resting caterpillars in double-seeds. None was found to parasitise the pink bollworm inside the developing cotton boll. This is perhaps mainly ascribable to the fact that the boll wall rapidly heals up after the young larva has tunnelled through it, and the insect is thus very adequately protected against most parasitic wasps and flies. The parasites obtained during the course of investigation were *Microbracon kitchenerii*, *Microbracon lefroyi*, an *Apanteles* sp. and unidentified Chalcid sp., Braconid sp. and Bethyloid sp. It is only in the flowers, in which the caterpillar is more exposed to attack of parasites, that any appreciable parasitisation was observed, and even here it did not exceed 1.8%. The indigenous parasites are therefore unlikely to be of much assistance. This does not completely rule out the possibility of biological control; but from the history of the pink bollworm it appears unlikely that an effective parasite will be obtainable from any other country.

The possibility of utilising light and scent traps was also tentatively explored. A small proportion only of the adult moths is attracted to light traps. No material was discovered to be effective as a scent trap.

The boring habit of the caterpillar precluded the use of poison dust or sprays both because the first stage larvae do not feed extensively on external tissues, and because the treatment would have to be repeated frequently throughout the cotton season, thus ruling this method out on the ground of cost alone, if it had otherwise been promising.

The problem was thus reduced to prevention of carry over in the harvested cotton, notably in the seed, and it is with seed treatment and its results that the investigation has been mainly concerned. The practical possibilities of dealing with cotton seed in bulk appear to be limited to fumigation, vacuum treatment and heat. Fumigation with poison gases such as carbon bisulphide and hydrocyanic acid was found to kill the enclosed caterpillars, given sufficiently long exposure at adequate concentration. The method is fraught with considerable danger, and is cumbersome. Caterpillars exposed to vacuum treatment survive very considerable periods of exhaustion, far longer than it would be economic to maintain on a large scale in practice. A combination of vacuum and fumigant was highly effective but combined the disadvantages of both treatments. Further investigation on these lines was therefore dropped and attention concentrated upon the application of heat.

The pink bollworm in common with other insects is unable to withstand a temperature of 140° F. This is the absolute lethal temperature at which mortality is 100%. The lower limit of lethal temperature for hibernating caterpillars appears to be about 120° F, but the lower the temperature within this range the longer must

be the exposure to ensure mortality. For practical purposes in the treatment of bulk seed, it is more economical to raise the seed to the absolute lethal temperature than to maintain it for long periods at a lower temperature.

Of the methods discussed heat is the only one which is applicable to small stocks of seed such as are held by the majority of cultivators for sowing purposes. Factory ginned seed in bulk requires to be treated by machinery. This is not possible for village stocks. Fortunately the sun temperature in the United Provinces during April and May is sufficient to raise the seed to within the lethal range. The temperature reached is dependent upon the time and length of exposure and on the intensity of solar radiation which is conditioned by the clearness of the atmosphere. On any day which is without cloud or heavy haze, exposure between noon and 3 p.m. has proved effective. Generally the sun heat during the hot months is sufficient at any time between 10 a.m. and 4 p.m. The seed is exposed to direct sunlight by spreading in a single layer on a clean earthen floor or on a pucca floor. It should not be spread on cloths. The maximum seed temperature recorded by sunning is 160°F on a pucca floor which had already heated up during the day. Under such conditions a few minutes exposure is sufficient to kill all the caterpillars. On earthen floors the seed temperature seldom rises above 140° F. At this temperature caterpillars fail to survive an exposure of 10 minutes. Between 130° and 135° 20 minutes exposure is necessary, while at seed temperature of 126° an hour's exposure was required. At 122° F, mortality was not complete unless the seeds were exposed for three hours.

This method of treating the cotton seed is readily carried out by cultivators for the small stocks of hand ginned seed which they retain for sowing. In no case has any damage to the germinating power of the seed been observed to result from exposure to sun for one day. Lengthy exposure of several days however depresses viability and in course of time kills the seed. This is probably the reason why self sown cotton plants are seldom, if ever, found in the fields of the United Provinces.

While the method is readily applicable to small quantities of seed, it is very laborious when applied to large stocks. It has been necessary in connection with the pink bollworm experimental control in the United Provinces, to sun heat several thousand maunds of cotton seed annually as cattle fodder, and the cost of such treatment has been from 8-11 pies per maund. Loss in weight naturally occurred on exposure to the sun, the loss varying between $3\frac{1}{2}$ — $7\frac{1}{2}$ %. The higher figure was reached from seed stored in merchants' godowns and exposed to sun for five hours. Much of this loss in weight which is due to drying is recovered on storage. Farm seed exposed for $4\frac{1}{2}$ hours lost 3.48 per cent of weight, more than half of which

was recovered in two days. The same seed exposed for six hours lost 3.62 per cent and recovery was much slower.

Sun treatment is undoubtedly the cheapest method of destroying the pink bollworm contained in the seed. It is, however, not applicable to factory conditions. One maund of cotton seed spread in a single layer occupies approximately 7 sq. yds. A ginnery handling 30 bales a day would thus require nearly half an acre of drying floor for its daily output of seed. An even more cogent consideration is that during most of the cotton ginning season the sun temperature is insufficient to destroy the caterpillars.

There are various types of seed heating apparatus applicable to the treatment of cotton seed. These all depend upon steam heating. The seed may be conveyed along a steam jacketed trough by a screw conveyer, or be heated in a cylinder with a set of revolving steam heated pipes with which the seed makes a large number of momentary contacts in its passage to the outlet. In any case it is essential to regulate the steam input so that the seed at the outlet has reached the maximum total temperature of 140° F. but has not appreciably exceeded this temperature.

Considerable attention was devoted to examining the tolerance of cotton seed to heat. Dry seed in a dry atmosphere retained its normal viability up to 180°F. With moist seed some loss of viability was observed at 146° F., with high temperature in the surrounding air. Below 146°F. no loss in viability was found under normal conditions. The temperature of 144° F. was thus adopted as the maximum limit to which the seed should be raised. As it is necessary to raise the seed to 140° F. there is obviously a very narrow margin within which the temperature regulator has to operate. The Simon cotton seed heater, provided with a specially sensitive thermostatic control, has proved capable of maintaining the seed temperature within this range. The equivalent centigrade reading of 62° with a mean temperature of 60° allowing for a variation of 2° C. above and below the optimum has been stipulated in the recent legislation in the United Provinces for controlling the pink bollworm pest.

The fear has been expressed that heat treatment would not only reduce the germinating power of the seed but would also affect its value for oil crushing. Not only does heating within the limits specified not cause any loss to germination, but the percentage of healthy seedlings is slightly raised. This is probably due to the sterilizing effect of the heat treatment upon bacteria or fungus spores which would attack the seed in early stages of germination.

Tests conducted on heat treated and untreated samples of seed disclosed no significant difference in the oil content or extraction.

As has been mentioned earlier one of the minor results of pink bollworm attack is that the cotton seed contains a smaller proportion of sound seed. The effect of this also upon the oil content of the bulk seed will be evident from the following data provided by the Harcourt Butler Technological Institute Oil Department.

Source of seed.	Oil content %	
	Seed not heated.	Seed heated to 140° F.
Unattacked bolls ..	19.27	19.41
Unsorted crop	14.64	14.71

The higher oil content figure in the heated seed is presumably due to the small dryage which occurs during heating. It may be noted that where all the seed is sound the increase in oil crushing value compared with the present attacked crop would be something over 30%. An improvement of 20%, has already resulted in the large field scale controlled crop.

Doubt has also been expressed whether the cotton seed after treatment would not be less valuable as cattle fodder. Large quantities of such treated seed have been consumed in recent years by the cattle of controlled areas and there is, as might be expected, no evidence of any such reduction in feeding value. Cattle owners are in fact only too glad to get the treated seed from the controlled areas on account of the very much higher percentage of sound seed.

Thus the heat treatment of cotton seed was found to be the most effective and practicable method of dealing with hibernating caterpillars; and if properly controlled to have no adverse effect upon the quality of the seed for sowing, for industrial consumption, or for feeding cattle.

Practicability of Control.—Having satisfied ourselves that by destroying the hibernating caterpillars in the harvested crop a very effective measure of control of the pink bollworm would result, the only question which remained was whether this method could be put into practical application for the benefit of the cotton grower.

Cotton cultivation is common throughout the west and north of the United Provinces. Its greatest concentration is in the Ganges-Jumna Doab. In much of this it is a major crop with high acreage intensity. Elsewhere the cultivation of cotton is more scattered, but it is extremely difficult to find any locality capable

of growing cotton in which there is not a small patch of the crop here and there. Cotton cultivation is thus more or less continuous. There are practically no natural boundaries dividing off one area from another. It was obviously necessary to test in the field and on an adequate field scale the conclusions arrived at ; and if these were confirmed to put the method into practical application. Could this be done by selecting small areas within the continuous belt of cotton cultivation, or would it be necessary to carry out our experiments and to organize our control on a very wide scale to meet the possibilities of heavy reinfection by flight ?

The moth is a small, comparatively feeble creature, sluggish in habit by day, and so far as we knew unlikely to make long flights even by night. The first attempts at field trial were therefore in areas of about 12 square miles representing three circles of 2 miles radius. Within this circle none but heat treated seed was sown, and the results were observed. At the same time the sectional cages were used to determine experimentally the distances at which flight reinfection would be serious. It was very quickly obvious that a two mile range was well within the flight distribution power of the pest ; in fact from the time of emergence of the first short cycle brood infection in the controlled area was very nearly as high as in the untreated fields outside the 2 mile circle. This completely precluded any possibility of conducting control village-wise or in small areas comprising a few villages. This was obviously so important that adequate experiments to determine the normal flight distribution range of the pest were essential. This necessitated working in an area in which cotton was not normally grown. A portion of Banda district in Bundelkhand was found to meet the conditions. Cotton was not common here, not because it could not be grown, but for lack of irrigation facilities and because of the precarious monsoon conditions. It was therefore possible to establish cages, and small strips of uncaged cotton, at known distances from possible sources of infection. By periodical stripping of the cotton plants of their fruiting bodies, and examining these for pink bollworm larvae it would be possible to determine with fair accuracy the dates of arrival of female moths and the distances over which they had travelled. The results showed that flight infection beyond 2 miles in one generation is unusual ; that at 4 mile range without any intervening cotton cultivation a fair measure of protection was achieved, and that at 6 miles reinfection by flight was very rare and usually encountered only late in the cotton season, so that such flight reinfection would be of small importance. This was substantiated in the field by expanding the field trial experiments to circles of 6 miles radius, something over 100 sq. miles. Such a comparatively large area was however incapable of providing an effective demonstration, as only the cotton at the centre of the circle was reasonably ensured against reinfection. For effective demonstration it would therefore be necessary either to control a large area allowing for a six mile wide belt of reinfected cotton all round an adequate protected area in the centre, or to find a cotton tract which was provided with natural barriers of about 6 miles width. A circle of 10 miles radius

allowing for a centrally protected area of 4 miles radius would cover more than 320 square miles. This was rather a large order at the outset. Fortunately a small cotton growing tract was found in Bijnor district near Hardwar, protected by a wide belt of Ganges Khadar and by jungle and hills, and which grew 300 or 400 acres of cotton. All the cultivators' seed was heat-treated in hot air ovens and the resultant crop proved to be almost entirely free from pink bollworm damage. The average yield for the treated area was 7 maunds *kapas* per acre, while that for the crop on similar soil beyond the protected belt was less than 4 maunds; and the crop was strikingly free from the staining associated with pink bollworm damage. Work was limited to this isolated block until 1929 by which time there was no further doubt that the results obtained in the protected cage experiments could also be achieved in the field. As the result of the elimination of the hibernating caterpillars from the sown seed, practically every early flower bud had developed into a ripe boll, and the crop remained free from pink bollworm attack until late in the season. Details of the 1929 crop are illustrated below. The average yield within the treated block was estimated to be about 10 maunds to the acre, while in untreated areas across the Ganges the yield was $6\frac{1}{2}$ maunds. The actual produce obtained from acre plots in the treated and untreated areas were as follows :—

TABLE A.

Sajanpur.	Treated.	Unirrigated.	Bahadradab.	Untreated.	Irrigated.
Clean ..	8 mds.	27 seers.	Clean ..	3 mds.	27 seers.
Damaged ..	1 „	2 „	Damaged ..	1 „	30 1/2 „
Useless ..	....	....	Useless ..	....	3 1/2 „
Total ..	9 „	29 „	Total ..	5 „	21 „

TABLE B.

Picking No.	Clean	Damaged	Useless.	Clean.	Damaged.	Useless.
	%	%	%	%	%	%
1	84	16	Nil	80	18.9	1.1
2	86	14	„	81	18.5	0.5
3	88	12	„	56	42.5	1.5
4	90	10	„	76	23.0	1.0
5	93	7	„	75	23.5	1.5
6	89	11	„	63	36.0	1.0
7	90	10	„	61.5	36.5	2.0

TABLE B.—*contd.*

Picking No.	Clean %	Damaged %	Useless. %	Clean %	Damaged %	Useless. %
8	90	10	„	59	38.0	3.0
9	91	9	„	74.5	24.0	1.5
10	90	10	„	55	43.5	1.5
11	91	9	„	50.5	47.7	1.8
12	89	11	„	45.3	53.7	1.5
13	86	14	„	51.0	47.0	2.0
14	87	13	„			
Total ..	89	11	„	66.5	32.0	1.5

The analysis of this crop picking-wise is also displayed.

In 1929 it was decided to extend experimental control to the whole of the Atrauli *tahsil* in Aligarh district, an area of approximately 340 sq. miles. There is no effective barrier to this area. The cultivators' seed was treated by sunning which was carried out by the cultivators themselves under the supervision of the staff of the Entomological section.

Atrauli *tahsil* is typical of the most important cotton growing area of the Province. It includes both irrigated and unirrigated cotton of which from 20-25 thousand acres are sown annually. In the first year the average yield in the treated area was estimated to be 9 maunds against less than 6 maunds per acre under similar cultivation outside. The produce from two typical fields treated and untreated, respectively, and its analysis for damage is shown below :—

TABLE C.

Raipur.	Treated.	Nanu.	Untreated.
Clean	9 mds. 20 srs.	Clean	3 mds. 2 srs.
Damaged	1 „ 1½ „	Damaged	3 „ 17 „
Useless	0 „ ½ „	Useless	0 „ 2 „
Total ..	10 „ 22 „	Total ..	6 „ 21 „

TABLE D.

Picking No.	Clean %	Damaged. %	Useless. %	Clean %	Damaged %	Useless. %
1	87.34	12.62	0.03	78.2	21.1	0.7
2	85.97	13.98	0.03	65.4	33.6	0.9
3	88.31	11.67	0.01	66.0	33.4	0.6
4	90.11	9.81	0.08	56.5	42.5	1.0
5	89.7	9.92	0.11	54.8	44.2	1.0
6	90.6	9.27	0.04	49.6	49.6	1.1
7	90.4	9.44	0.11	56.3	42.9	0.8
8	89.3	10.60	0.09	48.9	50.3	0.8
9	89.05	10.81	0.13	50.5	48.6	0.9
10	92.50	7.44	0.05	44.9	53.7	1.3
11	92.14	7.73	0.1	47.4	51.9	0.6
12	90.27	9.49	0.22	42.4	56.5	0.6
13	89.69	10.13	0.17	32.1	67.2	0.5
14	83.5	16.09	0.41	27.3	72.2	0.4
15				25.6	73.5	0.7
16				28.8	70.6	0.43
17				34.8	64.7	0.5
18				23.5	74.8	1.7
Total ..	90.09	9.81	0.09	46.6	52.4	0.8

Some description is necessary of the method of obtaining comparative data by which the effect of pink bollworm control has been measured. Up to 1931 check plots of one acre each were purchased after inspection. Fields were selected which appeared to be of average growth for the locality. The selection was made at the time of development of bolls. One fourth was set apart for the periodical examination of the buds, flowers, and green bolls to determine the incidence of bollworm attack during the growth of the crop. The remaining 3/4ths was harvested every 4th day, according to the local practice, by local woman labour. The pickings were made according to the normal practice, useless bolls being left unpicked. From 1932 onwards plots of 1/10th of an acre were selected from fields in different villages, thus extending the range of the source of data. The majority of these plots were utilised for harvested crop data, a sufficient number, usually 1 in 4, being kept for observation on the green material.

The crop is collected and stored picking-wise and is subsequently carefully separated out into the following categories of locks.

- Clean locks (unattacked).
- Saleable locks (damaged by pink bollworm).
- Saleable locks (damaged by other causes).
- Unsaleable locks (due to pink bollworm).
- Unsaleable locks (due to other causes).

The attacked plots in the uncontrolled area are similarly selected, care being taken that any bias introduced will be in favour of the untreated plots. The selection method is open to the objection that the bias introduced prevents statistical interpretation of the results. It has however not been practicable to depend upon random selection of plots, as the staff was insufficient to deal with the large number of sample plots which would be necessary. As will be seen, however, the observed differences have been so great that statistical interpretation is hardly necessary.

An individual example has been given above of the result in the first year's work. By 1935 the area under control in the Aligarh district was very greatly extended in two blocks, with over 44,000 acres sown entirely with sun treated seed. The average of the results of the check plots are shown below :—

TABLE E.

1935— <i>Treated area.</i>						
Number of plots	..	..	..	..	..	39
					Mds.	srs.
Average yield per acre	..	..	..	..	7	8
Average yield clean <i>kapas</i>	..	..	..	..	5	32
Average yield damaged <i>kapas</i> (saleable)	..	..	..	..	1	16
Average yield damaged <i>kapas</i> (unsaleable)	..	..	..	..	Free.	
<hr/>						
Average Pink Boll-worm damage to <i>kapas</i>	..	..	..	..	0.33	12.0
<i>Untreated area.</i>						
Number of plots	..	..	..	..	..	20
					Mds.	srs.
Average yield per acre	..	..	..	..	3	39
Average yield clean <i>kapas</i>	..	..	..	..	1	24
Average yield damaged <i>kapas</i> (saleable)	..	..	..	..	2	9
Average yield damaged <i>kapas</i> (unsaleable)	..	..	..	..	0	6
						4.0

		Mds.	srs.	%
Average Pink Boll-worm damage to <i>kapas</i>	..	1	28	43.2
Average increased yield per acre	.. ..	3	9	81.1
Average increased yield clean <i>kapas</i> per acre	..	4	8	262.5
Total area under treated seed	.. ..	44,200 acres.		
Estimated increased total yield	.. ..	1,42,500 maunds.		
Estimated increased total value	.. ..	Rs. 10,14,000/-.		
Average sale price	.. ..	Rs. 6/- a maund.		
Average premium	.. ..	Re. -/8/- a maund.		
Increased value per acre	.. ..	Rs. 23/-.		

The check plot yields for this season indicate an average increased outturn of over 80%, an increase in value of the crop per acre of Rs. 23/- and a total increased cash return to the cultivators of over 10 lakhs.

In the 1936 season over 60,000 acres of cotton were grown in the experimentally controlled areas at Aligarh and in Bijnor and Saharanpur districts. The results of these are still under analysis, and the increased yield and crop value cannot yet be assessed.

In the table appended is shown the estimated results based upon the yields derived from the observation plots of the field experiment and demonstration for the 10 years 1926-35.

CROP FIGURES OF FIELD EXPERIMENTS 1926-35.

Year.	Locality.	Area under treatment.	Average yield treated area.	Average yield untreated area.	Total increased yield.	Total increased value.	Average increased value per acre.
		Acres.	Mds. srs.	Mds. srs.	Mds.	Rs.	Rs.
1926	Hardwar ..	400	7 0	4 0	1,200	14,000	35 0 0
1927	" ..	400	7 20	4 20	1,200	9,000	22 8 0
1928	" ..	350	12 0	6 0	2,100	24,000	67 0 0
1929	Hardwar ..	1,800	10 0	6 0	7,200	65,000	36 0 0
	Aligarh ..	23,000	9 0	6 0	69,000	6,90,000	30 0 0
1930	Hardwar ..	1,800	9 0	7 0	3,600	30,000	16 8 0
	Aligarh ..	25,000	10 0	7 0	75,000	4,50,000	18 0 0
1931	Hardwar ..	3,600	8 10	6 30	5,300	42,500	12 0 0
	Aligarh ..	59,000	6 20	4 10	1,31,300	10,62,000	18 0 0
1932	Hardwar ..	4,900	6 20	5 20	7,840	63,000	10 0 0
	Aligarh ..	46,800	7 0	5 0	97,200	7,58,300	16 0 0
1933	Hardwar ..	5,100	8 20	4 0	22,800	1,37,000	27 0 0
	Aligarh ..	41,200	5 0	3 0	91,700	4,26,900	10 0 0
1934	Hardwar ..	4,900	7 30	4 30	15,000	75,300	17 8 0
	Aligarh ..	40,000	7 20	4 10	1,33,000	7,51,700	19 0 0
1935	Hardwar ..	2,900	8 10	4 0	12,500	79,000	27 0 0
	Aligarh ..	44,200	7 10	4 0	1,42,500	10,14,000	23 0 0
1926-1935	..	3,05,350	8 0	5 0	8,18,440	56,91,700	18 10 0

N.B.—The average increased value per acre per year over the period 1926-1935 is Rs. 23-13-0 per acre. Figures under column "Total increased value" from 1931-35 are based upon the value of the additional crop plus a premium which ranges from As. 0-4-0 to Rs. 1-0-0 per maund of *kapas*.

NECESSITY FOR TREATMENT OF THE BULK CROP OF COTTON SEED.

Experience has shown that the major obstacle to effective control is in the factory ginned seed. This contains a very great proportion of the hibernating caterpillars. It is quite true that much of this seed has been utilized commercially or for cattle fodder before the hibernating caterpillars can emerge as moths. The balance, however, which remains in local seed stores or with cattlemen for feeding their stock is a very potent source of reinfection. We have endeavoured in the controlled areas to arrange for the sun treatment of such local stocks, and for the supply of treated seed to meet all additional requirements. Nevertheless there are frequent and repeated cases of concealment or of the importation of untreated seed. The possibility of restricting seed treatment to the residue of the crop has been carefully considered by the research staff, and by a succession of committees including the committee appointed by the Local Government of which Sir Bryce Burt was a member. The decision invariably has been that the proposal is impracticable, and the danger so great that the risk must not be taken. Consequently the proposals which have been accepted by the United Provinces Government, and which have been incorporated in the recent United Provinces Cotton Pest Control Act, provide for the treatment of all factory ginned seed under approved heating apparatus, as well as for the sun treatment of all cultivators' seed within the area in which the provisions of the Act apply.

The necessary equipment for treatment of machine ginned seed is somewhat expensive. The capital cost of a suitable heater, with provision for steam supply and operation, is about Rs. 10,000 for a 30 gin factory, or about Rs. 12,000 for a factory of 60 gins. The actual working expenses for treating the seed works out at less than $\frac{1}{2}$ anna per maund, say -/5/- per bale of lint. After making provision for interest, and for depreciation at 10% of the capital cost, the all-in cost per bale will naturally be considerably higher. The exact cost per bale is of course dependent upon the number of bales of cotton ginned per season. On the present out-turn of the Aligarh area, in which the provisions of the Act are intended in the first instance to be applied, the all-in cost per bale is expected to be about Rs. 1/8/-. Allowing for the increased yield which will result from control of pest, this figure may be expected to come down to about Re. 1/-. This charge will fall ultimately upon the cultivator, through the price paid by the purchaser of his *kapas*. Allowing for an average outturn of $7\frac{1}{2}$ maunds, equivalent to half a bale of ginned cotton, the cultivator will pay -/12/- per acre for the advantage of growing his cotton under pink bollworm controlled conditions. These show sufficiently clearly that even the partial control of pink bollworm which has been achieved in comparatively small areas is a great boon to the cultivators. For this small contribution he may, on the basis of our check plot data, expect to receive in return an increment on his crop value of at least Rs. 15/-. There is therefore no necessity to weep over his hard lot

in carrying the cost of treatment as the return on his investment is 2,000 per cent; the ginner will benefit by an increase in the quantity of *kapas* which he will process; the cotton merchant will benefit by having superfine cotton to market, and the mills will benefit through the improvement of the spinning quality of the cotton and the decrease in loss during the spinning operations.

A further advantage which is expected to accrue is that the elimination of heavy pink bollworm attack will permit the cultivation in the United Provinces of staple cottons. At present, on account of the long growing period of staple growths, and the consequent intense pink bollworm attack when the bolls are maturing, staple cotton cannot profitably compete with the higher yielding, hardier Bengals.

COTTON ENTOMOLOGY

Paper No. 2.

CARRY-OVER OF PINK BOLLWORM (PLATYEDRA GOSSYPIELLA SAUND) THROUGH SOIL IN THE MAHRATWADDA DIVISION OF THE HYDERABAD STATE

BY

H. D. NANGPAL,

COTTON ENTOMOLOGIST, PARBHANI.

The soil in this part of the country is generally deep black, rather fine in texture and fairly well drained. During the monsoon it becomes inaccessible on rainy days and the following day or so, but becomes fit for interculture soon after. On the drying of the surface soil, cracks begin to appear which go deeper as the different layers of soil get dry. Such soils are very suitable for the cultivation of cotton. As many as 2,300,000 acres are devoted annually to this crop in this division, where it is sown as a *kharif* (autumn harvested) crop after the break of the south-west monsoon.

Observations on the behaviour of full grown pink bollworm larvae (Table I.) have shown that in the early part of the cotton season—September and October—larvae pupated in more numbers in the above soil situations, while after that they were found to go in greater numbers for pupation in soil. Towards the end of the season, *viz.*, in January and February, most of the caterpillars that went into soil, instead of turning into pupae, remained as such either free or in somewhat spherical resting chambers spun by them. To the latter were found adhered several small particles of black soil. On digging the soil of the cotton plots, from which plants had been removed after the last picking, up to a depth of eighteen to twenty inches in the off season, pink bollworm larvae were met with in varying numbers and at different depths in the soil throughout the period February-June. Such examinations of the soil were made at the farm plots during the last four seasons 1933-1936 and in the cultivators' fields in the two later years. The results of such diggings which are summarised below go to form the direct evidence of hibernation of pink bollworm in soil.

TABLE I.

BEHAVIOUR OF FULL GROWN PINK BOLLWORM LARVAE
IN THE FIELD.

Number of Larvae and Pupae in above and below soil situations. (1935-36)

Fortnight ending	Per 500 sq. feet of surface area						Pupae
	In the fallen forms		On the surface of the soil		In the soil		
	Larvae	Pupae	Larvae	Pupae	Larvae		
					free	in cocoons	
September							
6th	7.5	..	..	..	..	..	..
20th	4.2	..	..	..	..	..	..
October							
4th	14.0	..	..	..	..	..	..
18th	40.0	3.3	..	..	..	..	..
November							
1st	82.0	4.7	3.4	0.3	2.7	..	2.7
15th	155.0	14.0	23.0	30.2	8.3	11.0	7.5
29th	108.0	14.1	18.8	67.0	11.3	44.5	91.7
December							
13th	93.5	7.0	9.0	43.0	50.0	25.0	180.0
27th	120.8	3.6	7.9	17.1	41.7	66.6	94.4
January							
10th	177.7	19.3	20.6	5.0	8.0	80.6	77.7
20th	57.8	1.3	2.0	1.3	16.7	86.5	36.1
February							
7th	51.7	..	..	..	13.3	97.8	18.9
21st	88.6	..	..	..	13.3	48.5	..

In 1933, a plot measuring 17,270 sq. feet at the Main Farm, Parbhani, and under cotton in the previous season was sub-divided into seven sub-plots. From three of these, plants were grazed and removed and the land was ploughed on the 17th of March, 11th April and 1st May respectively. Plants from the next three sub-plots were grazed and removed on the same dates but no ploughing was done. In the last plot the plants were left standing after being grazed on 17th March 1933, thus avoiding further chances of the continuation of a short cycle generation in them. The digging was started on the fifteenth of April in the sub-plots in which the post harvest cultural operations were carried out on the seventeenth of March,

and fifteen days after the last operation in the rest of the plots. The observations were continued for about six weeks.

Hibernating pink bollworm larvae were recovered from all the plots throughout the period of examination. The plot ploughed on 17th March 1933 gave the highest number—974 to the acre—of hibernating larvae, while the least—363 to the acre—were recovered from the plot ploughed on the 1st of May.

TABLE II.
CARRY OVER OF PINK BOLLWORM THROUGH SOIL.

Examination of soil.

Government Main Farm, Parbhani. (1933)

Post harvest cultural operations.	Plants grazed, stalks removed and land ploughed			Plants grazed and stalks removed			Plants grazed only
	March 17	April 11	May 1	March 17	April 11	May 1	
Date of operation	March 17	April 11	May 1	March 17	April 11	May 1	March 17
Area (sq. feet)	2,460	2,400	2,520	2,460	2,400	2,520	2,460
Fortnight ending	NUMBER OF LARVAE FOUND						
April 30	27	..	..	15	..	..	14
May 15	15	11	..	26	20	..	13
„ 31	13	18	10	10	15	45	8
June 15	..	2	11	..	12	2	..
„ 30	..	..	..	..	..	..	..
Total :	55	31	21	51	52	47	35
Per acre :	974	563	363	903	944	812	619

In 1934 also about half an acre plot at the same farm was dug from fifteenth of April to the second week of June. Plants were removed from the plot in two instalments on the fifteenth and twenty-fifth of April. A total of 171 larvae from the plot or 352 to the acre were found hibernating in the soil. Some of them were obtained from the soil even after three inches of rain in the second week of June

TABLE III.
CARRY OVER OF PINK BOLLWORM THROUGH SOIL.

Examination of soil.

Government Main Farm, Parbhani. (1934)

Fortnight ending	Area. sq. ft.	Number of larvae found.	Larvae per acre.	Remarks.
April 15	550	17	1,346	Plants standing.
.. 30	5,402	78	629	
May 15	6,837	49	312	All plants removed in third week of April.
.. 31	5,900	12	89	
June 15	2,006	13	282	
.. 30	450	2	194	
Total :—	21,145	171	352	

In 1935, from the three farm plots of which two were at the Main Farm and the third at the Cotton Research Station, Parbhani, a total of 337,203 and 717 larvae to the acre were recovered during the full period of examination—February to June. All the plants from the first plot were removed on the fifteenth of January, from the second plot they were removed regularly fifteen days before the day of examination, while from the third they were removed on four different occasions. Gaorani 6, an early variety, was grown in the first two plots and Parbhani 710—a late maturing variety, in the third plot. Soil of the last plot was much more deeply mulched during the season. It was also observed that more caterpillars were recovered from the 5"—8" layer than from any other.

In addition to the examination of the soil at the farm plots at Parbhani, cotton plots at the Grant-in-Aid Farms at Nanded and Aurangabad were also dug and examined; while some further plots in the cultivators' fields at Parbhani and Nanded were also dug for the same purpose. As many as 622 and 207 hibernating caterpillars per acre were recovered in the two examinations made in the first week of May and the second week of June at the Aided Farm, Nanded, where the plot, like that at the Cotton Research Station, Parbhani, was well mulched during the season. From the plot at the Aurangabad Aided Farm, where a late ripening variety was grown, only three larvae were recovered from 2,640 sq. feet (or seventeen to the acre) of the soil dug in the first week of May. At this place the soil was very hard

and devoid of any mulch on the surface. During the last week of April and first week of May, only one caterpillar was recovered from 8,350 sq. feet of soil dug up to a depth of eighteen inches from cultivators' fields at Parbhani. From two cultivators' fields examined in the second week of June at Nanded, no caterpillars were taken; while from a third plot at the same place, four larvae from 240 sq. feet (726 to the acre) were recovered on the same day. The last plot was well mulched during the season and was between two rows of orange trees. The soil of all the remaining cultivators' fields was rather hard and there was no mulch at all on the surface.

TABLE IV.
CARRY OVER OF PINK BOLLWORM THROUGH SOIL.
Examination of soil. (1935)

Site.	Nature of soil.	Variety.	Post harvest treatment.	Period of examination.	Area examined. sq. ft.	Number of larvae found.	Per acre.
Main Farm, Parbhani	Black, mulched	Gaorani 4B.	Plants removed on 15-1-35	1-2-35 to 31-5-35	8,669	67	337
do.	do.	do.	15 days before each examination.	14-2-35 to 10-6-35	8,376	39	203
Cotton Research Station, Parbhani.	Black, deep mulched.	Parbhani 710	Plants removed four times during the operation.	1-2-35 to 23-6-35	13,854	228	717
Aided Farm, Nanded.	do.	Gaorani 4	Plants grazed on April 15th.	1st week of May.	2,871	41	622
do.	do.	do.	do.	2nd week of June.	3,150	15	207

TABLE IV.—contd.

CARRY-OVER OF PINK BOLLWORM THROUGH SOIL.

Examination of soil (1935).

Site.	Nature of soil.	Variety.	Post harvest treatment.	Period of examination.	Area examined. sq. ft.	Number of larvae found.	Per acre.
Cultivators' Field, Nanded.	Black, ordinary cultivation.	Local mixture.	Grazed in February.	11th June.	1,100	..	..
do.	Black, some mulch.	American.	Grazed & harrowed in April.	do.	240	4	726
Cultivator's Field, Parbhani. (1)	Light, no mulch.	Local mixture.	Plants well grazed in January.	Last week of April.	4,000	..	..
do. (2)	Black, ordinary cultivation.	do.	do.	1st week of May.	1,250	..	..
do. (3)	do.	do.	do.	do.	3,100	1	5
Aided Farm, Aurangabad.	do.	American.	Plants grazed, end of February.	Last week of April.	2,640	3	18

For elucidating the effect of mulching the plots during the season on the hibernation of pink bollworm larvae, some further plots at the farms at Parbhani and the Aided Farm, Nanded, were examined in 1936. Instead of examining a part of the plot every week during the period—February to June—as was done in the previous seasons, two or three periodical examinations were made in these plots during the off season. In addition to this, soil from plots of sixteen different cultivators' fields in different villages and under their normal operations was examined from the fourth week of March to the second week of June. In some cases a second examination was made about five weeks after the first.

The following results were indicated by the data collected during this year :—

1. Hibernating pink bollworm larvae were met with in the soil throughout the off season, their numbers being more in earlier examinations made in March or early April (3,000 to 5,300 to the acre). Recoveries made after the tenth of May were very few, especially this year.
2. More hibernating larvae were recovered from plots which had a good mulch on the surface during the season.
3. More larvae were recovered from plots where the cotton plants were allowed to stand ungrazed for a longer period, and the patches which were under shade of trees had still higher number of larvae hibernating in them. This was true for the cultivators' fields also.
4. From plots (cultivators' fields) with a lighter soil and an early maturing variety (*roseum* type) sown in them during the season, very few or no larvae were recovered even in the first examination made in April especially where the crops finished early and the grazing by cattle, goat and sheep was done soon after. But from plots growing Gaorani type of cotton or where there was a heavier pink bollworm attack in the season, some hibernating larvae were met with in April or early May.
5. More larvae were met with in the five to eight inches layer followed closely by the nine to twelve inches layer.
6. Even after *bakharing* (harrowing with a bladeharrow) caterpillars were obtained from some plots which had a deeper surface mulch on them during the season. In the two such plots from which hibernating larvae were recovered in the first week of June, harrowing was done on the fifteenth of May.

The above results confirmed the observations of the previous years.

Further support to the findings, by the direct method, of pink bollworm larvae hibernating in soil is lent by observations on :—

- (1) the incidence of pink bollworm attack on a stand-over or a ratoon crop enclosed in insect (Moth) proof cages. The former being left as plants

either completely stripped of their leaves by grazing or by hand, or unstripped normal plants. The grazing or stripping was done in March ;

- (2) the survival of pink bollworm larvae hibernating in bolls artificially buried at different depths in soil and (b) the emergence of moths from such buried bolls.

These two sets of observations formed the indirect method of determining the carry-over of pink bollworm through soil.

1. Re-infection of a stand-over or ratoon crop enclosed in insect proof cages :—

During the 1934 off season, cotton plants of the 1933-34 crop were enclosed in an experimental cage (66 ft. \times 16½ ft. \times 8ft.) in January and were allowed to remain as such in one half of it, while in the other half, separated from the first by wire gauze, they were thoroughly grazed on the fourteenth of March, so that only bare stems were left in the plot after that. Soil of both the halves was hoed on fourteenth of June and first of July. An examination of the various forms on the stand-over plants showed them to be free of pink bollworm attack in both the halves on the fourteenth of June. On the twenty-second and twenty-seventh of July two pink bollworm moths were caught from the first half while another was caught from the second half on seventeenth of July. Examination during July, August and September of the cotton forms picked from the plants and of the shed forms showed the presence of pink bollworm larvae of all instars in the material examined.

In the next two off seasons of 1935 and 1936, instead of enclosing the crop from the very beginning, the frame work of the cages was erected towards the end of March in the last year's cotton plots. The plants in one half the area of the cages were completely stripped of their leaves, buds, flowers and bolls, and in the other half they were ratooned (cut down to six inches from the soil). By the last week of May the wire gauze was put on and the plants were enclosed. Thus the soil of the two half cages was fully exposed to the natural atmospheric conditions of sun heat, etc., during the hot weather. An examination of the forms before enclosing the plants showed them to be free of pink bollworm. To ensure further that no pink bollworms were carried from outside, buds and bolls on all the plants in both the half cages were removed on three different occasions in the last two weeks of May and the first week of June (short cycle larvae have not been met with after the tenth of May in normal stand-over plants in the fields). All the fallen material on the surface of the soil was also removed.

Subsequent to the enclosing of the crop in the cages, examination of all buds, flowers and bolls picked from the different sets of one-fifth the total number of plants was made once a week from both the halves. In 1935 pink bollworm was found in the material examined from both the half cages on the fourth of July. While in

1936, buds in the first half (stripped plants) were found attacked in the last week of June and those in the second half in the first week of July. Further examinations showed quite a good deal of attack by pink bollworm in both the halves and in both the years. The attack was heavier in the second year. In 1935, attack in the control plants, which were near the cages and were treated similarly, developed two to three weeks later but in 1936 simultaneous attack was noticed on the outside plants also.

TABLE V.

CARRY-OVER OF PINK BOLLWORM THROUGH SOIL.

*Reinfection through soil of ratooned or stripped off plants enclosed
in a cage (1935).*

Week ending	Plants stripped.			Plants ratooned.		
	Number of forms examined.	Percentage attacked by pink bollworm.	Percentage caterpillars.	Number of forms examined.	Percentage attacked by pink bollworm.	Percentage caterpillars.
June						
27	33	..	..	6	..	..
July						
4	143	3.5	3.5	8	12.5	12.5
11	278	..	..	114	4.4	3.5
18	304	0.3	0.3	316	2.8	2.8
25	729	1.8	1.2	283	0.3	0.3
August						
1	787	2.4	2.2	689	..	..
8	1,244	0.1	0.1	842	..	..
15	1,687	0.7	0.6	1,808	..	..
22	957	1.8	1.4	854	2.0	1.8
29	927	1.8	1.7	599	2.7	2.8
September						
5	504	..	..	534	1.8	1.8
12	687	1.5	1.0	412	2.2	1.4
19	498	3.6	3.6	235	..	..
26	234	6.8	7.2	168	15.8	17.6

TABLE VI.

CARRY-OVER OF PINK BOLLWORM THROUGH SOIL.

Reinfection through soil of ratooned or stripped off plants enclosed in a cage (1936).

Week ending	Plants stripped.			Plants ratooned.		
	Number of forms examined.	Percentage attacked by pink bollworm.	Percentage caterpillars.	Number of forms examined.	Percentage attacked by pink bollworm.	Percentage caterpillars.
June						
28	157	3.2	2.5	16	..	..
July						
5	156	27.0	26.2	79	10.1	7.6
12	265	16.2	16.1	70	12.8	14.3
19	394	17.7	16.5	269	17.1	18.6
26	603	21.2	20.7	404	21.8	23.0
August						
2	494	58.1	64.0	520	34.0	31.5
9	599	38.6	38.7	309	12.0	11.6
16	626	39.5	37.4	855	19.9	20.8
23	941	27.3	39.5	873	25.2	27.8
30	395	33.9	33.6	620	46.8	63.4
September						
6	1,061	50.9	60.0	598	35.1	47.5
13	362	48.3	64.1	367	29.7	45.2
20	260	31.5	32.3	264	19.2	22.7
27	237	24.0	26.5	717	13.2	15.2
October						
4	363	12.6	11.5	257	8.6	7.0
11	469	6.1	2.2	352	9.4	8.3
18	1,395	10.0	8.5	617	10.2	9.7

It was interesting to note the three different generations of pink bollworm, well marked in the material examined from both the half cages during July-October 1935. Although a regular rise and fall in the percentage of attack, which was higher in 1936, was noticed in the later year, yet, there was never seen a complete absence of attack in the material examined. This meant a simultaneous emergence of a few moths in 1935 and that too in a short period as the results showed no over-

lapping of generations, while the continuity of attack and a higher percentage of infestation in the 1936 material indicated a greater initial emergence and that too over a longer period. It may be pointed out here that in order to ensure hibernation in soil, an additional 1,800 full fed caterpillars were released in February-March 1936 on the soil over which the cage was to be erected.

All possibility of an entry of the pink bollworm moths from outside was excluded by the enclosing of the crop in insect proof cages. Soil was the only source from where moths could have come. In 1934, three moths were actually caught in the two half cages and in 1936 also a single moth was caught at light trap on the first of June after which further attempts to catch the moths were given up. So the reinfection of the stand-over ratoon crop could be definitely ascribed to moths which might have emerged from the soil.

2. (a) Survival of pink bollworm larvae hibernating in bolls artificially buried at different depths in soil :—

During the examination of soil a few locks containing resting larvae were met with buried in the soil at different depths. To find the survival of larvae in buried bolls the following experiment was conducted in 1935 and repeated in 1936.

In the third week of February 1935, 400 well developed bolls, aired for a couple of days before interning, were buried in each of the pits of six different sets of five pits each. The different pits in each set were dug to a depth of two, four, seven, ten and thirteen inches respectively. At the time of burying an examination of the green bolls showed the presence of 45.2 per cent of third and fourth instar larvae.

The buried bolls and the surrounding soil from one set of pits representing all depths was dug and examined once a month. Six such examinations were made on the 26th of March, 24th of April, 18th of May, 6th of June, 3rd of July and 10th of August. In the first three examinations a good number of living larvae both from the buried bolls and the surrounding soil were recovered. A majority of them were found in material buried in pits two to nine inches deep. Bolls buried in the last pit gave a relatively low rate of survival probably due to the higher moisture content at that level. In the fourth examination in the first week of June, 4 per cent to 18.3 per cent of the original number of larvae were found alive in the various pits while a survival of one per cent to 14 per cent was noticed in the different pits in the first week of July when some living pupae were also found at different levels in the soil. In the last examination, on the tenth of August, only a few empty pupa cases were obtained.

TABLE VII.

CARRY-OVER OF PINK BOLLWORM THROUGH SOIL.

Survival of pink bollworm larvae in green bolls buried in different depths (1935).

Depth at which bolls were buried.	Initial percentage of living larvae in green boll.	Percentage of living pink bollworm larvae in bolls and surrounding soil examined on—						Remarks.
		26.3.35	26.4.35	20.5.35	6.6.35	3.7.35	10.8.35	
2"	45.2	31.8	10.6	14.8	6.2	0.2	..	P—Living pupae.
4"	"	14.6	9.2	16.0	2.8	5.0	..	
7"	"	19.0	19.2	12.0	6.6	..	..
10"	"	17.0	12.2	13.2	3.8	4.05P	..	
13"	"	10.0	5.2	4.0	1.6	0.2	..	

The observations in 1936 showed that an appreciable number of pink bollworm larvae buried in bolls were found living on the 14th of June when a number of living pupae were also recovered from both the bolls and the soil of the various pits. In the examination made in the first week of July one living larva and four pupae were found from three pits. In the last examination in the third week of July no living forms were recovered.

TABLE VIII.

CARRY-OVER OF PINK BOLLWORM THROUGH SOIL.

Survival of pink bollworm larvae in green bolls buried at different depths (1936).

Depths at which bolls were buried.	Initial percentage of living larvae in green bolls.	Percentage of living pink bollworm larvae in bolls and surrounding soil examined on—								Remarks.
		23.2.36.	15.4.36.	4.5.36	22.5.36	31.5.36	14.6.36	4.7.36		
3"	38.7	4.5 0.3 P	10.3 P	2.5 P	2.0 P	1.0 P	3.0 0.8 P P	P=Living Pupae.	
5"	18.5	12.3	13.5 0.3	4.8	4.0	3.3	16.8	0.0 0.3		
7"	32.	13.0 0.	0.5 14 0	7.5	2.0	2.0	9.0 1.0	.....	
9"	23.5	10.0 0.	3 11.0	3.5	3.0	0.8	8.0	0.3		
13"	23.	11.3 0.	3 10.8	2.3	1.5	0.3	4.8	.....	
18"	25.	9.0	11.0	9.3 0.3	2.5	2.0	9.3 0.5	.....	

A number of empty pupa cases were met with in the very first examination in both the years. This showed that some of the larvae in the buried bolls left them soon after burying, pupated and emerged as short cycle moths ; while the presence of living pupae in the material and the surrounding soil in June and the first week of July in both the years, and of the empty pupa cases in the last examination in the second week of August 1935 and third week of July 1936, clearly point towards the carry-over of pink bollworm through soil.

It was interesting to note that most of the surviving larvae recovered from the buried material were in hollowed out "double-seeds" which under normal above soil conditions is a rare occurrence in this part of the country.

(b) Emergence of moths from bolls buried in the soil :—

In the first week of March 1936, bolls were buried in another four pits A, B, C, and D dug to a depth of $2\frac{1}{2}$ ", $4\frac{1}{2}$ ", $6\frac{1}{2}$ " and $8\frac{1}{2}$ " respectively in between three rows of cotton plants which were ratooned to six inches. Small wire gauze cages were put on these pits on the first of June, after which date they were thoroughly examined daily for any moths that might have emerged in them from soil. In all sixteen moths were actually caught from the four cages during the period thirteenth to twenty-fifth of July. An examination of buds from the enclosed plants which had sprouted up in the cages showed a pink bollworm larval population of about eighteen per cent on the third of August.

From the above three sets of observations it would be clear that pink bollworm does carry over from one season to the next through soil in this part of the country.

It has been pointed out above that the number of such larvae hibernating in soil during May was much less as compared with those recovered earlier. Some further experiments, to determine the date of going into soil and the effective survival of these larvae, have been laid out for this year, the results of which along with the observations on the amount of cotton left unpicked at the different periods and their analysis for bollworm damage will go a long way in guiding us towards the control measures.

DISCUSSION.

Mr. P. B. Richards, in introducing the subject, said that his paper was written with the idea of providing the non-entomologist with a general conception of what the speaker had to do, how he had set about trying to do it and what he had succeeded in accomplishing in the United Provinces in regard to the control of the pink bollworm of cotton in the United Provinces. Drawing attention to the summary which showed the estimated results expressed in terms of the average increased yield per acre, the total area under experimental control, the estimated increased value obtained per acre and its average over a period of ten years, he said that as a result of the control of the pink bollworm an increased return to the cultivator of Rs. 18/- on an average of ten years or at least Rs. 15/- per acre could be secured. This result had been effected after several years of preliminary investigation which was undertaken to discover in the first instance whether the pink bollworm was controllable under local conditions and secondly whether it would pay to control it. The pink bollworm was not considered to be a serious pest until 1917 when Mr. Fletcher recorded it to be as serious a pest as the spotted bollworm. A considerable amount of work had accordingly to be done and this required the establishment of a research station in the United Provinces. It had to be discovered whether the only effective source of carry-over was in the seeds in which the hibernating caterpillars rested, and if so, what method should be adopted for killing the insects in the seed. The paper described the lines along which the work was carried out and showed how gradually it had been possible to eliminate the alternative carry-over of the pink bollworm hibernating in the soil or on cotton stalks standing in the field or cut and stored; living on alternative host plants; or surviving as short cycle larvae upon perennial cotton. The investigations had shown that these sources of carry-over were negligible and that the survival of the pest from year to year was almost entirely by hibernating caterpillars in the cotton seed. Effective control could readily be obtained by heating seed to a sufficient temperature in an apparatus in ginneries and in the open sunlight in the villages in April or May, which effectively destroyed the pest. There would, however, always be a residual carry-over but this could be brought down to the status of a minor pest. The pest had been considered sufficiently important to justify the United Provinces Government putting into law measures for the compulsory control of the pink bollworm in the United Provinces and it was hoped to put this act into operation in a short time.

Mr. H. D. Nangpal observed that Mr. Richards had shown that in the United Provinces the major source of carry-over was the seed. In the Hyderabad State the pink bollworm and the spotted bollworm were both found and both of them were considered serious pests. The pink bollworm itself was responsible for a damage of about 20—25 per cent of the crop. One of the two main sources of its carry-over was the soil and not the seed. Some caterpillars spin resting chambers in the fibres

of seed cotton which, if left unginned, serve as the second source of carry-over. His paper showed how the observations on the carry-over of pink bollworm through soil were made and provided data to indicate that the pink bollworm was carried over through the soil. Observations on the behaviour of the full grown pink bollworm caterpillars in the field, where the cotton crop was standing, showed that in the early part of the season, these caterpillars pupated in more numbers in above soil situations but with the advance of the season more of them went into the soil for pupation over there. Towards the end of the season, viz., in January and February, most of the caterpillars that went into the soil, instead of turning into pupae remained as such either free or in spherical chambers spun by them. In 1934 about half an acre of a cotton field at the Parbhani Farm was dug from the beginning of April to the second week of July. As many as 1346 caterpillars per acre were recovered from the soil in the fortnight ending on 16th of April, 629 in the next fortnight, 312 and 89 in the two fortnights of May, and 282 and 194 in the two fortnights of June respectively. The sowing season started towards the middle of June and long cycle caterpillars were found hibernating in soil even for some time after the break of the monsoon. In 1935 and 1936 similar observations were made.

In 1935 another set of experiments was conducted by enclosing, towards the end of May, ratooned cotton plants either cut about six inches from the soil or as full plants but kept bare of leaves in March, April and May, in an insect-proof experimental cage. Thus the soil was exposed to the natural atmospheric conditions of sun heat, etc., during the hot weather. An examination of plants before enclosing them showed them to be free from pink bollworm. They developed the pink bollworm attack in the cage after the break of the monsoon. In 1936 about 1,800 caterpillars were released in February and March on the soil over which the cage was to be erected for a similar experiment. In June a heavy incidence of bollworm attack, about 20 to 21 per cent, was noticed in the enclosed plants while in the outside ones there was very little infection at that time.

Another set of experiments was to find the survival of pink bollworm caterpillars by burying the attacked bolls in February and March. In 1935 and 1936 bolls were buried in the soil at different depths up to 13 inches in the first year and up to 19 inches in the second year. Living pink bollworm caterpillars were found at all depths in June and at some depths in July during both the years.

All these sets of experiments showed a definite carry-over of pink bollworm through soil.

To an enquiry of Mr. Y. D. Wad whether the moths were tested for egg-laying capacity after they emerged Mr. Nangpal replied in the affirmative.

Rao Saheb S. H. Prayag in referring to page 3 of the paper said that more hibernating pink bollworm larvae were found in plots which had a good mulch, but in

the case of the spotted bollworm mulching had been found to be a remedy. As in the case of pink bollworm more larvae were found in the mulched portion, this meant that mulching was not a remedy at all.

Mr. Nangpal remarked that not only was it not a remedy but more larvae actually went into the soil.

Rai Sahib Kalidas Sawhney considered that the question of mulching the soil should be looked at from two points of view. Whereas mulching might be effective in helping the pink bollworm to get into the soil, on the other hand, it might be effective in preventing the emergence of larvae hibernating in the soil. This was his personal view in the matter.

Mr. Nangpal said that he had carried out some observations on this point. He had buried some bolls in two plots one with mulched soil and the other with clods and found that practically 90% of the caterpillars in the soil had already come out both in the mulched and the cloddy plots. Mulching therefore may not be effective in preventing the emergence of the larvae.

Mr. V. Ramanatha Ayyar wished to know if any relationship had been found out between soil moisture and the incidence of larvae. In Madras he had experienced that the incidence of pink bollworm was less in rain-fed plots.

Mr. Nangpal gave an account of his work in the United Provinces where he had buried bolls in the soil and found that in the deeper layers which had some moisture there were fewer survivals than in the layers which had not much moisture.

Mr. Ramanatha Ayyar suggested that depth might have had something to do with the survival.

Mr. Nangpal agreed that depth had much to do with it.

Mr. Richards outlined the early attempts at control in Egypt where great care was taken to sterilise all the cotton seed, in spite of which the bollworm still persisted. This was ascribed to carry-over in the soil. In the Delta the soil temperature seldom rose to the lethal point for the caterpillar. As he had stated in his paper the absolute lethal temperature at which death was instantaneous was 140° F. With longer exposures a temperature of 120° F. was fatal while below 120° he had no record of the caterpillars being killed. Lethal temperatures were readily reached in the soil of the United Provinces. A survey of the soil in the submontane area had recorded a temperature as high as 155° F. while in the Gangetic plains generally a temperature of 130° F. was reached which was sufficient to kill the caterpillar. Thus in the United Provinces there was no serious soil carry-over except under shade. The temperature wave passed slowly downwards becoming less with depth. He enquired whether soil temperature observations had been made in the black cotton soils. He was inclined to think that a great deal of the difference in effective carry-

over in the soil of the Gangetic plains and Central India was due to the fact that in the United Provinces the caterpillar was in contact with the soil which did not crack while in the black cotton soil many of the caterpillars were exposed to the air and were not heated to the same extent.

Mr. Nangpal replied that they had not conducted experiments on this point.

Mr. Wad suggested that it would be useful to make these observations.

The President concluded the discussion on the two papers by observing that proper scientific information was necessary before any attempts to control the pink boll-worm were made. In the United Provinces the carry-over was almost entirely in the seed and they had met with very great success in controlling the pest by heat-treating the seed. In Madras, on the other hand, many years ago it was found by Ballard that there was no hope of controlling the pest without a Pest Act and a definite close season. Mr. Nangpal, who had worked both in the United Provinces and Hyderabad, had shown how great the differences were in the method of carry-over.

COTTON ENTOMOLOGY

Paper No. 1.

A BRIEF ACCOUNT OF THE INVESTIGATIONS ON SPOTTED BOLLWORMS IN SOUTH GUJARAT

BY

B. P. DESHPANDE,

ASSISTANT MARKETING OFFICER, POONA.

Attention was prominently drawn to the spotted bollworms for the first time, during the year 1905, due to the failure of the cotton crop in the Punjab. Since then, introduction of parasites, destruction of the damaged plants in the early part of the season and the use of *bhendi* (*Hibiscus esculentus*) as a trap crop were some of the measures which were advocated for the control of this pest. The position with regard to these worms was reviewed by the Indian Central Cotton Committee during 1922 and at their instance, further investigations on the spotted bollworms were started at Surat in 1923. This work continued at Surat till 1931 and was financed during all this period by the Indian Central Cotton Committee. The results of these investigations were embodied in a publication called "The Spotted Bollworms in South Gujarat" and were submitted to the Indian Central Cotton Committee. This publication has already gone to the press and is expected to be out shortly as Monograph No. 10 of the Imperial Council of Agricultural Research. In the meanwhile I was asked to read a paper on spotted bollworms before this Conference, and I am therefore taking this opportunity to place before you very briefly a summary of the several items of investigations on spotted bollworms which were carried out in South Gujarat.

The spotted bollworms are active throughout the year and the period of their life varies between 22 and 35 days. Oviposition takes place only during the night and the moths lay on an average 432 eggs. The larvae invariably go to the soil for pupation in this locality. Both *Earias fabia* and *Earias insulana* are present but it is the former which predominates on cotton, almost throughout the year.

A vigorous growth of the cotton crop commences soon after the close of the monsoon and the spotted bollworms appear in the cotton fields as soon as the plants are about 9 inches in height. In the beginning, vegetative shoots are destroyed in large numbers usually during the months of September and October. The larvae turn their attention to the flower-buds as soon as they begin to develop and the damaged buds drop away from the plants. Observations during three years from 1925 to 1928 showed that 34 to 51 per cent of the buds were found damaged by these insects out of the total number of buds which dropped away from the plants. A part of the larval population diverts its attention to the bolls as soon as they begin to appear. Young bolls drop away if they are attacked by these worms but the older ones continue to stick to the plants and yield a part of the damaged *kapas*. During the three years mentioned above, 20 to 69 per cent. of the shed bolls were found damaged by these caterpillars.

It was noticed that the rapid multiplication of the pest during the early part of the cotton growing season was considerably checked if heavy showers of rain were received during that period. The larval population of *Earias* on cotton was comparatively very high during the months of November and December, and normally it declined rapidly at the end of December or the beginning of January. This decline was partly due to the cold weather and partly due to the activities of the parasites.

We could devise a method (which is called the nightcaging method) for growing normal cotton plants free from bollworms for experimental purposes. Trials of growing more than 100 plants by this method, during each of the three seasons from 1928-29 to 1930-31, showed that the protected plants yielded 81, 54, and 7 per cent more *kapas* than the respective control plants. During the last season the increase was markedly low, because the caged plants suffered heavily from a storm which occurred at the end of October, when these plants had a very much larger number of forms on them than the control plants. On the caged plants the bolls opened about 4 to 6 weeks earlier than on the control plants, because the earliest growing forms on these plants were saved from the spotted bollworms.

Measures, which were studied for ascertaining the possibilities of controlling this pest, consisted of the removal of the attacked shoots, *bhendi* (*Hibiscus esculentus*) as a trap crop, attractants and deterrents for the moths, parasites, soil mulch, insecticides and the prevention of the carry-over of this pest from one season to another.

The removal of attacked shoots was not found to be very useful because only a small fraction of the total population of the *Earias* larvae could be destroyed by collecting the shoots which showed the damage prominently.

The use of *bhendi* as a trap crop also appeared to be of questionable utility, because it was found that these insects multiplied more rapidly on *bhendi* than on cotton and that the disadvantages of encouraging the cultivation of this crop in the midst of cotton seemed to be more than the advantages.

Cynogas dust and flowers of sulphur were tried as deterrents for the moths but both of them were found to be injurious to the cotton plants.

Several substances were tried for attracting the *Earias* moths. Cotton seed cake and sesamum cake, exposed in the cotton fields, after mixing with large quantities of water, showed a certain amount of attraction both for the spotted and pink bollworm moths. The attraction, however, was not sufficiently strong for using these baits as control measures.

All the known important parasites of *Earias* were found to be present at Surat and there was therefore no possibility of importing any of them from outside. A detailed study of the life and habits of the most important parasite, viz., *Microbracon leforyi*, showed that it was not practicable to increase its utility by artificial means.

Preliminary trials indicated that the presence of fine soil mulch in the cotton fields prevented the larvae from going deep into the soil for pupation and thus exposed them to the heat of the sun and to their predators. It was also observed that if any of the pupae happened to be buried below a small layer of an inch or two of pulverised soil most of the moths emerging from them could not make their way out of the soil. Further critical observations, however, showed that it was impracticable to maintain the required type of soil mulch in the fields, on a large scale, for its successful use as a control measure.

It was ascertained that spraying or dusting the cotton plants with lead arsenate or Paris green was not useful in controlling this pest. Later on it was found that calcium arsenate and sodium silico fluoride were very effective in reducing the population of *Earias* larvae in the cotton fields because the larvae were killed in large numbers on the dusted plants (especially the tiny ones, which wandered about, before commencing to feed after emerging from the eggs). Serious *aphis* infestation, however, developed on the cotton plants dusted with these insecticides a few weeks after the use of these poisons, and it proved to be a great obstacle in the way of using these substances for combating the bollworms. It appeared that the winged *aphis* were attracted to the plants dusted with these white poisons and they could multiply there, very rapidly because it seemed that the insecticides afforded them immunity from their enemies. Blackening these insecticides before using did not help to get over this trouble entirely. Of course it was ultimately very clear that insecticides like calcium arsenate and sodium silico fluoride could be successfully used against these insects if a cheap and efficient method could be discovered for preventing the subsequent trouble, viz., *aphis* infestation.

The cotton crop in this locality is harvested in the month of March or April and the next crop is normally sown after the third week of June, according to the condition of the monsoon. The spotted bollworms are active throughout the year and they get their supply of food, between the two cotton growing seasons, from the fresh shoots sprouting from the standing plants of cotton and their stumps, from the *bhendi* plants growing during that period and from the stray malvaceous weeds, if any of them happen to be in green condition at that time. These observations show that it will be possible to prevent the carry-over of this pest from one season to another, by cutting off its supply of food during the period between the two cotton growing seasons. This can be achieved if all the cotton plants are uprooted immediately after the harvest of *kapas*, if the cultivation of *bhendi* is prevented during this period and if stray malvaceous weeds found in green condition during summer are destroyed.

After all these trials, the experience gained by us at Surat indicated that with the available knowledge the only method of controlling this pest in this tract was the prevention of the carry-over of these insects from the cotton crop of one season to the cotton crop of the next season.

It was therefore decided to give a trial to this method on a large scale in a selected locality. An island would have been an ideal place for these trials but in the absence of such a place, an area of about 480 square miles in Broach district, where cotton is extensively grown, was selected for these trials for the following reasons :—

- (1) A considerable portion of this area was bounded by sea and rivers and hence the extent of areas from which fresh infection could come was greatly minimised.
- (2) This tract had no irrigation facilities and hence there were no possibilities of the cultivation of *bhendi* (*Hibiscus esculentus*) in this area and there were also less possibilities of other host plants thriving during the carry-over period.
- (3) There were no forest areas where alternative food plants might harbour this pest.

The clean-up campaign was therefore carried out in this locality during the years 1931 to 1934.

The main problem in this area was to get the cultivators to remove their cotton plants immediately after harvesting their *kapas*. The old method of removing these plants was to hack them out with a light pick-axe. By this method the stumps were left in the soil which used to sprout rapidly and provided food for these insects during the carry-over period. An implement had therefore to be devised for uprooting these plants efficiently.

The work of this clean-up campaign and the results achieved are well summarised by the Publicity Officer of the Indian Central Cotton Committee in a pamphlet on this subject and I should therefore like to repeat only the relevant portion here.

An implement, called the plant puller, which could uproot the cotton plant efficiently, was rapidly evolved and arrangements were made to get it manufactured on a mass scale at Baroda for supplying them to the cultivators at a low price of Rs. 1/2 per puller. It was essential for the success of this scheme that all the cultivators from the area should adopt the method of uprooting the cotton plants with plant pullers instead of hacking them with *kudalis* (light pick-axes) as they used to do before. In fact a strong bias against the idea of uprooting cotton existed in some of the villages. An extensive educational propaganda was undertaken for explaining the damage caused by this pest and for advocating the control measures by personal discussions with a large number of cultivators, magic lantern lectures, by demonstrating the actual working of the pullers and by holding competitions and awarding medals and prizes. The Publicity Officer of the Indian Central Cotton Committee rendered valuable help by issuing illustrated hand-bills and leaflets on the advantages of the measures, by obtaining for them wide publicity in leading newspapers and by personal visits to the tract when the propaganda was going on.

In spite of all these measures, however, about 7 to 8 per cent of the cotton area remained uncleared by the second week of May 1933. A sum of Rs. 3,000 had to be spent for direct action for clearing these fields and the clean-up was finally completed on the 23rd of May 1933. The next cotton crop was then kept under observation for noting the effect of these measures.

The area selected for the clean-up trials formed a very backward part of the district of Broach. In most of the villages, the cotton sticks were allowed to stand till very late in the season and prior to the propaganda work of this scheme, uprooting of the cotton plants was practically unknown in these villages. The cotton crop inside the clean-up zone was more severely attacked by the bollworms than the crops from the outside villages at the beginning of this work *i.e.*, during 1930-31 and 1931-32. In the 1933-34 season, although the first traces of the bollworms were detected during the latter part of August, the general crop continued to be free from attack till the second fortnight of September. The infection at all centres inside the zone varied between 3 and 6 whereas at the centres situated on the boundary and in the outside areas it varied between 5 and 26. A range of about 14 or 15 miles, represented by the centres Derol, Argama, Vagra, Vahial and Pakhajan, showed comparatively a very low infestation of bollworms as compared with almost all other centres during the important period of the growth of the cotton crop, *viz.*, the months of October and November.

In order to ascertain the effect of the clean-up measure on the cotton crop of 1933-34 season, observations were made on the following points also :—

- (1) Growing cotton plants by night caging ;
- (2) Observations on the general stand and progress of this crop during the season ; and
- (3) Yield of *kapas* from several villages.

Observations on the night caged plants were arranged at eight centres, both inside and outside the clean-up zone, and about 50 plants were kept under observation at each place. The results from these plots are summarised below :—

TABLE 1.

SUCCESSFUL RESULTS.

Yield of Kapas from caged and non-caged plants at different centres during 1933-34.

		Number of plants under observa- tion.	Number of bolls per plant.	Kapas per plant in tolas.	Percentage in- crease of kapas from caged plants over non-caged plants.
1.	Kadodra caged plants ..	59	27.30	4.19	
	Kadodra non-caged plants ..	59	22.60	3.55	18 per cent.
2.	Pakhajan caged plants ..	61	58.38	8.81	
	Pakhajan non-caged plants ..	61	53.90	7.67	15 per cent.
3.	Vagra caged plants ..	60	61.50	10.1	
	Vagra non-caged plants ..	60	46.25	7.6	33 per cent.
4.	Samni caged plants ..	60	34.13	3.85	
	Samni non-caged plants ..	59	26.7	2.57	50 per cent.
5.	Nabipur caged plants ..	51	49.3	8.2	
	Nabipur non-caged plants ..	51	38.14	5.64	45 per cent.
6.	Palej caged plants ..	53	45.43	6.9	
	Palej non-caged plants ..	53	40.8	5.25	32 per cent.
7.	Karmad caged plants ..	58	63.9	11.02	
	Karmad non-caged plants ..	59	51.66	7.94	39 per cent.
8.	Ankhi caged plants ..	40	68.62	11.28	
	Ankhi non-caged plants ..	42	45.38	6.6	71 per cent.

From the above results, it is seen that the increase in *kapas* from the caged plants varied from 15 to 33 per cent in the clean-up zone while on the border and at the outside centres the increase varied between 31 to 71 per cent. It is therefore apparent that the difference between the performance of the caged and non-caged plants was smaller inside the zone than elsewhere. This fact was also evident during the growing period of the plants. The nature of growth and of bearing of bolls was very similar in the case of the caged and non-caged plants at the inside centres.

Observations regarding the plants protected by night caging during the two previous seasons are also available and it is desirable that the results of these trials be also examined along with the results of the 1933-34 season.

TABLE 2.

Comparison of the increased yield from the caged plants over the non-caged ones at different centres during 1931-32, 1932-33 and 1933-34.

Name of place.	Percentage increase in 1931-32.	Percentage increase in 1932-33.	Percentage increase in 1933-34.	Remarks.
Kadodra ..	No plot.	23	18	Inside centre.
Pakhajan ..	29	57	15	Do.
Vagra ..	67	43	33	Do.
Samni ..	No plot.	48	50	Border centre.
Nabipur ..	28	35	45	Outside centre.

All these results have therefore shown that the difference between the caged and non-caged plants are minimised in the clean-up area after the commencement of the clean-up work and consequently have led to the improvement of the position of the cotton crop in the clean-up area.

OBSERVATIONS ON THE GENERAL STAND AND THE PROGRESS OF THE COTTON CROP.

At the commencement of the scheme the cotton crop in the clean-up area used to be stunted in growth and had a bushy appearance, indicating damage to the main and side shoots. However, during the 1933-34 season field after field in the experimental zone showed that a majority of the plant had escaped the shoot damage and consequently the main stems had grown tall and the side branches had attained good length.

Apart from the growth of branches, the plants showed very prolific bearing and the lowermost sympodia also had a good number of bolls on them, thereby indicating that the earliest forms had escaped the damage of the bollworms during the months of October and November. Some of the progressive cultivators express that comparatively the shedding of the forms observed by them, in the year 1933-34, was very limited.

A further proof of the success was obtained from the fact that the first pickings in the clean-up area commenced in 1933-34 about 2 to 3 weeks earlier than the previous season in most of the villages.

YIELD OF KAPAS.

Over and above this, the out-turn of the cotton crop of the 1933-34 season was exceptionally good in most of the interior villages as compared with the crop of the previous season (which was a season of a bumper crop) and it was admitted on all hands that the yield of the cotton crop in this zone would have been unprecedented if it were not for the three spells of intense cold which affected this crop during January 1934. Inquiries at the close of the season showed that the out-turn of the cotton crop in this area was easily about 25 per cent more in the 1933-34 season than during the previous year, whereas elsewhere the crop was not even as good as that of the last season.

A comprehensive view of all these indications therefore showed that the clean-up measures fulfilled the expectations to a very great extent.

DISCUSSION.

Mr. B. P. Deshpande stated that the spotted bollworms were known to be a serious pest in 1903. Much work had been done on them occasionally in the past but not regularly until the constitution of the Indian Central Cotton Committee in 1923 when it decided that planned work should be started in Gujarat and sanctioned a scheme for the purpose. The work was divided into three parts. The first part was to find out in detail the life history of the pest, the second the amount of damage caused by it and the third the measures necessary for its control. The work on the second and the third parts was conducted simultaneously with the first and not left over until the life history of the pest was studied, because certain control measures had previously been tried and the utility of these measures had to be ascertained. The study of the life history of the pest was taken up and after that the number of bolls shed and the number of bolls damaged were studied to give a good idea of the damage done. A method was devised to find out what the extra crop would be if the pest was controlled and this was provided by the study of the life history of the pest. This was called the night-caging method, by the use of which the plants could be exposed to the sun during the day time. That appeared to be a fairly practical measure to study damage and it was found from three years' continuous trials that the damage was very serious in Gujarat. When that was being determined simultaneously control measures were thought out. The removal of the shoots in which the pest appeared at first on the cotton plant was tried. That was not found to be very successful. Trap crops were also tried but that method was found impracticable on a large scale. Insecticides like calcium arsenate and sodium-silico-fluoride were tried but they were not helpful. The life history of the insect had shown that larvae went into the soil for pupation anywhere between 2 to 12 inches below the surface of the soil and small scale experiments were therefore started to prevent larvae from entering the soil and coming out again as moths by maintaining mulch. These experiments showed that fine mulch did prevent the moths from coming out successfully. Later on large scale trials, however, showed that fine mulch could not be maintained on a large scale. At the same time it was found that the carry-over of the pest was a very important item. By that time five years' work had been completed and the Sub-Committee appointed to review the progress of the scheme suggested that the carry-over of the pest should be more critically studied in that tract as there appeared to be good possibilities of controlling the pest by preventing its carry-over on the plants. That was the main point of attack and attention was thereafter concentrated on finding out whether the carry-over of the pest in the cotton plant itself could be stopped in the cotton fields of Gujarat, where they remained green during the 12 months of the year. The cotton plants that remained in the fields until May and June put forth new sprouts which provided very good material for food for the pest. It was found that that was the method by which

the pest was carried from one year to the other and but for the fresh cotton shoots the carry-over would be very considerably reduced. In order to prove this conclusion definitely a large scale experiment had to be tried in a certain compact area. An island area was not available. The next best was to select in a cotton growing part of Broach district a compact area of about 480 square miles surrounded by water on three sides. The next difficulty was to find out an effective implement for uprooting cotton plants. By using a pick-axe it was not possible to pull out the plants completely. A small implement called the plant puller was devised and arrangements were made to supply these implements at a cheap rate of Re. 1/- each by getting them manufactured on a large scale. In the above area of 480 square miles propaganda was carried out and 18,000 plant pullers were sold in about sixteen to eighteen weeks because people liked the idea as it helped them to clear the soil of the stumps which were found to be very troublesome. In the year in which the cleaning campaign was started the crop in the area dealt with was extraordinarily good and gave almost unprecedented yields. People were themselves quite satisfied with the experiment as they had a bumper crop.

Mr. Dabral stated that while in Surat the spotted bollworm pupated only in the soil, in Sind it was found to die down when the soil was flooded after about ten days. In Sind it had however an alternative place, viz., the leaves of plants, where he found it pupating. He wished to know if such an instance had been observed anywhere else.

Mr. Deshpande pointed out that in Gujarat there were only dry crops and there was no irrigation. When the soil was flooded naturally the spotted bollworm found an alternative place to live and so it went to the leaves on the plant.

Mr. Afzal Husain said that in the Punjab night-caging had given during some years the same results as in Surat, and the crop grown in cages had been regarded as very good. His own feeling was that the good crop was not so much due to safety from the bollworm pest as to some other causes. He could not say what these causes were but it appeared there was some other factor which had increased the yield and that would be clear from the figures given in his paper on page 6, Table 1. Besides night-caging and humidity there was in his opinion some other cause which was responsible for the good crop. In the Punjab there was some factor that affected the yield but it was difficult to ascertain what it was.

Mr. Deshpande said that, first of all, the bolls that were protected would naturally give more kapas. The second point was that even allowing for a certain amount of extra produce due to climatic advantage he did not think that the climatic advantage alone would bring in such a wide difference.

Mr. Afzal Husain stated that the first effect was the dropping off of the bolls but he did not think that increase in yield could be explained by the mere fact

that the insect had been kept out. The first figure given in Table 1 of the paper under discussion was from the cleaned area, the fourth one was from the borderland and the last three were from the uncleaned area and still the number of bolls was less in the first, i. e., plants from the cleaned area.

Mr. Deshpande pointed out that only the caged and the uncaged areas should be compared.

Mr. Hutchinson observed that it looked to him that the proportionate increase in bolls was about the same as the percentage increase in the kapas yield.

Mr. Nanjundayya said that Mr. Deshpande's remarks dealt with the yield of cotton and that it would be interesting to know what effect the experiment would have on the quality of cotton, e. g., whether it would affect the fibre weight per inch, maturity, ginning percentage, etc.

Mr. Deshpande replied that caging had affected to a certain extent the quality of cotton. Thickening of the fibre was more in the caged plants and it would give a better ginning percentage.

Mr. Nanjundayya said that perhaps the ginning percentage was more because of the difference in seed weight.

Mr. Wad enquired whether the increased yield was not due to the pulling out of cotton stalks and consequent better opening of the soil.

Mr. Deshpande replied that the uprooting of the plants did not affect the soil to that extent.

Mr. Wad wanted to find out whether the operation of uprooting had any share in increasing the yield in addition to the eradication of the bollworm because by uprooting further growth was stopped and the soil probably got a longer period for recuperation. He also enquired whether there was any measure to show what effect soil disturbance would have and what amount of soil was so disturbed.

Dr. Nazir Ahmad observed that the question raised regarding the effect of attack of the spotted bollworm on the quality of cottons was very interesting and there was some information available on this point. He had received some years ago from Mr. Richards samples of lint in which one boll in the lock, two bolls in the lock and three bolls in the lock had been attacked by the pink bollworm, and he had carried out tests on those samples. The results showed that in attacked bolls the fibre weight was very much less than in the healthy bolls which also gave a greater percentage of mature hairs. Since the lint was taken from the boll as a whole its fibre weight was less and although the fibre was less mature the spinning value of the cotton had gone up. The spinning quality was inversely related to the fineness of cotton and in the case under reference it so happened that on account of the

attack the fibres became finer due to lack of nutrition and therefore the spinning quality went up. The attacked lint was badly discoloured and even if it spun slightly better the spinner or the millowner would not look at that lint because of the discoloration. This discoloration should not be looked upon merely from the point of view of appearance because if the lint which had been attacked were stored it would discolour and deteriorate more in the course of time than the unattacked lint. If Mr. Deshpande sent some samples from uncaged and caged plants, he would be very glad to make tests on them.

Mr. Deshpande said that samples had been sent to the Laboratory and the results would shortly appear in a bulletin. The ginning percentage of lint from the caged plant was slightly (1%) higher than that from the uncaged plant. In the length of the fibre there was not very much difference in the two cases.

COTTON ENTOMOLOGY

Paper No. 3.

THE COTTON JASSID

BY

KHAN BAHADUR M. AFZAL HUSAIN,

ENTOMOLOGIST TO GOVERNMENT, PUNJAB, LYALLPUB.

The family Jassidae includes a number of pests of plants of economic value ranging from fruit trees to fodders. These small sucking insects are known to attack mango, apple, cotton, rice, maize, sugarbeet, potato, tomato, tea, lucerne, alfalfa, clover, etc. etc. And one or another of the jassids is a pest of importance in practically every country of the world. If the Potato Leaf Hopper (*Empoasca fabae*, Harris), is a major pest in the United States of America, we have the Apple Leaf Hopper (*E. Maligna*, Walsh.) in Southern Canada, New Zealand and United States. In England, *E. viridula*, Fall. is a pest of potato, in Central European Countries *E. flavescens*, F., attacks sugar-beet. *Nephotettix* spp. attack rice in Japan and *Empoasca flavescens* is destructive to tea in India.

Coming to the cotton plant, we have a number of species which are considered as pests more or less serious. *Empoasca facialis*, Jac., is a serious pest of cotton in many parts of Africa, especially Rhodesia. In many parts of South Africa, at least, the cotton that is not Jassid-resistant has no chance of success. *Erythroneura lubiae*, China, infests and damages cotton in the Anglo-Egyptian Sudan and the Italian Somaliland. Several other species, e.g., *Empoasca distinguenda*, *E. benedettoi*, and *E. doliche*, Paoli, infest cotton in various parts of Africa, but their economic status is, at the moment, uncertain. To these may be added, *Empoasca devastans*, Distant, which is certainly a major pest of cotton in India, being particularly serious in the Punjab, Sind and Madras. Lefroy (1906) mentioned jassids as serious pests on the experimental farms where introduced varieties were being acclimatised

and of many varieties of American and Egyptian cotton being tried in Bihar. Burt (1916) mentions *E. gossypii* occurring in small numbers in the fields on the Cawnpore Agricultural Farm. Misra (1919) reported *E. notata* among the pests of cotton in North Bihar and he states that he noticed these insects as early as 1906. Probably this was the species as referred to by Lefroy as the Cotton Leaf Hopper. It may be stated that the taxonomic validity of some of the Indian species on cotton is uncertain.

E. devastans has come into prominence during the last 23 years, *i.e.*, since the introduction of American cottons in the Punjab. In this Province the failure of 3 F cotton during 1913-14 was attributed to this insect. During recent years a very heavy outbreak occurred in 1930. *E. devastans*, more than any other insect, has been a nightmare for the cotton breeder in the Punjab and the position to-day can be stated to correspond to that in South Africa, *viz.*, that no cotton which is not jassid resistant has any chance of success in this Province.

Life History.

The life-history of *E. devastans* in the Punjab is as follows :—

The eggs, which are laid in the veins, hatch in 4-11 days. The maximum number of eggs laid by a female has been 29, and 15 eggs at the rate of 2 eggs a day may be considered a good, average performance. The nymphs of the 1st and 2nd instar prefer to feed near the bases of leaf veins. During the later instars, however, they get distributed all over the leaf, but feed chiefly on the underside. There are five moults and six instars. The nymphal life may be 7 days in autumn and 21 days in winter. The maximum life of the adults which have been allowed to pair is 36 days in summer and 48 days in winter. Adults not allowed to mate and supplied with fresh food may live for three months or more. The adults exhibit seasonal variation in colour, the winter broods being markedly reddish while the summer broods are greenish yellow. They are easily recognised by two prominent black spots, one on each forewing. Mating may take place 2-16 days after emergence, according to the season, and oviposition may occur 2-7 days after mating.

Two facts emerge out of the study of the life-history.

1. Although the number of eggs laid by a female is not large, the life-cycle is short and there are many generations in a year as the insect does not hibernate; consequently rapid multiplication is assured.

2. The adults live long for their size and can, therefore, tide over adverse climatic conditions.

Host-plants.

E. devastans can live and breed on cotton, hollyhock (*Althea rosae*), brinjal (*Solanum melongina*), potato (*S. tuberosum*) and bhindi (*Hibiscus esculentus*), the last named unquestionably is its most favoured host.

Seasonal History.

This insect breeds throughout the year, except for about two months in February and March. Early in April, eggs are laid on hollyhock and brinjal and from there the infection is spread to ratoon cotton and bhindi. Towards the end of June cotton seedlings are attacked and from this time on, bhindi and American cottons are heavily infested. About the beginning of November the jassid population on cotton and bhindi declines but the insect begins to appear on potato and it is on this plant that the pest passes its winter.

Injury caused.

Jassids cause injury to their hosts through sucking and de-sapping the plant. This damage may, possibly, be insignificant as compared to the harm which they may be causing by injecting toxic saliva into plant tissues which are killed, resulting in crumpling, browning and withering of the leaf and its subsequent death.

Jassids have been recognised as vectors of diseases in other crops and they are known to produce the curly-top in sugar-beet, mosaic in rice, streak disease of maize, yellow in peach, etc. The cotton jassid has not been found guilty of any such behaviour. The attack of cotton jassid in the Punjab usually leads to the curling of the leaves, followed by necrosis of their tissue. This curling, however, is very different from leaf crinkle which has been reported from Sudan. In the case of severe attacks almost all the leaves of a plant may be blighted.

Varietal susceptibility to attack.

Jassids exhibit considerable discrimination in their attack on different varieties of cottons. In the Punjab, as a rule, the *Desi* cottons are more or less immune, while in general the American cottons are susceptible, although certain varieties such as 4 F and L. S. S. are less susceptible than certain others, such as 38 F, 43F and 289 F. It is also interesting to note that the South African variety U4 which is immune to jassid attack in its native habitat becomes susceptible when grown in the Punjab.

Hairiness of cotton and Jassid attack.

Perhaps the most widely-held view is that hairiness of leaves makes a variety jassid resistant. It is true that practically all jassid resistant varieties of cotton

are hairy, but it is also a fact of no little importance that all hairy varieties are not always resistant. The Punjab-American variety 43 F though exceedingly hairy is liable to suffer from jassid attack and at times badly.

It is not only in regard to cotton that this opinion has found currency, but it is interesting to note, that hairiness of leaves in the case of potato and certain leguminous fodder crops was considered of importance against attacks of *Empoasca fabae* in America. Hollowell, Monteith and Flint (1927) concluded that smooth succulent English varieties of red clover were injured sooner than the hairy American types. Later, Hollowell and Monteith (1929) discovered that while in many cases greater resistance to jassid attack appeared to be correlated with more pronounced pubescence, there were some indications of actual resistance to the injury caused by jassid being within the plant. Poos and Smith (1931) made observations on *E. fabae* by breeding it on a number of hosts and came to the conclusion that there was some correlation between the amount of injury caused and the hairiness of the plants. At the same time, they observed that a larger number of nymphs hatched from hairy Peruvian alfalfa than from Kansas alfalfa, a much less pubescent variety. Similarly Poos and Haenseler (1931), who worked with 30 or 40 different strains and varieties of *Solanum melongina*, concluded that susceptibility to Leaf Hopper attack cannot be correlated definitely with any morphological characteristics, although thick hairy types seem to be less subject to injury than thin leaved, relatively smooth varieties.

It is, therefore, necessary that the correlation of hairiness and susceptibility of cottons to jassid attack should be carefully re-examined. It has been shown by Afzal (1936) that hairiness varies not only with the varieties but also with the season, age of the leaf and its position on the main stem. Since it is in the veins that eggs are laid—the hairiness of the veins must be very fully studied. Experiments should also be designed to prove conclusively that hairiness alone is the protective feature. It is possible that jassid resistant characters in the cotton plants are linked with hairiness, but hairiness itself may not be an important feature.

It must be recognised that for successful breeding of the insect on a plant two different operations are involved. The insect should be able to deposit its eggs in the veins of the leaves and secondly, the nymphs and adults should be able to feed on these leaves. Work at Lyallpur has shown that nymphs as well as the adults if caged on leaves of *Desi* cottons can flourish and complete their life history. Even very young nymphs experience no difficulty in obtaining subsistence from the most hairy or immune of the varieties. On the other hand it was discovered that egg laying (or may be egg hatching) was very scarce on the less susceptible varieties.

Experiments were carried out to test the capacity of development of *E. devastans* nymphs on six varieties of cotton, namely Jublee cotton, *Mollisoni* 15, *Mollisoni* 39, *Rosae* 10, 45 F and 4 F. Equal numbers of 1st instar nymphs were caged

on each of these plants and the numbers developing to the adult stage were counted. The results are given in the two following tables :—

Emergence of adults from nymphs bred on different varieties of cotton.

(50 nymphs were caged on each variety
and the plants were 41-45 days old.)

Variety.	Total No. of adults emerged.	Percentage of success.	Maximum duration of nymphal life.	Range of emergence.	Date.
Jublee cotton	39	78	16 days	11 days	1.x—16.x
<i>Mollisoni</i> 15	40	80	16 „	10 „	1.x—16.x
<i>Mollisoni</i> 39	40	80	16 „	8 „	1.x—16.x
<i>Rosae</i> 10	40	80	15 „	7 „	1.x—15.x
4 F	39	78	13 „	8 „	1.x—13.x
45 F	40	80	13 „	8 „	1.x—13.x

Emergence of adults from nymphs bred on six varieties of cotton.

(80 nymphs were caged on each variety
and the plants were 61-65 days old.)

Variety.	Total No. of adults emerged.	Percentage of success.	Maximum duration of nymphal life.	Range of emergence.	Date.
Jublee cotton	79	98.7	21 days	15 days	20.x—10.xi
<i>Mollisoni</i> 15	65	81.2	18 „	13 „	20.x— 7.xi
<i>Mollisoni</i> 39	76	95.0	20 „	13 „	20.x— 9.xi
<i>Rosae</i> 10	62	77.5	21 „	16 „	20.x—10.xi
4 F	65	81.2	18 „	11 „	20.x— 7.xi
45 F	75	93.7	18 „	11 „	20.x— 7.xi

Another set of experiments was performed in which the comparative numbers of eggs laid on American and *Desi* varieties by equal numbers of *E. devastans* were determined. Plants of *Mollisoni* 39 were used against 45 F and 38 F, respectively, as controls. These were all of the same age and offered approximately equal leaf area. The number of nymphs hatching day to day was counted as indication of egg-laying, direct counting of eggs being impossible without injuring the plants.

The results are tabulated as follows :—

Variety.	Age of plant (days).	No. of adults put on.	No. of nymphs hatched.	Percent- age of nymphs to the highest in the batch.	Date and duration of experiment.
<i>Mollisoni</i> 39 (Pot 4)	52	60 males 60 females	12	26.0	3. vii-27. vii 24 days
<i>Mollisoni</i> 39 (Pot 5)	52		7	15.2	4. vii-27. vii 23 „
45 F.	59	„	46	100	4. vii-29. vii 29 „
<i>Mollisoni</i> 39 (Pot 1) —	52	„	8	6.8	2. viii-18. viii 16 „
<i>Mollisoni</i> 39 (Pot 2)	52	„	3	2.5	3. viii-18. viii 15 „
<i>Mollisoni</i> 39 (Pot 3)	52	„	8	6.8	4. viii-18. viii 14 „
45 F.	54	„	117	100	4. viii-18. viii 14 „
<i>Mollisoni</i> 39 (Pot 6)	56	25 females 15 males	31	20.1	17. x to 2. xi 16 „
<i>Mollisoni</i> 39 (Pot 7)	56	„	29	18.8	17. x to 31. x 14 „
<i>Mollisoni</i> 39 (Pot 8)	56	„	26	16.8	17. x to 1. xi 15 „
38 F	56	„	86	55.8	17. x to 5. xi 19 „
38	56	„	156	100	17. x to 5. xi 19 „

A suspicion arose that although the nymphs could develop equally well on immune varieties, the resulting imago, though morphologically normal, may suffer

from a physiological disability such as sterility. This was set at rest by rearing adults on *Indicum* 50 (a resistant variety) and *Hibiscus esculentus* (a favourite host) respectively and putting them on to 45F (a susceptible variety) for egg-laying. The result was as follows:—

Eggs laid on 45 F.

Adults reared on :	No. of adults put on for egg-laying.	No. of nymphs hatched.	Duration of experiment.
<i>Indicum</i> 50	13 females 9 males	141	20. viii-24. ix 27 days
<i>Hibiscus esculentus</i>	„	60	28. viii-24. ix. 27 „

The following conclusions can be drawn from the experiments described above:—

1. The nymphs of *E. devastans* of all stages have no difficulty in developing on cotton varieties, immune and resistant, hairy and non-hairy.
2. That there is a marked reduction in egg-laying on immune varieties. Whether this is because of hairiness remains to be proved.
3. That nymphs reared on immune varieties are fertile.

Control.

Various sprays and dusts have been tried against jassids on a variety of crops. Kerosine emulsion, tobacco and soap wash, Bordeaux mixture (2-2-50) and sulphur dust have been recommended against leaf-hoppers on apple and mango. Recently McDaniel (1936) has observed that the Potato Leaf Hopper can be controlled on dahlia by dusting with such inert but white (not coloured) substances as flour, talc and infusorial earth which act as repellents.

The economics of spraying cotton has been worked out in connection with the white-fly investigation, and the insecticide used therein, namely Rosin compound, would effectively kill *E. devastans* both nymphs and adults. It must, however, be recognised that control by chemical means presents serious difficulties in the present stage of our agriculture, when the co-operative effort is still lacking and the cost of production must be kept down to the very minimum. No wonder that spraying on a really large scale against the cotton jassid has been attempted nowhere, so far.

Destruction of alternative host plants is not to be recommended as all of them are of good economic value. Even if it were possible it is more than likely that

jassid adults would survive on almost any green plant and multiply whenever favourable conditions returned.

The Agricultural Conference held at Nairobi in 1926* recommended that the possibility of controlling jassids by fungi be further explored but so far no effective fungal parasite has been discovered. Insect enemies, of which there are several, are singularly ineffective in controlling the pest and hold out little promise for the future.

The only hope, at the moment, lies in evolving jassid-resistant varieties of cotton. This will only be possible if the cotton breeder knows exactly what are the characters which make a variety resistant to jassid attack. The discovery of these characters, therefore, will be one sure step towards the control of the cotton jassid. Such a discovery will have to be based on a sound knowledge of the biology of the insect and its habits, especially in relation to egg-laying and the chemical and physical characters of the cotton plant. Nor would an ecological study of *E. devastans* be less important in any scheme of jassid investigation. It seems probable that like many other pests, jassids multiply at a rapid rate so as to become serious only periodically. This year jassid attack has been very low in the Punjab. A year of heavy attack was 1930 and also 1934 to some extent. The causes leading to this are not clearly understood. An ecological study of the insect would throw light on this problem and may prove helpful in forecasting future outbreaks.

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DISCUSSION.

Mr. Afzal Husain, in introducing the paper, said that, unlike the pink boll-worm, the Jassid did similar damage and followed the same life-history, both in Southern India and in Northern India. Referring to observations made at Lyallpur he confined himself to the discussion of the general opinion that jassid-resistance was correlated with hairiness. Table on page 5 of his paper showed the emergence of adults from nymphs bred on different varieties of cotton. He stated that the duration of the nymphal stage did not show very great difference and nymphs could feed and develop on all the varieties tried. As regards the range of emergence, that is from the first day of the emergence of the adult to the last, it was greatest in the case of Jubilee cotton, but there was no large difference in this respect either. These tests showed that resistance was not due to the fact that the plants were such that the nymphs could not live on them, but because they were not born on them.

The egg laying capacity of this jassid on different cottons, given in the table on page 6, would show remarkable differences, the number of nymphs hatching, and therefore eggs laid, on 45-F and 38-F being much greater than on Mollisoni. It would appear that varieties might be resistant because eggs were not laid on them.

Although nymphs might breed on various types of cotton, certain types might lack in certain chemical substances, perhaps vitamins, and the adults hatched out of such eggs might have reduced fecundity. Table on page 7 showed that adults reared on leaves of *Indicum* 50—"an immune variety"—and *Hibiscus esculentus*—a susceptible food plant—laid eggs freely on 45-F showing thereby that there was nothing in the juice of the non-susceptible plants, resistant and inimical to the development of the sexual organs in these insects.

He stressed the importance of the question of evolving Jassid resistant types in the Punjab, as had been done in some of the other cotton growing countries, as no cotton which was not resistant had any chance of success. He maintained that for a solution of this problem it was essential for the cotton breeder to know what were the factors which were responsible for producing jassid resistant types. It was true that most hairy cottons were resistant and this was also true of some other hairy plants attacked by jassids. It was, however, not true that all non-hairy cottons were not resistant. Perhaps the factors for hairiness and some other factor which produced a jassid resistant type generally went together. Summing up he said that the field open for enquiry was very wide and that the results of these tests had shown that the egg-laying capacity of the insect on different varieties had to be investigated.

Mr. B. M. Dabral referring to the problem of red leaf in the physiological work at Sakrand stated that it was found that a greater portion of the trouble was due

to jassids. Viewing from the aspect of plant growth he stated that there were certain varieties like 289-F which were monopodial and that they thrived through the reproductive stage better than those which were sympodial. Jassids came into Sind between July and August during cloudy weather and attacked the plants in the fruiting stage, but after the attack the plants make fresh vegetative growth so that in the month of September when they are flowering and fruiting jassids disappear resulting in a normal crop. This character was definitely associated with the glabrous varieties. As regards the nature of the jassid injury, whether it was purely mechanical or physiological, investigations showed that when the jassids attacked in very large numbers, immediately the colour of the leaf changed from green to yellow and from yellow to red and so on; but when the attack was mild, after a few days a sort of curling of the borders occurred followed by the yellow and red colours. The leaves were succulent enough but the pigments changed.

Mr. Ramanatha Ayyar said that in Madras some studies were made with regard to jassid resistance and that it was found that the incidence was greater in the months of November, December and part of January. It was also found, as in the Punjab, that hairiness was not a good criterion for resistance to jassids, but it was clear that jassid resistant strains could easily be bred. He said he had half-a-dozen strains which would completely resist jassid and referred to a cross, which was in the F6 generation, between U-4, an imported strain from South Africa and Cambodia, a completely jassid resistant strain probably in the whole of India. He continued that his experience in the studies of factors relating to immunity of Cambodia cotton to stem weevil (*pempherus affinis*) led him to think that investigations with regard to finding out the criteria for resistance might not take one very far in economic work. In the case of pempherus he had tried entomological means of control, but found that breeding resistant strains seemed to give more hopeful results. In the Punjab the difficulty seemed to be that the insect incidence was not uniform year after year, but he opined that by finding out a region where the incidence might occur year after year and by carrying out breeding experiments in that region it would be possible to evolve a strain which would be economically useful. He did not in any way decry the study of other characters, but if the work was to be done in the shortest time, he thought that by crossing with resistant types it was quite possible to evolve a strain resistant to jassid, as Mr. Parnell was able to do in South Africa.

Rao Saheb G. L. Kottur thought that hairiness was not a sufficient reason for jassid resistance, but it had something to do with other factors. In the case of Cambodia cotton there were two types, one with dark green leaves and the other with yellow green leaves, and the latter was found to be susceptible while the former was resistant. He made a cross between the susceptible type of yellow green leaves with the hairy Cambodia, and the F1 was found to be very resistant although both

were susceptible. Again in regard to hairiness there were differences in the character of the hairs as for instance in the case of Cambodia cotton he found that in some plants the hairs were coarse, in some soft and in some others there were the so called "stinging hairs." There were also great differences between the hairs of the various types. Plants with stinging hairs were more resistant than soft haired plants.

Mr. F. W. Andrews said that in the Sudan there was trouble in the cotton of the black cotton soils under irrigation where Egyptian Sakel was grown particularly in the northern parts of the area. Red leaf appeared late in the season and work on it seemed to indicate that it did not cause much damage. It has been assumed that jassids are partially responsible for this reddening of the leaves.

Dr. Nazir Ahmad referring to the data given on the incidence of jassid on different varieties, wanted to know whether data were available on the same variety grown under different conditions which might result in different degrees of healthiness of the plant. Taking the same variety, either 4-F or Mollisoni, he enquired whether there was any difference in the attack of jassid on very healthy and unhealthy plants.

Mr. Afzal Husain replied that he did not know about the observations made in other parts but that he proposed to try the experiment in the Punjab during the current year.

Dr. Nazir Ahmad suggested that if the conditions of the plants were different, the differences in the degree of emergence also should be found out. The effect of different manures might make the plants so healthy as to resist the attack.

Prof. C. J. George remarked that the damage by jassid was over-estimated at Coimbatore as from his experience he thought that the damage from jassid was very slight.

Mr. Ramanatha Ayyar pointed out that when Prof. George was at Coimbatore only resistant type like Cambodia was being grown; since then susceptible varieties were also being tried for breeding purposes.

Mr. Wad enquired whether the resistant variety would be found to be so all over India.

Mr. Mohammad Afzal replied that the South African variety U-4 was immune to jassid in South Africa, but when it was brought to the Punjab it was very susceptible.

Mr. Wad observed that in that case other factors might not be quite so unimportant. If differences regarding them were really found, it might be possible to devise means by cultural methods also to adapt these resistant strains to other areas. As regards the opinion of Mr. Ramanatha Ayyar that chemical and entomological methods

were not likely to lead to practical results in the shortest time, the speaker considered that this type of work, although not immediately profitable, might be so in the long run and such work should not therefore be relegated to the background.

Mr. Hutchinson drew attention to the difference in resistance of the same variety in different places as shown by the fact that U-4 broke down under Indian conditions while Cambodia did not do so, whereas in South Africa Cambodia was acknowledged to be less susceptible than U-4. He observed that so far as relative resistance was concerned it was the same in India and South Africa.

COTTON ENTOMOLOGY

Paper No. 4.

PRELIMINARY OBSERVATIONS ON THE DISTRIBUTION, FOOD PLANTS AND ORIGINAL HOME AND HABITAT OF PEMPHERES AFFINIS FST., THE COTTON STEM WEEVIL OF SOUTH INDIA

BY

P. N. KRISHNA AYYAR,
PARASITOLOGIST, AGRICULTURAL RESEARCH INSTITUTE,
COIMBATORE.

Pempherus affinis Fst. is well known as a destructive weevil stem borer of both exotic and indigenous cottons occurring in vast areas in South India. The history of the species coupled with the course of its distribution seems to indicate that it has come into prominence with the introduction of an exotic variety of cotton, namely, Cambodia from its native home Cochin-China, and with the spread of its cultivation the insect has also increased its range of distribution. Hence the information as to whether the pest is introduced or indigenous is indispensable for an economic worker in order to decide upon the proper course of action. This aspect of the problem has not been tackled hitherto and it is the purpose of this paper to present the results of a brief study of the same. It may be stated that this note is of the nature of a preliminary report and the conclusions drawn are therefore essentially of a tentative character. In discussing this problem it is necessary to touch upon in some detail the history, distribution, seasonal occurrence and food plants of the species which form the main source of evidence in support of the proposition.

HISTORY OF THE SPECIES AND DISTRIBUTION.

Since the original description of the species by Faust (1898) the first published account of this insect appears to be by Lefroy (1906) who has described it for the first time as "the cotton stem weevil" occurring in Bihar. The next reference to the

insect is by the same author (1909) under the name "Phylailis" wherein he has made the first record of its presence in South India. Fletcher (1913) refers to the insect as being restricted to Coimbatore district. He again (1917) records its occurrence in Cuddapah in Madras. Ramakrishna Ayyar (1919) and Ballard (1922) have recorded its spread into many of the cotton growing districts of the South.

Recent studies by the writer have shed new light on its distribution and ecological associations. It is now known definitely to occur in cotton or an allied food plant like *Bhindi* in the whole of Coimbatore district, the whole of Ramnad district, the southern portions of Tinnevely district, North and South Malabar, Southern border of South Canara and portions of adjoining native states of Cochin and Travancore. In Malabar and South Canara the insect has been noted as breeding in *Bhindi* and not in cotton. Previous records include Salem, Trichinopoly and Madura. The pest has been observed by the writer as breeding in hill tracts like Mudgole agency in Vizagapatam and Manantoddy (2600 ft.).

The weevil has not been observed as a pest of cotton in other Provinces in India. It has been observed to infest *Bhindi* in Pusa Sasa Musa in Bihar, Dehra Dun in the United Provinces and Surat in Gujarat. From Dehra Dun it has been recovered also from *Urena lobata*, Hollyhock, *Sida rhombifolia* and *Sida acuta*. Outside India this weevil has been recorded as a pest of cotton in Burma and the Philippines. Negative reports have been received from Indo-China, F.M.S., Ceylon, New Zealand, Queensland, Australia, Brazil, Uganda, Cyprus, Malta, Kenya, Khartoum, Pretoria, Egypt, Rhodesia, Java, Buitenzorg, Canada, Jamaica, Barbados, Nyasaland, Hawaii, British West Indies, Guiana, Antigua, Greece, France, Russia, Middle Asia, North Caucasus, South Eurasia, and British Solomon Islands.

OTHER SPECIES OF PEMPHERES KNOWN.*

The Genus *Pempher* as it exists to-day comprises only five known species as follows.*

Name of Species.	Known distribution.
<i>P. affinis</i> Fst.	India, Philippines, Burma.
<i>P. hapena</i> Pascoe.	Singapore, Malacca, Philippines.
<i>P. pleurostigma</i> Fst.	India.
<i>P. picta</i> Heller.	Tenasserin (Lower Burma).
<i>P. trilineata</i> .	Batchian (Dutch East Indies).

The genus is seen thus to be confined to Indo-Malayan region. Three of the five species are restricted to Indo-Burman Zone and two species are known in India.

*The writer is indebted to U. S. Bureau of Entomology and British Museum for this information.

Hence the genus may be regarded as Indian or Indo-Burman in origin.

SEASONAL HISTORY AND SOURCES OF INFESTATION.

The insect is probably capable of occurring throughout the year and can theoretically have about five to six generations provided the crop is kept on indefinitely. In a normal season beginning with September and ending with March there appear to be three generations, the third being rather indistinct.

TREND OF WEEVIL INFESTATION IN COTTON 1935-36.

COIMBATORE.

Month.			No. of plants examined.	Percentage of attack.
September	1935	.. ..	1200	Nil.
October	1935	.. ..	3158	3.2
November	1935	.. ..	803	23.2
December	1935	.. ..	1381	28.4
January	1936	.. ..	1228	55.7
February	1936	.. ..	1577	77.2
March	1936	.. ..	869	91.7

It is seen by the end of the cotton season there is a great reduction in live *Pempheres* population as also in its natural enemies. There appear to be three probable sources of infestation in the first generation of the succeeding crop, (a) local off-seasonal survival of *Pempheres* adults, (b) from local alternate hosts infested, (c) migration from adjoining fields of country cottons. Evidence so far obtained goes to emphasise the first two as the more potent causes under Coimbatore conditions.

Parasites and Predators.—A word about these may not be out of place. Four Hymenopterous parasites and a predaceous mite have been definitely noted on the pest. The mite—*Pediculoides ventricosus* Neupt. is a nuisance in the laboratory and may be dismissed as of no value in its control. The four parasites are (1) *Spathius* Sp. (Braconidae), (2) *Euderus* Sp. (Enlophidae), (3) *Aplastomorpha calandreae* How. (Pteromalidae), and (4) *Eupelmus* Sp. (Eupelmidae). Among these *Spathius* Sp. seems to be more promising although *Euderus* Sp. happens to be more numerous in certain seasons. The maximum percentage of total parasitism has not exceeded 5% at the end of the season. In the first generation they are scarce. After the third brood they become rare. Their occurrence is irregular and erratic.

Food plants.—Since its discovery as a pest of cotton by Lefroy (1906) its range of food plants has been on the increase so that the list of known hosts is now fairly long and varied. Ballard (1922) lists about thirteen food plants and states that it has been noted to breed on all except three. The recorded food plants mainly belong to two families, Malvaceae and Tiliaceae with the exception of *Dombeya angulata* (Sterculiaceae) and *Cannabis sativa* (Urticaceae). The data obtained from recent studies may be summarised as follows. It has been actually seen to breed on the following alternate hosts, Bhindi, *Malvastrum coromandelianum*, *Sida acuta*, *Sida spinosa*, *Sida rhombifolia*, *Sida glutinosa*, *Urena lobata*, *Corchorus olitorius*, *Corchorus trilocularis*, Hollyhock, *Hibiscus vitifolius*. Besides, a few infestations similar to those of *Pempher*es have been noted in *Abutilon glaucum*, *A. hirtum*, *Sida cardifolia*, *Triumfetta rotundifolia*. Among these cotton and Bhindi may be considered as preferred hosts and the rest as occasional or accidental. The intensity of infestation may be reckoned in the descending order of enumeration.

Its original habitat.—The present state of our knowledge on this question may be gauged from the opening sentences in one of the latest publications (Madras Agricultural Journal, Vol. XXII. 1934, p. 206) on this problem. "It is not definitely known when and how this pest was introduced into this country; in fact it is even difficult to say whether it is one of the introduced forms at all."

The question of the original habitat of *Pempher*es came into prominence and relevant evidence was obtained for the first time by the writer in the course of a survey in North Malabar in December 1935. The main centres of investigations were ecologically very diversified and included many tracts entomologically unknown and unexplored. These areas comprise heavily forested and hilly tracts isolated by barriers from any cotton. In altitude these varied from sea level to nearly 3000 ft. In these localities as in the rest of Malabar cotton cultivation is absent except on a few hill slopes. Cotton plants from such localities were found to be free from *Pempher*es. In certain localities like Pudupadi at the foot of Wynaad hills and Kallar in Kasaragode taluk, the strains of Cambodia, Bourbon, etc., grown for trial at the instance of the Cotton Specialist, were also free from the pest. Various species of *Sida*, *Hibiscus*, *Abutilon* and Tree cottons were also free from its attack except *Bhindi* (*Hibiscus esculentus*). *Bhindi* plants invariably showed phenomenally heavy infestation of *Pempher*es. The weevil was discovered in heaps in Calicut Taluk, Pudupadi, Mauntoddy (2600 ft.), Tellicherry and Thiruvangad, Cannanore and surroundings. Plenty of adults, pupae, prepupae, grubs of all stages were recovered. As many as twenty adults and as many of the other stages were obtained from a single old stem. Consignments of such stems caged in Coimbatore laboratory yielded numerous weevils. Such abnormally heavy infestations have never before been observed in any of its food plants including Cambodia cotton. Again the heavy incidence in *Bhindi* and its total absence in adjacent cottons appear to be of significance.

This discovery stimulated further search in other parts of Malabar as also in a few other districts. The following observations made by Mr. V. Margabandu, Assistant Entomologist in the scheme, provide additional data in support of the proposition advanced. In a suburb of Pollachi in Coimbatore district, a notable cotton growing centre, both cotton and *Bhindi* were seen to harbour the pest. In villages, Velanthalam and Kozhinjanparai in the eastern border of Cochin State, *Bhindi* was infested but cotton was free. In Trichur Government Farm, *Bhindi* and a Cambodia crop of two years' standing showed attacks but the first year Cambodia crop was free. Other localities like Kollengode, Ottapalam, Perunthalamanna (S. Malabar) all showed infestations in *Bhindi*. It has been noted in *Bhindi* in Coimbatore and Ramnad district. In other provinces, it has been observed to breed in *Bhindi* in Pusa and Sasa Musa in Bihar, Surat in Gujarat, and Dehra Dun in the United Provinces. An analysis of these observations brings out the following facts.

- (a) Occurrence of weevil in *Bhindi* in areas where cotton cultivation is unknown as in Tellicherry, Cannanore, Manantoddy and Dehra Dun.
- (b) Its occurrence in *Bhindi* in such distant and obscure corners and hill tracts like Manantoddy in Malabar, Mudgole in Vizagapatam and Dehra Dun in the United Provinces.
- (c) Profuse breeding of same in *Bhindi* in Tellicherry, Cannanore and Manantoddy.
- (d) Presence of weevil in *Bhindi* and its absence in cotton grown for trials, e.g., Pudupadi, Kallar, Anakapalle.
- (e) In places where cotton is of recent introduction weevil is found in *Bhindi* and an older crop of cotton and not in a younger crop as in Trichur which appears to indicate the transition from *Bhindi* to cotton by gradually acquiring a taste for the latter.
- (f) The weevil occurs in both *Bhindi* and cotton in areas where cotton cultivation has been carried on for years as in Coimbatore, Pollachi and Ramnad districts.

According to flora of British India, *Bhindi* was probably wild in India originally. The weevil appears to have been primitively attached to *Bhindi* and it may be more appropriately renamed as the *Bhindi* stem weevil.

THE HISTORY OF THE RISE OF PEMPHERES AS A COTTON PEST.

Evidence now available seems to warrant a brief statement of the hypothesis which looks tenable. The species *Pempheres affinis* is confined to India, Burma and Philippines. Three species out of five occur in Indo-Burma region and its

primitive host is a native of India. The species is reported to be absent in Cochin-China. It looks reasonable, therefore, to assume that the weevil is indigenous to India and that changing agricultural conditions brought about by the introduction and rapid extension of Cambodia cotton—a preferred food plant and an ideal all round host—it slowly acquired a taste for this exotic cotton and from this habit it enlarged its tastes to other cotton varieties. A simple explanation might now be offered for its multiplication into pest proportions due to abundance of food and favourable climate coupled with absence of natural enemies which it might have escaped in the course of its transference from its primitive habitat of *Bhindi* to its new environment of cotton fields.

More extensive ecological researches are needed for further elucidation of the problem but the observations recorded above may form the basis for planning rational methods of biological control particularly with reference to the source and selection of suitable parasites.

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DISCUSSION.

Mr. Ramanatha Ayyar, in introducing the paper, acknowledged that he was not an Entomologist, and said that the only reason why he came forward to say a few words was that the work was being conducted under his charge. *Pempher* did damage in Southern India, especially on Cambodia cotton, by burrowing into the stem particularly into the hypocotyl portion of the plant, as a result of which the plant produced a number of galls. If the tissue regeneration was not quick, the plant succumbed and the mortality in many cases rose up to 25%. In the case of weevil attacked plants that managed to live the yields were reduced from 10-25% due to the mere incidence and the production of galls. One of the remedial measures tried by the Madras Government was the promulgation of "The Pest Act" in parts of the Madras Presidency. But owing to variations in the agricultural and meteorological factors in certain tracts the Pest Act could not be enforced there strictly, with the result the object aimed at by the Act was not achieved fully and control by biological and breeding methods was resorted to. Mr. Krishna Ayyar working on the biological aspect of the problem had come to the conclusion after a survey of the distribution of the insect throughout the Presidency, that *pempher* was not an introduced insect but it was an indigenous one probably affecting *Hibiscus* species. As regards parasites, four different types were found and the maximum percentage of total parasitism seemed to be very low, being only 5% at the end of the season. The Parasitologist was, therefore, sent to various parts of India to import parasites which would be useful for the control of the *pempher*, and he had brought down a few species which are under study. He said that it was too early to say anything about the work so far done and that he would be thankful if more profitable lines of work could be suggested.

Mr. Richards pointed out that if the author of the paper was not present much of the value of the discussion was lost, and said that he wished that the author could give his own experience and not through some other person who was doing work on quite a different problem.

The President observing that the point raised by Mr. Richards was of some importance expressed his view that in future conferences no papers should be read unless the author or the joint author was present. He invited the views of the members of the Conference on the question.

Dr. Nazir Ahmad said that the Conference was suggested by him after he visited the Empire Cotton Growing Conference in England in 1934. The practice there was, as was done here, to divide the work into various sections and that if the author of a paper was not present his paper was generally taken as read unless the members present wanted special discussion on it in view of its importance. The same procedure may be followed here.

Mr. Hutchinson agreeing with the views expressed said that the object of conducting the Conference was for exchange of views and the experience of the various workers, and that if the author was not present the object would be defeated.

Mr. Ramanatha Ayyar, while expressing agreement with the view put forward said that owing to administrative difficulties, sometimes it might not be possible for the authors of papers to attend the Conference. In the case of the particular paper, however, he could speak, because he was in charge of the scheme.

Rao Bahadur S. S. Salimath observed that one of the administrative difficulties was that some could not get travelling allowance to attend the Conference.

The President summing up said that the whole essence of the Conference was personal discussion. There were ample facilities for discussion and if an author undertook to present a paper, he must be present or if two people were working together on the same piece of work, there was no objection to the paper being a joint one. He took it to be the general wish of the Conference that they should not consider any paper unless the author was present himself.

This was agreed to.

The President remarked that **Mr. Ramanatha Ayyar** was closely associated with the work on the stem weevil in the Madras Presidency and that if there were any questions which members wished to ask him, he would be able to answer.

Mr. Richards said that some statements in the paper on the amount of work done and data collected were definitely anticipations and he wished to know how much evidence there was for the reasoning adopted in the last two sentences in the penultimate paragraph of the paper under discussion. He considered that it was not a question of transference of parasites by being taken from one portion of the field to the other, but it was by shifting within the same locality. He would very much like to know what the author had in mind when he stressed about transference, as the idea was completely new in biological control. Another point was that on the examination a few months after the discovery of pempheres in certain areas, the author had assumed that there was sufficient evidence that this was indigenous. The whole point of this enquiry into pempheres and biological control was that in its source of origin it might be possible to find an effective parasite. If the case was established after a few months' work that India was the source of origin, then the question of biological control of the pest might be dropped. He opined that it was a sweeping conclusion of a few months' work, and that the points raised by him could be clarified only by personal discussion with the author.

The President observed that the comments should be forwarded to the author for eliciting more information.*

This was agreed to.

*Additional information since received from the author is printed as an appendix at the end.

COTTON AGRONOMY

Paper No. 1.

WATERING EXPERIMENTS ON COTTON

AT THE

COTTON RESEARCH STATION, RISALEWALA, LYALLPUR,

BY

M. MOHAMMAD AFZAL,

COTTON RESEARCH BOTANIST, LYALLPUR.

The Punjab has perhaps the biggest irrigation system in the world. Of the total cultivated area of about 30 million acres, about 50% is irrigated from canals, wells, tanks and other sources of water supply. The canals, however, are by far the biggest source of irrigation, supplying water to more than 70% of the irrigated area; the total canal irrigated area being about 10 million acres.

The Punjab canals have turned vast desert areas into flourishing agricultural districts. It is also in these canal colonies that some 65% of the total cotton crop of this Province is produced. Further the total bulk of the Punjab American crop is produced under canal irrigation.

In ecological relation to the cotton crop, the climate of the canal colonies may be described as hot and dry during the period of sowing, germination and early growth, i.e., during April-May-June, followed by a short spell of monsoon weather during late July and August, when most of the vegetative growth takes place. The main flowering season (September-October) is mild and dry. The picking season, i.e., November, December and early January, can become very cold. The summer rainfall, as has already been said, is usually confined to the later part of July and August and there is a general expectation of light showers about Christmas. The first frost usually occurs during the third week of December. There are no frosts after 15th February. During summer, hot winds are very common and there are usually 10 to 15 severe dust storms.

The canal water supply is plentiful throughout the year. The authorized discharge of the lower Chenab Canal which feeds the Lyallpur colony—the oldest and probably the most prosperous of the canal colonies—is 9900 cusecs in *rabi* and 11,000

cusecs in *khari*. The duty of water on this canal is 352 acres of which the permissible cultivation is 264 acres. This would mean that the canal authorities guarantee irrigation to 75% of the cultivated area. The high level of prices of agricultural produce during post war years, coupled with a lack of proper appreciation of the water requirements of various crops, induced the cultivators to sow areas much in excess of the permissible. The inevitable result was that on account of a larger area under crops than was justifiable on the basis of water supply, all crops received less water. In order, therefore, to study the water requirements of cotton a Watering Experiment on 4 F was started in 1928 as a part of the Punjab Botanical Research Scheme, financed jointly by the Indian Central Cotton Committee and the Punjab Government. Another object of this experiment was to test Milne's suggestion that heavier applications of water during September, October and November would mitigate the bad opening of bolls in Punjab American cottons.

The systems of irrigations under experiments were as follows :—

Type I. Irrigation after every three weeks.

Type II. Irrigation after every four weeks.

Type III. Irrigation after every five weeks.

For the first five years of the experiment these three types of waterings had both ridged and flat beds.

Type IV. First two irrigations were given at an interval of three weeks and subsequent irrigations after every fortnight.

Type V. (Started in 1930) First irrigation 3 weeks after sowing and subsequent irrigations as for type VII.

Type VI. (Started in 1930) Irrigations as for type VII with two late irrigations.

Type VII. *Zamindari* irrigations.

A cultivator in a nearby village was taken as the standard and water was applied to these beds on the dates that this cultivator irrigated his cotton.

It may be mentioned here that the holdings, in general, are not large and several farmers have to take turns of water from the same outlet. The normal interval between successive turns is 12 or 13 days. There are sometimes canal closures which upset this routine. An average programme of irrigation to cotton followed by the *Zamindars* is as follows :—

The first irrigation is given 7 weeks after sowing followed by 3 irrigations after an interval of 3 weeks. The last two irrigations are given at an interval of two weeks.

The programme of irrigations was disturbed by the Monsoon rainfall and suitable adjustments had to be made.

The quantity of water applied at each irrigation was measured by means of Cipolletti Weirs.

The area of each experimental bed was 1/10 acre, and to avoid the effect of lateral seepage, non-experimental strips 9 ft. broad were left between the experimental beds. There were 8 to 10 replications in different years.

The details of irrigations are given in Table I.

TABLE I.
Irrigations and Rainfall.

Year	IF	IR	IIF	IIR	IIIF	IIIR	IV	V	VI	VII	Rainfall.
N	7	7	5	5	5	5	10			6	
1928 W	16.39	14.89	12.39	11.55	12.50	11.24	24.54			14.59	11.7
T	23.10	26.60	24.10	23.26	24.2	22.95	36.2			26.3	
N	6	6	4	4	3	3	9			5	
1929 W	17.84	17.78	11.15	12.85	9.38	9.03	22.58			13.97	8.64
T	26.5	26.4	19.8	21.49	18.00	17.67	31.2			22.6	
N	7	7	5	5	5	5	9	6	7	5	
1930 W	16.58	18.81	13.11	14.03	12.43	13.86	21.78	16.33	13.96	11.36	5.43
T	22.0	24.2	18.5	19.5	17.9	19.3	27.2	21.8	19.4	16.8	
N	6	6	4	4	3	3	7	4	6	5	
1931 W	17.95	17.88	11.84	11.76	8.97	9.03	20.84	11.08	17.79	15.15	15.73
T	33.7	33.6	27.6	27.5	24.7	24.8	36.6	27.4	33.5	30.9	
N	7	7	5	5	4	4	10	7	8	6	
1932 W	20.07	19.89	14.29	14.22	12.00	12.06	29.25	20.06	23.11	17.15	6.72
T	26.8	26.6	21.0	20.9	18.7	18.8	36.0	26.8	29.8	23.9	
N	6	..	4	..	4	..	9	4	5	3	
1933 W	18.03	..	11.96	..	11.96	..	26.97	12.13	14.89	8.98	13.05
T	31.1	..	25.0	..	25.0	..	40.0	25.2	27.9	22.0	
N	6	..	5	..	4	..	9	7	8	6	
1934 W	17.99	..	15.03	..	12.09	..	26.92	20.94	23.95	17.83	5.48
T	23.5	..	20.5	..	17.6	..	32.4	26.4	29.4	23.3	
N	7	..	5	..	4	..	10	7	7	6	
1935 W	21.09	..	15.07	..	11.85	..	30.02	21.02	21.02	17.93	3.57
T	24.7	..	18.7	..	15.4	..	33.6	24.6	24.6	21.5	

N—No. of irrigations.

W—Acre inches of water applied through irrigation.

T—Total acre inches of water applied (irrigation + rainfall).

Counts of flower production and boll maturation were kept in all years. Full data are not given here, but it may be mentioned that the correlation co-efficient between water applied and flowers produced was insignificant. The flowering and bolling and bolling and watering were, however, correlated.

$$rfw=0.232$$

$$rbw=0.346^x$$

$$rfb=0.831^{xx}$$

The yields obtained from the various beds in different years is given in Table II.

TABLE II.

Tabulated yields in lbs. per acre of Watering Experiment.

Types.	1928	1929	1930	1931	1932	1933	1934	1935	Average 1928-35
I Flat	444	1069	1603	892	845	1581	1360	823	1077
I Ridge	465	1078	1522	878	916	..	..	..	972
II Flat	339	920	1044	885	1100	1339	1259	823	964
II Ridge	368	1000	1087	711	978	..	..	..	829
III Flat	382	709	1058	781	1031	1399	1128	445	867
III Ridge	371	799	1006	599	1027	..	..	..	760
V Flat	751	1139	1624	919	1153	1491	1811	1210	1262
IV	..	..	1339	875	1276	1358	1559	1112	1270
VI	..	..	1250	796	1043	1402	1497	976	1161
VII	541	921	1336	828	922	1389	1110	1005	995
S. E.	<u>+60</u>	<u>+67</u>	<u>+78</u>	<u>+36</u>	<u>+78</u>	<u>+77</u>	<u>+100</u>	<u>+93</u>	<u>+75</u>

The statistical examination of this table will be dealt with later ; only broad conclusions are given here :—

Types I, II and III are comparable. It may be said that ridge sowing *versus* flat sowing has given indifferent results and the extra cost of ridging and hand sowing does not seem to be justified. As regards flat beds, there was no significant difference in yield during the two years, 1928 and 1934. During 1930 and 1933, type I was significantly better than both types II and III, while during 1931, both types I and II were significantly better than type III. The year 1932 presents a peculiar case ; the application of greater quantity of water depressed the yield. This was on account of the occurrence of very early frosts in this season and heavily watered beds having become late suffered more than those which had received less water and were therefore earlier in ripening.

On the average of eight years it may be said that the crop which was irrigated after every three weeks gave a heavier yield than the crop irrigated at longer intervals.

Type IV is in a class by itself. It received the heaviest irrigation and except during three years (1931, 1932 and 1933) gave the highest yield. The explanation for these lower yields as compared to the beds with lesser irrigations during these particular years is to be sought in the fact that unusually high rainfalls in 1931 and 1933 masked the effect of differential irrigations and this type probably suffered from excessive water. During 1932 frosts occurred early and crops which had become late on account of abundant water supply suffered much more than those which were early.

Types V, VI and VII are again comparable. Type V is significantly better than either one or both of the other types in three out of six years. It is also significantly better on the average of six years. This finding has a great agricultural importance. The *Zamindars* of the Punjab are in the habit of delaying the first irrigation for 5 or 6 and sometimes even 7 weeks after sowing. This experiment has, on the contrary, proved that one irrigation early in the season is very beneficial. It may also be noted that irrigation water is easily available at this time of the year and the *Zamindars* can easily afford to apply an irrigation.

Late irrigations, on the other hand, do not materially increase and indeed sometimes depress the yield. Waterings after 15th October are not required and need not be applied to 4F.

Statistical study of the analysis of variance and co-variance for the amount of water applied and the yield obtained show that yield is, in general, correlated with the amount of water. The co-efficient of correlation for the years 1928-35 being 0.617^{xx}. The data are given in Table III.

TABLE III.

Analysis of variance and co-variance (y-w)					
Source of variation.	D.F.	Sum of squares y	Sum of squares w	Products.	Co-efficient of correlation.
Within years	44	1379786.9	1034.09	23330.8	.617 ^{xx}
1928	4	27738.0	20.31	685.9	.913 ^x
1929	4	89216.8	60.81	2138.2	.917 ^{xx}
1930	6	322814.0	76.19	3643.7	.734 ^x
1931	6	16411.72	108.14	593.4	.445
1932	6	122747.4	198.28	1164.0	.236
1933	6	43041.4	215.46	2018.0	.661
1934	6	382351.9	156.66	5868.3	.760 ^x
1935	6	375465.7	198.24	7214.3	.837 ^{xx}

The insignificance of the correlations for 1931, 1932 and 1933 can, as suggested above, be explained on the basis of very heavy rainfall in 1931 and 1933 and very early frosts in 1932.

Considering the whole data it may be stated that within the limits of the present experiment, higher yields were obtained with heavier applications of water.

From a consideration of Tables I and II, it may be broadly stated that on the average 24 to 28 acre inches of water are required to mature a good crop of 4F.

As regards the second object of this experiment, namely, to find out the effect of irrigations applied late in the season on the bad opening of bolls, it may be stated that the differential response could not be very well studied. The year 1928 was the only really bad season and all the beds showed a fairly even amount of bad opening. It cannot, however, be definitely stated that late irrigations would help in materially decreasing the extent of bad opening.

The technological properties of cotton produced under various systems of waterings were determined by the Director, Technological Laboratory, Matunga, during the last five years of the experiment and the following information has been taken from the Technological Reports on these samples.

I shall confine my remarks to the following characters :

- (i) Mean fibre length as determined by Balls sorter.
- (ii) Mean fibre weight.
- (iii) Fibre maturity.
- (iv) Spinning counts.

These characters are dealt with separately below but are given together in Table IV.

(i) *Mean fibre length.*

Variations in the lint length of a pure strain of cotton may be ascribed to environmental variations. Adverse climatic conditions result in reduced lint length. A reduction of as much as 3.7 m.m. in staple length has been noticed in St. Vincent in years of excessive rainfall which results in partial waterlogging of soil. The optimum amount of irrigations would, therefore, tend to produce the best fibre. Taking types I, II and III into consideration, it will be seen that more frequent irrigations are conducive to the production of longer fibre. Type IV which received the highest amount of irrigation gave indifferent results and a somewhat poorer fibre in years of heavy rainfall. From among the variations of the "Zamindari" type of watering there is not much to choose.

There appears to be a general trend towards an improvement in this character during the five years under discussion. This is perhaps on account of the generally good environmental conditions obtained and the good handling of the crop.

(ii) *Mean fibre weight.*

Considering types I, II and III it is seen that except during 1934, there was a general tendency for the fibre not to increase with the additional supplies of water to the crop, thus making the fibre coarser. Type IV which received the heaviest quantity of water again gave indifferent results possessing very fine fibres in 1933 and very coarse indeed in 1932. It has not been possible to discover the causes for this behaviour. Types V, VI and VII also did not give any consistent results.

The discordant behaviour of this character of the cotton fibre, in this experiment, shows that the environmental factors other than the quantity of water applied to the crop have a preponderating effect. The data presented here are, however, sufficient to show that Harland's opinion that "the small hair weight and consequently neppy character of the Punjab American cotton is possibly due to excessive water" is not justified.

(iii) *Fibre maturity.*

Fibre maturity seems to be well correlated with irrigations and generally increased with irrigations.

Of special interest is type V and it is pretty clear that an additional watering three weeks after sowing is very beneficial. This finding is very important and shows that the system of delaying the first irrigation in vogue at present is very faulty. By giving an irrigation early in the season the *Zamindar* can reap a bigger and better harvest.

1933 is outstanding in giving very high figures for maturity. It may be recalled that during this year there was plentiful, well distributed rain, frost was very late and this was a year of record cotton crops in most parts of the province. Thus the crop enjoyed very good climatic conditions which is reflected in the high maturity figure.

(iv) *Highest Standard Warp Counts.*

The spinning performance, in any one year, does not show much variation in different types, but type IV gave a somewhat better performance than the rest.

The best year so far as this character is concerned was 1934 when the performance of 4F exceeded all expectations.

Table IV is also noteworthy from another point of view. There appears to be very little interdependence between the four characters mentioned. It is already well known that the spinning performance of cotton can only be judged by nothing short of an actual spinning test and the figures presented in Table IV lend additional weight to this opinion.

TABLE IV.

Fibre Properties from Technological Reports.

Fibre Property.	Type of watering.	Season.					
		1931	1932	1933	1934	1935	
Balls Sorter Mean (inches)	I	0.74	0.77	0.76	0.83	0.80	
	II	0.70	0.77	0.73	0.79	0.81	
	III	0.69	0.76	0.73	0.76	0.77	
	IV	0.72	0.78	0.78	0.84	0.84	
	V	0.73	0.78	0.76	0.82	0.81	
	VI	0.72	0.78	0.76	0.82	0.83	
	VII	0.72	0.77	0.77	0.80	0.82	
Mean fibre weight per inch (10-6oz)	I	0.153	0.160	0.158	0.137	0.151	
	II	0.161	0.156	0.142	0.148	0.156	
	III	0.146	0.143	0.139	0.155	0.156	
	IV	0.163	0.176	0.129	0.149	0.150	
	V	0.163	0.153	0.136	0.154	0.157	
	VI	0.153	0.148	0.144	0.153	0.128	
	VII	0.161	0.143	0.145	0.153	0.141	
Maturity	I	40/24	44/42	61/25	33/36	46/31	
	II	34/22	41/44	53/34	34/36	47/30	
	III	27/25	49/40	49/40	35/36	47/32	
% age of mature fibres	}	IV	41/20	52/35	60/29	44/32	47/34
% age of immature fibres		V	50/21	43/45	57/34	40/30	46/26
		VI	43/20	36/50	57/28	42/28	49/26
		VII		41/16	56/32	32/35	44/34
Highest Standard Warp Count.	I	18	24	23½	30½	26	
	II	18	23½	22½	29½	24½	
	III	17½	24	24	29½	21½	
	IV	19	25½	22	34	28	
	V	18½	24½	23	32	29	
	VI	18	26	23	31½	28½	
	VII	20	25	22	31	27	

DISCUSSION.

Mr. Mohammad Afzal, in introducing the paper, said that watering experiments on Punjab-American 4F Cotton were started as a result of the recommendations of Mr. Milne who carried out a very thorough survey during 1919 and 1921 of the cotton failure problem. Mr. Milne came to certain tentative conclusions and formulated the theory that the proper application of water during September, October and November, i.e., during the time of flowering and opening of bolls, was mainly responsible for mitigating the bad opening of bolls. When the cotton research section was started this theory was put to test. Watering experiments on 4F were started to find out whether more water during the latter part of the year would help the cotton plant. Incidentally this data was also expected to give information on the water requirements of the crop. The variations in watering treatment were as given in the paper. Digressing for a moment he said that the ordinary practice of the cultivator was to delay the first irrigation very considerably. The cultivator sowed some time at the end of April or the beginning of May and did not give water for 5 to 7 weeks after sowing. The general belief among the farmers was that the longer the first irrigation was delayed the heavier would be the yield. This idea also was tested by giving water three weeks after sowing. The technique of the experiment was that each experimental bed consisted of 1/10th of an acre. Difficulty was at first experienced in applying water in measured quantities, but later on it was overcome and exact quantity was given to the various beds. The measurement was done by means of Cipolletti Weirs. Between every two beds there was a non-experimental strip of 9 feet broad growing three rows of cotton so that there might be no lateral seepage. The number of irrigations and the amount of water applied through irrigation and the amount of water by rainfall from the 1st of May to 31st December is given in Table I, and the yields in Table II. The number of irrigations were divided later on into three types, viz., waterings after 3, 4 and 5 weeks and the conclusion drawn was that watering after three weeks throughout the crop season gave the best yield on the average of 8 years. Type 4 which got the highest quantity of water in these experiments gave the highest yield.

The most important part of the experiment was in types 5, 6 and 7 which were the variations of the "zamindari" system. For type 5 one irrigation was given in addition to zamindari early in the season. Type 6 had two irrigations more than the zamindari crop but late in the season. Type 7 was zamindari irrigation. Type 5 was better than type 7 and there was hardly any difference between types 6 and 7. Two irrigations in the later part of the season were not as beneficial as one irrigation early in the season. This finding was of very great economic importance because early in the season during the months of April, May and early June plenty of irrigation water was available. By that time the zamindar had harvested his wheat crop while later on in the year, in September, October and November, there was dearth of

water as there were two competing crops, viz., Toria and Wheat. The experiment had definitely been useful in that direction.

Mr. Hutchinson, referring to the last column of Table III giving the co-efficient of correlation, enquired whether he might take it as of high significance and whether watering experiments were carried out on the same land or, on different lands by rotation.

Mr. Mohammad Afzal replied that actually all the experiments were carried out in different lands in rotation.

Mr. Hutchinson asked whether there was any progressive trend in yield on account of different waterings when they were given to the same block in different numbers and also whether high quantity of water spoiled soil conditions.

Mr. Mohammad Afzal answered that he had not done that experiment.

Dr. Nazir Ahmad referred to the technological part of the paper and said that at the bottom of page 7 it was stated that "There appears to be very little interdependence between the four characters mentioned. It is already well known that the spinning performance of cotton can only be judged by nothing short of an actual spinning test and the figures presented in Table IV lend additional weight to this opinion." This, he said, was not correct. It was true that these results did not show any interdependence between the spinning quality and fibre weight per inch. But the position was quite different with the mean fibre length. If the results for all the seasons from 1931-1935 were taken into consideration the correlation between the two was highly significant. Again it was highly significant for 1935, and also significant for 1934. He thought that the statement should be modified. He also pointed out that in such cases where only one variety was considered it was necessary to take into account the effect of season. A general statement of the kind made by Mr. Mohammad Afzal would be misleading. Again, it was said on page 6 that higher yields were obtained with heavier application of water. It would be more correct to say that higher yields were obtained with the particular plan of irrigation adopted in the experiment. It was not the total amount of water given that was so much important as the number of irrigations and the spacing between each irrigation. He therefore suggested that this statement should also be suitably modified.

Mr. Mohammad Afzal agreed to the suggestions.

Mr. Wad asked whether it would not be better if irrigation experiments were conducted with an idea to ultimately regulate the soil moisture by restoring its losses to a certain level. The periods, extent and methods of regulating would depend upon the fluctuations of the season and the quantity of water available. Then the problem would be understood much better. A slight addition to the estimated quantity of water

would have to be made according to the ability of the soil to absorb it and transmit it to lower layers because anything that remained on the upper layer would be a waste owing to evaporation losses. If the intervals when irrigation was required to restore soil moisture in each successive period of the season could be found out they could provide a standard for the cultivators to economise their water requirements.

Mr. Dabral said that he had carried out similar experiments in Sind. He did not offer any criticism on the paper but wished to point out how in slightly different soils different results might be obtained. The conclusion in the first watering was that 3 to 4 inches was optimum. Regarding the variance during the course of the season he agreed that the soil moisture was better judgment of the water requirement of the cotton crop. He did experiments on that basis and arrived at a method which gave an increase in yield of say 20% to 60% in certain seasons. That method was to water at long intervals during the early stages of the growth and then as the plant grew bigger, to decrease the intervals from 15 to 10 days. This had given very good help to the plants. The interval was based on the physiology of the plant and on the moisture content of the soil and it actually gave increased yield. He thought this system was very good for the ordinary cultivators. The only point was that in lands where the crop had been standing for a long time the original moisture content of the soil was a factor to be considered and the system would have to be adopted to suit local conditions, but in a Province like Sind where rainfall could not be counted upon the method had worked very well. Another point was that in the Punjab the water requirement was 26 to 30 inches while in Sind it was higher from 35 to 40 inches.

Mr. Mohammad Afzal, referring to Mr. Wad's point of soil moisture, admitted that he had done no work on that phase of the problem from the ryots' point of view. The Agricultural Chemist has done considerable amount of work from the other end of the problem. He took samples of all beds getting different "types" of irrigation every week throughout the season up to a depth of 9 feet. He did this work for three years through the special staff engaged by the Indian Central Cotton Committee for this work. A great mass of data was collected, but the chief conclusion arrived at was that it was very difficult to estimate correctly the soil moisture contents of a whole field. No deductions had so far been made from this data. Regarding Mr. Dabral's point of varying the intervals he thought that it was a sound one but it had to be tested and seen whether it was workable. In the Punjab, it was not workable because, as already mentioned, people got their turn of water only at an interval of 13 to 14 days. Sometimes water was available when the crop did not require it and when it required water it could not be obtained. So it was very difficult to fix any hard and fast rule for general application.

Dr. Burns enquired whether there was any evidence as regards the effect of this on bad opening or otherwise.

Mr. Mohammad Afzal replied that as 1928 was the last year of serious cotton failure he was unable to say.

The President mentioned that this particular set of experiments was laid out in order to find out what was the most suitable general canal rotation for the Chenab Colony, an important cotton tract. Canals had to be run on a comparatively rigid system because large volumes of water were involved. A proposal had been made for a more elaborate set of experiments on the water requirements of crops to be carried out at Lyallpur with the aid of a grant from the Imperial Council of Agricultural Research. The set of experiments now under discussion represented an attempt to find out in an important area what would be the best method of applying water and how far the Irrigation Department could adjust supplies to the water requirements of the plant. It was by no means a theoretical question.

Mr. Wad said that he was simply suggesting the utilisation of some of the data regarding soil moisture which the author had already got for three years. It might be interesting to apply the recent conception of pF scales to this moisture determination and see what could be got out of it. pF scale indicated the degree of a moistness just as pH showed acidity. The availability of water for growth may thus be measured and graded.*

Mr. Mohammad Afzal remarked that he would simply send the data and Mr. Wad could clarify the same.

Mr. Wad agreed to clarify the moisture data if sent to him and said that samples of soils taken from the fields would also be needed for the purpose.

Rao Saheb S. H. Prayag, referring to the spinning performance, pointed out that in certain parts of the Nasik District one or two irrigations were given for cotton. Samples of such cotton and also of unirrigated cottons were sent for spinning tests and it was found that in the case of irrigated cotton the staple became coarser and the spinning capacity went down by less than two counts than in the dry cotton.

* Schofield, R. K. (1935) "The pF of the water in Soil." Trans. 3rd Int. Cong. Soil Sci., Oxford, England, Vol. II, pp. 37-48.

COTTON AGRONOMY

Paper No. 4.

NOTE ON FACTORS IN THE ACCLIMATISATION OF EXOTIC VARIETIES OF COTTON IN SIND

BY

B. M. DABRAL,

COTTON PHYSIOLOGIST, SAKRAND.

CONTENTS.

- I. INTRODUCTION.
- II. MATERIAL.
- III. RESULTS OF OBSERVATIONS.
- IV. GENERAL DISCUSSION.
- V. SUMMARY.
- VI. REFERENCES.

I. INTRODUCTION.

Attempts to grow long stapled and superior varieties of cotton in Sind have been made ever since the middle of the last century. After the opening of the Jamarao canal in 1900, the question of cultivating exotic cottons in Sind was taken up in right earnest. Seeds of varieties from Egypt were grown in portions of the districts commanded by the Jamarao canal and very good results were obtained during the years 1904 to 1906. In 1906, the British Cotton Growing Corporation reported most favourably on the quality of the Egyptian cotton in Sind and expressed its willingness to buy all the cotton grown from the Egyptian seed. During sub-

sequent years, however, the Jamarao canal did not function properly and water was not available early enough so as to sow the Egyptians. Several varieties of American cotton including Triumph, Black Rattler, Texas Big boll, etc., were tried as they had a shorter growing season. Triumph gave some promise but the others failed. Trials to grow varieties of 4F, 285F, and 289F from the Punjab were, however, more successful. These varieties have formed the bulk of the American crop in Sind up to the opening of the Barrage canals in 1932.

The Indian Cotton Committee (1919) considered that experiments with the Egyptian and American cottons in Sind, though in the past they had ended in failure, showed that these varieties could be successfully cultivated in the Province. Their opinion about the prospect of establishing these varieties is quoted below.

“We are emphatically of opinion that the fundamental cause of failure has been the unsatisfactory character of the irrigation. Provided a perennial supply of water can be assured, we hold the view that there is no other part of India which offers such hopeful prospects of the successful cultivation of long staple cotton. The climate and soil are in every way most suitable and all that is wanted is water at the right time and in sufficient quantities.”

With the opening of the Lloyd Barrage at Sukkur and its canal systems, the above limiting factor has been removed. Experiments for testing the suitability of long stapled Egyptian and American cottons under the new conditions were laid out at the Agricultural Research Station, Sakrand, mainly with a view to breed out a hardy and well adapted type from amongst the above groups. The present notes give a few observations made on the behaviour of the exotic cottons grown at Sakrand and the problems they present on the larger subject of acclimatisation.

II. MATERIAL.

Representative varieties from a majority of the cultivated species of Genus *Gossypium* growing in widely different parts of the world have been tried at Sakrand ever since 1926. The most important of them are given in the following list.

A.—Egyptian types (*G. barbadense*)

1. Sea Island
2. Boss III
3. Ashmouni

B.—American types (*G. hirsutum*)

1. Acala Ardamore	}	Imported from America.
2. Hart's Ville		
3. 4F	}	Punjab Americans.
4. 285F		
5. 289F		
6. Cambodia		Madras.
7. U4 and other types		South Africa.

C.—Indian types (*G. Neglectum*)

1. 27 W. N.	Sind <i>Desi</i> .
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In addition to the above, plants belonging to other Asiatic cottons from different localities in India were also grown and observed.

All the groups differ from each other both morphologically and genetically. They were grown in adjacent rows on replicated plots under similar climatic and soil conditions*. Observations on their development and growth were carried on throughout the season. The response which each type of cotton gave to the local climate and soil in the matter of germination, growth, flowering and fruiting was recorded and studied.

III. RESULTS OF OBSERVATIONS.

SEEDS AND GERMINATION.

The Egyptian cotton seeds are all naked. The Americans are from light to intensely fuzzy, while the local *Desi* is very fuzzy. The fuzz on the seeds of the *Desi* cotton is closely fixed to the seed-coat while it is more loosely attached in the case of the American cottons. This morphological difference influences the rate of absorption of water by the seeds when put in the soil. There is also a greater chance of saprophytic fungi and bacteria entering the seed through the fuzz in the Americans when the seed is put in the soil. Viability tests both in the laboratory and the field have shown that 27 W. N., the local *Desi*, gives the highest per cent of germinations. There is a lesser percentage of partially developed and empty seeds in this variety than in the others. Kalar or soluble salt in the soil is a major factor in local adaptation. Experiments both in the laboratory and the field have shown that almost all varieties fail to germinate in concentration of salt higher than 5 to 7 p.c. of dry soil. There is a negative relation between the rapidity of germination and the salt content of the soil.

The average temperature of the irrigated soil during the sowing season varies from 80° to 98°F. The seeds of all varieties germinate very well within this range. The percentage germination and the time taken by the seed to germinate are given in the following Table.

* During the first few years, the plants studied were grown for me by the Botanist, Agricultural Research Station, Sakrand, in his plant-breeding area.

TABLE I.

Germination of seeds in different varieties of cotton.

Name of variety.	Average p. c. of germination.	Average No. of days taken for germination.	Average weight of 100 seeds in gms.	Remarks.	
1	2	3	4	5	
Egyptian	Sea-Island	59	5.6	9.04	Period of sowing 1st week of May. Average temperature of soil at 6" depth during the period 90°F.
	Boss III	69	5.8	8.74	
	Ashmouni	66	6.0	9.68	
Imported American	Hart's Ville	66	6.2	11.73	P. C. moisture in the 0—6" layer of soil 15%.
	Acala	78	6.0	11.08	
Punjab American	4F	57	5.8	8.70	Depth at which seeds are planted 2".
	285F	73	5.9	7.31	
	289F	55	6.1	9.28	
	27W. N.	85	5.4	5.25	

SEEDLING STAGE.

The cotyledonary leaves vary in size according to the weight of the seed. The third leaf appears after about 11 days of sowing and almost simultaneously in all varieties. The rate of elongation of the hypocotyl in the Egyptians and the imported Americans is higher than in the Punjab Americans and the *Desi* cotton plants. The seedlings of all varieties grow vigorously. During this stage three factors of the environment come into play (1) the white ants begin to feed on the seedlings and destroy them in large numbers. They prefer the Egyptian plants to the Americans and the latter to the *Desi*. (2) Certain percentage of seedlings die on account of damping off due to some fungoid attack near the surface of the soil. The Egyp-

tians and the Americans are more susceptible to this kind of injury than the *Desi*. (3) Large number of seedlings die on account of very high temperature at the surface of the soil. Here also, the local *Desi* plant is less susceptible than the exotic. As the seedlings develop, air temperature and the insolation become the limiting factors for growth. When the mean maximum temperatures during a period of about a week reach values higher than 110°F, the leaves of the Egyptian cottons crinkle and assume an unhealthy appearance. It is remarkable that the smooth leaved American plants like Acala and Hart's Ville stand high temperatures much better at this stage. Among insect pests, different kinds of caterpillars appear at this time but they do not exhibit any partiality towards any group.

EARLY VEGETATIVE GROWTH STAGE.

When the cotton crop is sown by the middle or end of April, the early vegetative development is subjected to severe climatic conditions. In all varieties, the plants wilt every afternoon and remain in that condition till late in the evening. Under similar conditions of soil moisture, etc., the Egyptian plants begin wilting the earliest of all. On many days the leaves and tender shoots become flaccid soon after about ten to eleven a.m. When high temperature is accompanied by strong winds, the leaves become permanently injured and get deformed. There is general curling and drying of leaves and malformations and abnormalities of the laminae tissues resembling the leaf curl virus-disease of Sudan.

The effect of the severe climatic conditions during this phase of plant growth has in some cases been considered responsible for permanent injury to the plant. The general prejudice against too early sowing of cotton on account of its yielding greater percentage of badly developed bolls and sometimes in its complete failure, is explained on the basis of the after effects of a severe climatic complex coming in operation at the end of May when the early sown crop is in its preliminary vegetative stage. Experience has shown that provided there is enough of moisture in the soil, the seedlings survive the shock due to climate much better than the well established plant. Almost all varieties suffer on account of the severity of the climatic conditions during this critical period, but there is a varietal difference in the degree of ultimate damage. The Americans suffer the most, while the Sind *Desi* is affected the least. The Punjab Americans seem to be more susceptible to this kind of injury than even the imported American varieties.

Of the insect factors, white ants are the most important at this stage. There is a distinct selectivity shown by this pest. The following Table gives comparatively the damage done by white ants to different varieties of cotton throughout the season. The largest number of plants die during their early vegetative stage.

TABLE II.

Damage by white ants in different varieties of cotton.

	Varieties.						
	Egyptians.		Americans.				<i>Desi.</i>
	Boss III.	Ashmouni	Acala	4F	285F	289F	27 W.N.
% of plants dead during the season per unit area:	90	86	..	55	49	56	32

It is difficult to explain the reasons as to why the white ants prefer an Egyptian plant to any other. Many probable causes have been suggested including the fact that climatic severity weakens the vigour of the exotic plant and thus makes it more susceptible. Observations, however, tend to show that the nature of the injury by white ant is purely mechanical. The strong wiry character of the roots and shoots of the *Desi* plant offers a greater resistance to the mandibles of the insect than others. In this connection, the relative quantity of ash in the tissues of the different varieties given in the following Table seems to offer a probable explanation.

TABLE III.

Percentage of ash in the leaves of different varieties of cotton.

	Varieties.						
	Egyptians.		Americans.				<i>Desi.</i>
	Boss III.	Sea Island.	Acala	4F	285F	289F	27 W.N.
% ash on dry matter:	15.95	13.40	17.45	20.70	20.25	18.10	25.2

The capacity to resist damage due to white ants appear to be related directly to the percentage of ash in the leaves.

On ordinary soils which are free from large quantities of kalar or soluble salts all varieties develop well. When however the concentration of the soil solution in the upper layers begins to go higher so as to be injurious a certain amount of varietal difference in tolerance of salts is exhibited. The *Desi* 27 W. N. has been seen to thrive better under the condition of salt-land where the others fail. The growth rate of the shoots and roots in this variety is comparatively greater and its root habit a little different. The tap root grows vigorously down before throwing off strong laterals. In the Americans and Egyptians there is a simultaneous development of the whole root system. In an exact pot experiment where known quantities of injurious salts were added to good soil, the response of 27 W. N. to sodium chloride and sodium sulphate (added as salts) was a little more favourable than others.

MAXIMUM VEGETATIVE GROWTH STAGE.

As soon as the maximum and mean temperatures fall by the end of June, all varieties enter their vegetative phase with great vigour, even though sown on widely different dates. During July and August the temperature and relative humidity are near the maximum for metabolic activity. The relative growth rate of the main axis in terms of the efficiency index calculated from the initial and final height is given below.

TABLE IV.

Vegetative development of the varieties of cotton at Sakrand.

Name of variety.	Average height of plant when mature.	Average relative rate of elongation of the main axis 'b' *	Average diameter at zero node of main axis. cms.	Average No. of nodes on the main axis.	Average No. of monopodial branches on the main axis.	Average No. of sympodial branches on the main axis.
1	2	3	4	5	6	7
Sea Island ..	131.4	.2556	2.38	47.8	21.8	33.3
Boss III ..	144.0	.2477	2.45	50.4	18.8	28.5
Ashmouni ..	153.1	.2603	2.52	49.2	15.3	31.4
Acala ..	89.4	.1981	1.90	34.0	8.1	25.5
Hart's Ville ..	92.7	.2292	2.11	33.8	7.2	24.0
Cambodia ..	193.8	.2998	2.32	41.0	30.0	2.0
4F ..	105.3	.2294	2.30	40.9	14.8	33.0
285F ..	88.7	.1935	2.35	38.5	4.5	30.2
289F ..	120.5	.2457	2.65	45.3	13.6	31.5
27 W. N. ..	134.0	.3078	2.10	47.0	17.7	22.0

*'b' Calculated from the formula $H=H_0e^{bt}$ where H=final height, H_0 =initial height, b=relative growth rate, e=base of the Naperian log., and t=number of days.

Generally, varieties with monopodial habit of branching continue growing at a higher rate for a longer period than those with sympodial habit. 27 W. N., the Egyptians and the Cambodia have shown the highest rate of stem elongation. Comparing the vegetative growth of the Egyptian plant in Sind with that it has in its home, *i.e.*, Egypt, *vide* Balls (1915) and Baily and Trought (1926), the Sind plant is faster to grow, the main axis and branches getting too long and slender. They droop down when fruits develop on them. The long vegetative period has also the effect of delaying the successful period of flowering and the maturation of bolls. In the case of Cambodia the vegetative period is prolonged very much and the flowering starts very late in November after which the factors for boll maturation become unfavourable. Thus in the case of these two exotics, the primary effect of the local climatic condition is to increase the vigour of the vegetative system which, though it does not inhibit flowering and fruiting, yet delays it considerably and as such does not allow their normal performance.

The American exotic varieties like Acala and Hart's Ville which are genetically sympodial types respond to high temperatures very favourably and in the matter of early growth of shoots and roots are even better than the Punjab Americans. The *Desi* plant like the Egyptian grows vegetatively for a longer period but matures its bolls at a quicker rate than them. The growth of the roots follows that of the shoots. In Acala and Hart's Ville, concurrent with a cessation of growth in the main axis and development of the bolls, the roots stop further development.

During the latter part of the vegetative phase the rapid appearance of jassids brings in a new and important factor into the environmental complex. As soon as cloudy weather begins to appear in July and showers of rain come, this pest dominates over all other factors. All glabrous varieties are attacked by the hoppers in large numbers and within a short space of time, the whole character of growth is changed. On account of the sucking of sap from the leaves, discoloration sets in, the chlorophyll mechanism is disturbed and they turn yellow, red, brown, and copper-red. The effect of jassids in reducing yields is observed more on varieties which have early fruiting habit. Detailed observations at Sakrand and elsewhere in Sind have shown that 'jassids' is the limiting factor in the successful acclimatisation of long stapled but short season exotic American cottons. It is interesting to note that some of the South African types, which are hairy and monopodial, are thus more resistant to the permanent injury of jassids and have greater promise of adaptation in Sind.

Kalar (soluble salts) continues to be the major soil factor at this phase of growth also, but plants which have escaped its harmful effects during the first stage become callous to its presence. Roots have by this time developed to their maximum and the salts at the surface cannot injure them.

REPRODUCTIVE PHASE.

The appearance of the first fruiting branch (generally called the sympodium) on the main axis is the first indication of the reproductive phase. It is determined by the morphology of the type and is correlated with earliness or lateness of the fruiting season. The following Table gives the time which the different types take to come to the fruiting stage under the local soil and climatic conditions when the normal sowings are done by the last week of April.

TABLE V.

Relative earliness of cotton varieties.

1	No. of nodes on the main axis at which the first fruiting branch arises.	Number of days from sowings to			Remarks.
		Appearance of first sympodium on the main axis.	Appearance of first flower.	Boll setting.	
Sea Island	24.4	67.0	76.0	135	Late.
Boss III	25.3	60.7	91.0	135	Late.
Ashmouni	16.9	45.4	85.8	135	Late.
Acala	6.5	29.1	51.1	100	V. early.
Hart's Ville	6.6	31.5	58.9	100	V. early.
Cambodia	40.0	135.0	131.0	190	V. late.
4F	7.6	34.8	69.8	115	Normal.
285F	5.8	30.4	52.3	105	Early.
289F	10.8	33.7	71.0	120	Normal.
27 W. N.	17.9	43.7	69.3	110	Normal.

The figures in the table show that the best adapted varieties (Punjab American and *Desi*) are neither too early like Acala, nor too late like the Egyptians and Cambodia. The *Desi* plant does begin its flowering late but its fruiting and picking season is almost simultaneous with the Punjab Americana. Thus the

flowering and the bolting habit is one of the most important factors in successful acclimatisation. This point has always to be kept in mind both when breeding out a superior type or in devising cultural and manurial treatments.

The effect of climatic conditions on the maturation of bolls and varietal difference will be seen from the following Table.

TABLE VI.

Number of days taken by the boll to mature fully from flowers opened in the months July to October.

Name of varieties.	July	August	September	October	Remarks.
1	2	3	4	5	6
Sea-Island	..	53.1	59.9	65.8	
Boss III	..	44.9	53.2	64.6	
Ashmouni	..	47.2	51.5	56.6	
Acala	46.4	37.5	46.1	60.8	
Hart's Ville	44.1	41.7	46.9	61.9	
4F	..	43.7	48.6	63.8	
285F	..	40.7	42.9	58.8	
289F	..	39.3	43.0	64.4	
27 W. N.	..	36.8	43.8	52.7	

The mean daily temperatures specially the night temperatures from August onwards are continually falling and seem to be responsible for the increasing delay in the maturation period of the boll.

NON-DEHISCENCE OF ANTHERS.

Shrivelling of anthers in flowers and consequent failure of pollination observed in almost all exotic varieties grown in Sind both before and after the boll setting period is definitely a response to local climate. There are no records of this phenomenon appearing in the native homes of these varieties. Trought (1928) has observed it in the Punjab. The majority of the flowers opening before the months of July and August show complete failure of the anthers to shed any pollen. During the boll setting period (August to October) the dehiscence is good and anthers normal.

Later on again a greater proportion of flowers have shrivelled anthers which do not open at all. Non-dehiscence of anthers like the shedding of flowers and bolls is however never completely absent from these plants in Sind. Weather and internal correlations between the different growing points seem to be the causes of this peculiar behaviour. It has never hindered normal setting of bolls, and can only be considered as a contributory cause of the huge amount of shedding of flowers and bolls that occur in all varieties of the cotton plant. It is however important to note that F1 plants from hybrids between *G. hirsutum* and *G. barbadense* types or of those within the same species do not exhibit non-dehiscence of anthers to the extent the parents do.

BOLL SETTING AND YIELD.

Table VII gives the inherent differences in characters which determine the yielding capacity of the different varieties. Provided the number of plants per unit area and the vigour of plants represented by the number of flowers per plant were the same in all varieties, the yield per unit area would be proportional to the product of the number of bolls per plant and the weight of seed-cotton per boll given in column 4 below.

TABLE VII.

Percentage setting of bolls and weight of cotton per boll in varieties.

Name of varieties.	No. of bolls per 100 flowers opened.	Weight of seed-cotton per boll.	Product of columns (2 x 3)	Remarks.
1	2	3	4	5
Sea-Island	23.6	1.43	33.75	
Boss III	32.6	1.61	52.49	
Ashmouni	33.6	1.63	54.77	
Acala	19.4	3.04	58.97	
Hart's Ville	19.8	2.95	58.41	
4F	22.4	2.75	61.6	
285F	15.3	2.82	43.43	
289F (Sind Sudhar)	28.3	2.34	66.22	
27.W.N.	36.5	1.87	68.26	

Inasmuch as the environmental conditions during the vegetative stage do not allow of a uniform stand and vigour to all varieties, the yield per unit area from each variety changes considerably from season to season. The superiority of the local *Desi* cotton thus lies not only in its power of resistance to all unfavourable soil, climate and insect environments during the early phases, and enabling it to bring a larger number of vigorous plants per unit area to the fruiting stage, but also in giving a greater quantity of seed-cotton per unit number of flowers.

QUALITY OF LINT AND SEED.

The influence of the three components of the environmental complex (climate, insect and soil) on the quality of the commercial produce is a vast subject of an all absorbing interest. It has been observed that the Sea Island cotton possessing staple length of $1\frac{3}{4}$ to 2 inches in its original home has never produced staple longer than $1\frac{1}{4}$ " to $1\frac{1}{2}$ " at Sakrand. In Sind, the cotton growing areas can be divided into three climatic zones. The behaviour of the local and the exotic varieties in these three regions is interestingly different. Generally, the seed of cotton produced by a variety under the soil and climatic conditions on the right bank of the river Indus is heavier than the one produced on the left bank. At Sakrand, the ginning is slightly lower than at Mirpurkhas. Soil seems to be playing a very important part in influencing quality. Technological tests carried out on two samples of lint from the variety (Sind Sudhar 289F) grown at Sakrand on soils differing in certain important respects revealed a difference of 4 counts between them.

Amongst the insects, the bollworms which attack green developing bolls, adversely affect the quality of lint and seed by forcing premature opening and yielding immature cotton.

IV. GENERAL DISCUSSION.

The summary of observations given in the foregoing pages indicates the extent of the possibilities of the different groups of cottons to get acclimatised successfully in Sind. The three components of the local environment (1) atmospheric factors, (2) the soil conditions, and (3) the insect pests, all make their relative influence felt in the different stages of plant growth.

The cotton plant is said to respond to new environment by showing abnormal behaviour during the first few years. A majority of the exotic varieties tried at Sakrand did not, however, show such behaviour. A few exotic strains of the *G. barbadense* group showed a straggling habit with malformation of leaves, etc., during the summer months. This seems to be a temperature effect, as the strains

that have been considered well acclimatised, exhibit these characters even now. The higher growth rate of the main axis and branches of the Egyptian and Cambodia cottons as compared to the behaviour in their original homes influences their subsequent history to a very great extent. The critical temperature for the onset of the reproductive phase is another important factor in local adaptation. Even in the local varieties, the boll setting period commences only after the temperatures have fallen below a certain maximum. The age of the plant or its time of sowing are not so important. The Cambodia and the Egyptian cottons prefer a lower range of temperature for their fruiting than the Americans or the *Desi*. This delay in the starting of fruit development pushes the crop far in the winter, when very low temperatures further inhibit the opening of bolls and under frosty conditions even kill the whole crop. Insect pest, notably White ants and jassids, are the other important limiting factors against the success of the Egyptian plants. Cambodia cotton can resist them well but is rather late to fruit. It is important only as a base for hybridisation with an earlier but less hardy type like Hart's Ville or Acala. The long stapled Americans (*G. hirsutum*) have to contend against the insect environment, specially jassids. Their response to the local climate is very favourable but the susceptibility to jassids and the habit of very early maturity makes them ill-adapted. They are also useful as bases for crosses with other types.

The soil environment along with the facilities of irrigation and consequent control of the water factor is admirably suited for almost all kinds of cottons in the world. The inherent differences in root system are immaterial, as with controlled supply of water, cultural methods can easily be devised to suit them. The *Desi* plant (27 W. N.) has the habit of throwing off lateral roots all along the length of the tap root as it goes on growing down in the soil. The exotics belonging to the Americans, Egyptians, and the herbaceum group of Asiatic cottons have the habit of throwing off laterals only from certain limited zones on the main root and inducing growth of the branches in various directions. The *Desi* root system thus gets an advantage in soils with kalar (soluble salts) at different levels below the soil surface.

The problem of acclimatisation of exotic varieties in new places has also a wider interest to the plant geneticist, physiologist and ecologist. All over India, efforts to introduce new and superior varieties of cotton have been made and the results have all emphasised the complexity of the problem. The Upland American cottons have been considered unsuited to rainfall tracts of the black cotton soil zones and the cause ascribed to the ill adapted root system of the exotics. Probably, the water requirement of these cottons at the critical periods is higher and in spite of a perfect root system the soil is unable to support it. Sampson (1911) reports for Madras that in 1907, a year of heavy showers in the latter part of the picking season, the Cambodia plant responded very readily to those and gave a yield greater even than

that of the indigenous black cotton soil cottons. The insect environment has been given a secondary place, but the reports of trials of Upland cotton in almost all Provinces in India have shown that a rough leaved variety does better everywhere than a smooth leaved one. This indicates that a variety which can ward off jassids is better suited.

Besides acclimatisation, there are a number of practical problems like sterility, deterioration in the quality of staple and ginning, etc., and the periodical failure of crops, which are at present evading solution. It appears that an approach to their proper understanding can be made through a detailed analysis of the three components of the environmental complex and their effect on the expression of the various genetic factors which determine the specificity of the various types. Turesson (cf. Barton-Wright, 1932) has aptly termed this combined physiological, ecological and genetical work as "genecology." It has been suggested by him (1922, 1923) that the response of a certain genetic constitution to the selective action of environment is different in different plants. A factor for dwarfness and its allelomorph for tallness may not have a great range in character expression in one species while in other species the variability of the expression may be great. Hence in the first phase, selection of the phenotype will adversely affect one factor, while in the second case, where the phenotypic range of one genotype is great, the differential selection between two factors will be less intense (*vide* Sansome and Philip, 1932). Lunde-gaardh (1931) has emphasized the importance of the physiological character of the genotypes in survival of species and adaptation to different environmental conditions. Ample evidence is forthcoming to show that intensity of assimilation, respiration, and osmotic pressure, etc., have specific tendencies and these are related to some morphological characters. The plasticity of these characters determines the adaptability of plants to new surroundings. The cotton plant in India, of all agricultural crops, gives the greatest scope for experimental ecology, or "genecology" as termed by Turesson. Investigations on the above lines are likely to lead to results of great practical value and fundamental importance.

V. SUMMARY.

The influence of the environmental factors (soil, climate and insect) on the growth and fruiting, etc., of a number of cotton varieties grown at Sakrand has been traced and compared.

Out of the soil factors, kalar is the most important and the local *Desi* has the easiest means of tolerating it to a comparatively greater extent in the field.

Temperature during the vegetative and the reproductive phase is the most dominating atmospheric factor. A majority of the Americans and the *Desi* cotton

plants show normal behaviour under local condition, but the Egyptians are not so well at home. Their vegetative organs grow at a rapid rate, becoming lanky and weak. The flowering period starts later and the fruiting is adversely affected.

White ants during the early phases and jassids during the later ones are the main factors of the insect environment. The Egyptians and the smooth leaved varieties of the American types suffer the most on their account.

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DISCUSSION.

Mr. Dabral, in introducing the paper, said that representative varieties of Egyptian and American cottons from a majority of the cultivated species of Genus *Gossypium* growing in widely different parts of the world had been tried at Sakrand ever since 1926. The most important of these were *G. Hirsutum*, *G. Barbadosense*, *G. Neglectum* and other Asiatic cottons. All the groups differed from each other both morphologically and genetically. They were grown in adjacent rows on replicated plots under similar climatic and soil conditions. Observations on their development and growth were carried on throughout the season. The response which each type of cotton gave to the local climate and soil in the matter of germination, growth, flowering and fruiting was recorded and studied. Viability tests both in the Laboratory and the field had shown that the local *Desi* gave the highest per cent of germination. Kalar or soluble salt in the soil was a major factor in local adaptation. Experiments both in the Laboratory and the field had shown that almost all varieties failed to germinate in concentration of salt higher than 5 to 7 % of dry soil. There was a negative correlation between the rapidity of germination and the salt content of the soil. The average temperature of the irrigated soil during the sowing season varied from 80° to 98° F. The seeds of varieties germinated very well and the seedlings of all varieties grew vigorously within this range. During this stage three environmental factors came into play. (1) The white ants began to feed on the seedlings and destroy them in large numbers. They preferred the Egyptian plants to the Americans and the latter to the *Desi*. (2) A certain percentage of seedlings died on account of damping due to some fungoid attack near the surface of the soil. The Egyptians and the Americans were more susceptible to this kind of injury than the *Desi*. (3) A large number of seedlings died on account of very high temperature at the surface of the soil. Here, also, the local *Desi* plant was less susceptible than the exotic. As the seedlings developed, air temperature and insolation became the limiting factors for growth. It was remarkable that the smooth-leaved American plants like *Acala* and *Hart's Ville* stood high temperatures much better at that stage. When sowing took place by the middle or end of April, the early vegetative development was subjected to severe climatic conditions. When high temperature was accompanied by strong winds, the leaves became permanently injured and got deformed and there was general curling and drying of leaves. The effect of the severe climatic conditions during that phase of plant growth had, in some cases, been considered responsible for permanent injury to the plant. Experience had, however, shown that, provided there was enough of moisture in the soil, the seedlings survived the shock due to climate much better than the well established plant. Almost all varieties suffered on account of the severity of climatic conditions during that critical period, but there was a varietal difference in the degree of ultimate damage. The Americans suffered the most, while the *Sind Desi* was affected the least. The *Punjab-Americans*

seemed to be more susceptible to that kind of injury than even the imported American varieties. Of the insect factors, white ants were the most important at that stage. There was a distinct selectivity shown by the pest. It was difficult to explain the reasons why the white ants preferred the Egyptian plants to any other. Many probable causes had been suggested including the fact that climatic severity weakened the vigour of the exotic plant and thus made it more susceptible. Observations, however, tended to show that the nature of the injury by the white ant was purely mechanical. The strong wiry character of the roots and shoots of the Desi plant offered a greater resistance to the mandibles of the insect than others. In that connection the relative quantity of ash in the tissues of the different varieties seemed to offer a probable explanation. On ordinary soils which were free from large quantities of kalar or soluble salts all varieties developed well. The Desi had been seen to thrive better under the condition of salt-land where the others failed. The growth rate of the roots and shoots in that variety was comparatively greater and its root habit a little different. When the maximum and mean temperatures fell by the end of June, all varieties entered their vegetative phase with great vigour even though sown on widely different dates. The temperature and relative humidity were near the maximum for metabolic activity during July and August. Varieties with monopodial habit of branching generally continued growing at a higher rate for a longer period than those with sympodial habit. The Desi, Egyptians and the Cambodia had shown the highest rate of stem elongation. The long vegetative period had also the effect of delaying the successful period of flowering and the maturation of bolls. The American exotic varieties of Acala and Hart's Ville, which were generally sympodial, responded to high temperatures very favourably and in the matter of early growth of shoots were even better than the Punjab-Americans. The Desi plant, like the Egyptians, grew vegetatively for a longer period but its bolls matured at a quicker rate than those of Egyptians. The rapid appearance of jassid brought in a new and important factor into the environmental complex during the latter part of the vegetative phase. When the cloudy weather began to appear in July and showers of rain came, this pest dominated over all other factors. All glabrous varieties were attacked by the hoppers in large numbers and within a short space of time the whole character of growth was changed. Detailed observations at Sakrand and elsewhere in Sind had shown that jassid was the limiting factor in the successful acclimatisation of long stapled but short season exotic American cottons. It was interesting to note that some of the South African types which were hairy and monopodial and were thereby more resistant to the permanent injury of jassids, had greater promise of adaptation in Sind. Kalar continued to be the major soil factor in the initial stage of growth but plants which had escaped its harmful effects during the first stage thrived well afterwards. The appearance of the first fruiting branch on the main axis was the first indication of the reproductive phase. The best adapted varieties—Punjab-American and Desi—were neither too early like Acala, nor too late like Egyptians and Cambodia. The Desi plant began its flowering late but its

fruiting and picking season was almost simultaneous with the Punjab-Americans. Non-dehiscence of anthers had never hindered normal setting of bolls, and could only be considered as a contributory cause of the huge amount of shedding of flowers and bolls that occurred in all varieties of the cotton plant. It was, however, important to note that F^1 plants from hybrids between *G. hirsutum* and *G. barbadense* types or of those within the same species did not exhibit non-dehiscence of anthers to the extent their parents did. His observations as regards boll setting and yield showed that inasmuch as the environmental conditions during the vegetative stage did not allow of a uniform stand and vigour to all varieties, the yield per unit area from each variety changed considerably from season to season. There again the local Desi cotton on account of its power of resistance to all unfavourable soil, climate and insect environments during the early phases was enabled to bring a larger number of vigorous plants per unit area to the fruiting stage and also to give a greater quantity of seed-cotton per unit number of flowers than the rest. A vast subject of all-absorbing interest was the influence of the three components of the environmental complex (climate, insect and soil) on the quality of the commercial produce. It had been observed that the Sea Island cotton possessing a staple length of $1\frac{3}{8}$ " to 2" in its original home had never produced staple longer than $1\frac{1}{2}$ " to $1\frac{1}{8}$ " at Sakrand. The cotton growing areas in Sind could be divided into three climatic zones. In these three regions the behaviour of the local and exotic varieties was interestingly different. The bollworm attacked green developing bolls and adversely affected the quality of lint and seed by forcing premature opening and yielding immature cotton.

Mr. Hutchinson said that there was a statement which was found in the introduction of almost every article on cotton growing in Sind, viz., that the climate and soil were in every way suitable to the growing of long staple cotton. He asked Mr. Andrews whether in Egypt and the Sudan they got similar conditions in the early stages of the growing season.

Mr. Andrews replied that he could not answer for Egypt but the Sudan had a type of soil very similar to that in Sind and it was irrigated by flood inundation canals. Sowing took place in September and the temperature never reached the Sind level, being only about 103° to 105° maximum.

Mr. Hutchinson thought that it was worthy of a certain amount of emphasis that, so far as he knew, the whole of the species *Gossypium barbadense* was grown in much more mild climates than were found in Sind and also the proportion of the species which was annual and anything like early enough for Sind was very small. He thought it was worthy of consideration whether that species was about the least likely to suit Sind conditions and whether it was not probable that the people who were working in Sind always suffer to some extent from the troubles involving the loss of stand in the early stages and the lateness of the crop later on. That

was one point, and the other was the number of nodes given in Table V, column 2. The number on the Sea Island was 24, Boss III 25, Ashmouni 16 and Cambodia 40. That was rather amazing. He enquired whether any investigations had been made on the effect of the length of day on the earliness of the first fruiting branch in those types.

Mr. Dabral replied that he was studying that problem and referred to page 104. The height of Cambodia on the 31st August was $6\frac{1}{2}$ '.

Dr. Nazir Ahmad referred to the bottom of page 103 where it was stated that the capacity to resist damage due to white ants appeared to be related directly to the percentage of ash in the leaves and enquired if any data were available on the point.

Dr. Burns observed that plants with hard root system suffered from bad opening.

Mr. Dabral added that *hirsutum* types also suffered.

Mr. Ramsaran Koshal referred to the statement on page 102, viz:—

“Experience has shown that provided there is enough of moisture in the soil, the seedlings survive the shock due to climate much better than the well established plant”

and asked whether that could be avoided if the amount of initial supply of water was increased. If the amount and distribution of initial sucking were regulated there would be evidently a larger amount of moisture present. He asked whether the initial soaking could not be regulated.

Mr. Dabral replied that whatever higher dose was given, in about ten days the upper layer dried up and the humidity was affected. That did not much mitigate the atmosphere.

Mr. Ramsaran Koshal asked whether it would be beneficial to give initial soaking in two instalments of 4" each, separated by an interval of about a fortnight, or a large dose (8") at one time.

Mr. Dabral answered that the method suggested did not at all come in. Sind agricultural practice was such that the seed was sown after a month of the soaking dose.

Mr. Mohammad Afzal said that Mr. Dabral had stated in his paper that all the American and Egyptian types suffered from non-dehiscence of anthers. There was similar trouble in the Punjab. Recently, however, another observation had been made. The Punjab-American types usually have clear coloured anthers, but occasionally one came across plants with yellow pollen. It had been observed that such plants with yellow pollen dehisced their anthers much earlier in the season than their sister plants with cream pollen. He wondered if Mr. Dabral had noticed a similar thing in Sind.

Another point was that Mr. Dabral had laid great stress on the resistance to jassids. While discussing an earlier paper Mr. Dabral had made a similar point and had now said the same thing over again that if there were plants which produced sympodia later in the season the jassid could be avoided and good yield obtained simply because the plants were late and mainly monopodial and that the first sympodial node was higher up. That was not the speaker's experience. One of his earlier types 43-F was, like Desi cottons, given its first picking on or about the 20th September, while 4-F was given its first picking on 7th or 10th October. 43-F starts producing flowers, along with Desi cottons, from the middle of July and usually gives a very high yield. It is resistant to jassids in spite of the fact that it is an early maturing cotton. He had other varieties, both early and late maturing, which were definitely susceptible to jassids. He therefore thought that a strong point need not be made of inducing jassid resistance by merely delaying sowing and postponing the appearance of the first sympodium.

Mr. Dabral, in reply to the first point, referred to the sentence in his paper on page 108, viz., "It is, however, important to note that F1 plants from hybrids between *G. hirsutum* and *G. barbadense* types or of those within the same species do not exhibit non-dehiscence of anthers to the extent the parents do," and said he could not give a prediction in Mr. Afzal's case. Sind hirsutums had creamy pollen and he could not say what the Punjab yellow pollens were like, but certainly Sind F1 hybrids got their dehiscence much earlier. As regards the other point, he was certainly not an authority on jassids, but very hairy plants saved themselves in spite of severe jassid attack and the glabrous variety which was early in flowering succumbed. The glabrous variety might get no resistance from its leaf, but if it was late in maturing, it was not affected so badly.

Mr. Ramanatha Ayyar stated that the range of variation in the position of the first sympodial node in Cambodia was about 7 to 17 in the Madras Presidency. The statement that in Sind Cambodias produced sympodial branches at fortieth nodes seemed to him to be rather puzzling. He had tried some Broach cottons at Coimbatore and he found in all cases that the difference in the readings obtained at Surat and Coimbatore was between two to three nodes and not so high as between 17 and 40.

Mr. Dabral explained that he tried Cambodia in Sind only during the last two years and he had a definite account of it. It might happen sometimes that when they grew a variety in a new place sympodial types showed abnormal behaviour during the first few years.

Rai Sahib Kalidas Sawhney wanted to know when the Cambodia was sown.

Mr. Dabral replied that it was sown in May.

Rai Sahib Kalidas Sawhney suggested that this abnormal behaviour might be due to difference in the time of sowing.

Mr. Ramanatha Ayyar said that with regard to the suggestion of **Rai Sahib Kalidas Sawhney** he knew as a matter of fact that Cambodia had been tried throughout the year in the Madras Presidency, and that the range of variation of node had not exceeded from 7 to 17.

Rai Sahib Kalidas Sawhney pointed out that April in Coimbatore and April in Sind could not be compared. Climatic conditions varied in different places in the same month.

The President proposed that the manner of publication of the papers read and of the Proceedings of the Conference should be settled. He suggested that the best way would be to circulate to all speakers a complete summary of the discussion on the subject concerned. On receipt of their replies and comments, the Proceedings would be edited, printed and supplied to members of the Conference.

COTTON AGRONOMY

Paper No. 5.

THE COTTON LEAF AS AN INDEX OF THE PHYSIOLOGICAL REQUIREMENT OF THE COTTON PLANT

BY

B. M. DABRAL,

COTTON PHYSIOLOGIST, AGRICULTURAL RESEARCH STATION, SAKRAND.

While moving in fields of cotton in the countryside, one is struck with the large amount of variation in colour and size displayed by the leaves of the cotton plant under different conditions and during the different stages of its growth. It is sometimes difficult to believe that the crop one is inspecting in a locality belongs to the same strain or variety of cotton which has been observed elsewhere. The cultivators themselves are struck with the differences that are apparent to the eye and very naturally seek guidance as to their causes and remedies if and when associated with disease or poor yields. The present note gives a few of the changes in leaf colour and size, etc., that are commonly met with in the cultivated areas of Sind.

All variations from the normal colour and size of the leaf, observed in the different types of cotton, can be grouped under the three heads given below.

- A. Abnormalities and malformations.
- B. Wilting and drying, etc.
- C. Changes in colour.

The details of the variations met with under each, along with their probable associations and causes, are given in the following paragraphs.

A. ABNORMALITIES AND MALFORMATIONS.

1. LEAF CRINKLE AND LEAF CURL.

The Egyptian and the American cottons with glabrous leaves when in their early vegetative growth show a peculiar deformity of the leaf laminae and borders. The Egyptians show it to a greater extent. The borders of the leaf incurve towards the mid-vein and break at various places. The mature leaves look very unhealthy and the growth of the plants is partially checked. These symptoms appear mostly during the months of May and June when the mean maximum temperature is above 110 °F. Damage by the leaf caterpillar is also an additional associated factor, especially among the American plants. Leaves which originate after June do not exhibit this character and it is therefore probable that the abnormality is an index of the effect of high temperatures on the smooth and glabrous varieties of cotton.

2. LAMINAR MALFORMATION.

In plants belonging to the Egyptian groups, leaf crinkle and leaf curl are sometimes accompanied with malformation of the entire lamina. The surface of the leaf is thrown into many undulating folds; and warty gatherings of dark green tissues appear over the whole surface. The symptoms resemble those described for the "leaf curl" virus disease in Sudan. These symptoms continue up to the end of July. Zinnia, sesamum, sunflower and a few other garden plants also show similar malformations of their leaves during this period. Transverse section of the affected cotton leaf shows an abnormal arrangement of the chloroplastids and their general enlargement. It is very likely that this is a genuine virus disease. It is however worth noting that unlike many virus diseases, it appears more during periods of high temperature than during cooler weather.

3. CYSTOSIS OR STENOSIS.

The symptoms associated with this type of malformation are well known all over India. In Sind, they have been observed only on the *Desi* (*G. Neglectum* var *roseum*) types. More often, the symptoms appear late in the season and are confined to a few branches only. The affected branches produce very small leaves, all crowded together on the stem. They are dark green in colour. Vegetative and flower-buds arise in large numbers. The flower-buds have abnormally large bracts and sepals while the petals and other essential organs are suppressed. Very few flowers open on such plants or branches. There is a seasonal difference in the appearance of these symptoms but the exact causes are not known.

4. DIMINUTIVE LEAVES.

Sometimes in a crop sown very early in the season there is observed a diminution of size of the leaves appearing after July or August. There is no crowding of branches but the number of leaves increases and the plant looks unhealthy.

The flower-buds, flowers and bolls are smaller in size and the percentage of badly opened bolls is increased. In an experiment on 4F (Punjab-American) cotton where flowers were plucked away just as they opened, the plants responded in the above manner. The local *Desi* variety shows this character to a greater extent than any other. The probable reasons seem to be some internal metabolic disturbance due to prolonged vegetative growth.

5. RANK VEGETATIVE GROWTH.

It is observed that the *Desi* cotton when grown in a new locality or on very rich soil grows almost in a wild manner. The main axis goes on throwing off monopodial branches only, and the sympodia, if at all, arise very high. They are generally abortive. If such plants survive the winter, a crop of flowers and bolls is given during the next season. The phenomenon can be compared to reversion to the ancestral tree habit under stimulus of extra fertility of the land.

B. WILTING AND DRYING.

1. AFTERNOON WILTING.

During summer (April to September) the leaves and tender shoots of almost all varieties of cotton droop down in the afternoon. They revive late in the evening and are again fresh on the morning of the next day. This daily wilting of leaves is due to excess of transpiration over absorption of water by the roots during the day and helps to counteract the harmful effects of high temperature and excessive water loss.

2. WILTING, YELLOWING AND SHEDDING OF LEAVES.

Very often, the afternoon wilting is followed by changes in the colour of the leaves and their shedding. The period during which the plant remains in a wilted condition every day goes on increasing as the plant gets older. The roots grow deeper and longer but are slender and sparsely branched. The branches of the plant are also slender. The leaves get yellow and finally shed to the ground. These symptoms have been found to be associated with the sandy and coarse nature of the soil near the surface and indicate the necessity of applying larger doses of water and manuring with heavy organic matter.

3. WILTING WITHOUT YELLOWING OF LEAVES, ETC.

Under certain circumstances, the prolonged afternoon wilting is not followed by the usual yellowing and shedding of leaves. The leaves, on the contrary, take on a dark green colour and remain attached to the plant. The plants get stunted and develop very few fruits. The root system of plants under these circumstances

is entirely different. The tap root does not go vertically down but is bent sideways at about 9" to 1½ feet layer below the surface, and the laterals are poorly developed. The most important difference is however observed in the structure and shape of the tap and the branch-roots. Under normal conditions they are cylindrical in form but under the above conditions they become wedge-shaped or flattened. The internal vascular ring also becomes bilateral in shape instead of the usual circular one. This deformity in root structure apparently suggests that there is some mechanical pressure exerted on the young rootlets at certain layers in the soil. This pressure indicates the presence of a hard pan in the soil probably formed during the growing period and connected with irrigation practice. Application of water to the wilting cotton crop under the above circumstances does not help to any extent. This phenomenon is thus a very important index of soil changes due to irrigation and requires more critical and thorough study.

4. SUDDEN WILTING.

The damage by white ants at the hypocotyledonary zones of the plants or its tap root are the main causes of sudden wilting of the whole plant observed in cotton fields during summer. Root-rot also makes the plant wilt suddenly but more often the wilting proceeds slowly from a few branches to the whole plant. Sometimes after heavy irrigation on harder and kalar soil a large number of plants wilt suddenly. On examination, the roots are found constricted at two to three inches layer below the soil surface. The plant is, as it were, strangled to death by pressure (as in a vice) due to the expansion of the soil mass after irrigation.

C. CHANGES IN COLOUR AND FORM OF LEAF, ETC.

There are many types of colour changes exhibited by the leaves of the cotton plant during its course of life and their classification in accordance with associated factors is very difficult. Widely different stimuli result in similar response by the plant. There are however a few distinguishable symptoms which can be dealt with separately.

1. RED-LEAF (ORANGE-RED TO CRIMSON-RED).

At the end of the season, in November and December, almost all varieties of the American and Egyptian cottons change the colour of their leaves. The phenomenon is akin to the autumnal pigmentation of wild plants so common in sub-tropical and temperate regions. Lowering of temperature and senescence of the leaves, etc., and the resultant metabolic changes in the leaf sap are responsible for this display of colour.

2. RED-LEAF (YELLOW-GREEN TO YELLOW-RED).

In almost all cotton growing areas of Sind, there are large stretches of soil where the crop looks yellow-green from an early stage in its growth. Reddening of leaves appears earlier on such a crop. It is sometimes difficult to believe that the crop standing on such areas belongs to the same variety as the one which has normal green foliage. The yellow-green plants ultimately yield barely half as much as the normal ones. Analysis of the plant and soil have shown that the symptoms are associated with a deficiency of the soil in the matter of its nitrate content and soluble salts. It is a very important indication of the deterioration of soil and as such very useful to agriculturists.

3. CHANGES DUE TO INSECT PESTS.

Jassids by their direct and indirect injury modify the colour and shape of the leaf considerably. Curling of the leaves, gradual yellowing of the leaf from the border towards the centre, followed by reddening or drying to copper red colour are the usual progressive changes consequent on jassid attack.

Aphides and white-flies induce secretion of glistening honey dew on the ventral surface which later on turns black on account of the spores of fungi mould that appear on this surface. Thrips dot the surface of the leaves with dark brown patches while certain kinds of caterpillars eat away the succulent tissue and leave the surface as a network of veins. Fungi and Bacteria attack the leaf in the wake of the insect pests and further patch its surface with necrosed areas imparting varying shades of colour to it.

MISCELLANEOUS.

In addition to the above, splashes of red, variegated and mottled patches, etc., suggesting virus diseases or other symptoms due to soil deficiency, etc., appear occasionally. Sometimes partial to fully white (albino) leaves are also observed to arise during the early vegetative stages of the different varieties of cotton.

DISCUSSION.

Mr. Dabral after making a passing reference to the first part of the paper which was mostly concerned with Egyptians said that the important point which he would discuss was the wilting of cotton plants in Sind. He doubted whether the wilting of the cotton plant every afternoon after 11 a.m. which was commonly complained of by the cultivators was due to deficiency of water in the soil as such. In investigating this complaint he observed that though the plants were green enough and soil moisture was sufficient the plants were still wilting. He just took up the root system and found that for some reason or other there was a deformation of the roots, the tap and branch roots becoming wedge-shaped or flattened. The future problem to be tackled in this connection would be the effect of irrigation on the upper layers of soil. As regards the changes in the colour of the leaf they might be due to many causes, such as adverse effects of the soil, insect damage or the deficiency of plant food in the soil which might be local. In Sind the colour change might be due to a certain deficiency while in some other place it might be due to some other deficiency.

Dr. Sankaran, referring to the statement on page 5 of the paper that "the yellow-green plants ultimately yield barely half as much as the normal ones: analysis of the plant and the soil have shown that the symptoms are associated with a deficiency of the soil in the matter of its nitrate content and soluble salts," expressed his view that the chlorophyll content of the leaves could be associated more with the pale colour, in which case, unless the chlorophyll content was lower, it would lead to diminution in the assimilable activity which would entirely account for the lower yield. He, therefore, would like to know if Mr. Dabral had made a study of the chlorophyll content of such leaf as well as the assimilable activity.

Mr. Dabral replied that in fact he tried that method, but that curiously enough he found that the carbohydrate potency was equal to, and the depth of the mesophyll was nearly three-fourths of the green leaf. That was a very crude method of investigation but the yield in those places was gradually diminished and the whole trouble was with the protein content. There was disparity of storage of protein and as a result there was definite difference in nitrogen contents of the stem, boll, leaf, roots and the soil. He was, therefore, of opinion that though there might be some other ingredients deficient, nitrogen deficiency looked to be the major factor.

Replying to a query from Mr. Afzal Husain regarding the statement on page 5 of the paper that "Aphides and white flies induce secretion of glistening honey dew on the ventral surface which later on turns black on account of the spores of fungi mould that appear on this surface," Mr. Dabral explained that different kinds of insects give different reactions in the plants.

Dr. Burns remarked that the paper was a valuable one in so far as it laid stress on the necessity for good field observation as a basis for more exact laboratory work later.

Professor Dastur said in his investigations of the red leaf problem in the Punjab he had been making some analysis of the leaves from the plants which were badly open and which had reddened leaves, and also plants which had green leaves. To his surprise it was found that the nitrogen content of the leaves, roots and stems of badly opened plants was higher than the nitrogen content of the plants that had opened well. He did not know whether the total nitrogen that had been estimated by Mr. Dabral was protein nitrogen or inorganic nitrogen. He was certain that the nitrogen content of the plants, so far as he could speak from his analysis of three samples, was higher in the badly opened plants than in the well opened plants. He could not, at that stage, make any attempt to explain the differences but he was trying to find out whether this total nitrogen consisted more of inorganic or protein nitrogen. About the nitrate content of the soil he had not made any estimation but so far as he had read various reports in Sudan and other places, during those years when yields were low the soluble nitrates in the soil were not deficient. He had also carried out experiments and found that in those areas when the crop was bad the soluble nitrates in the soil were not low. Nitrogen might be one factor, but there were other factors also in the soil which might be co-operating with it.

Mr. Dabral stated that he sent samples of cotton from green plants and yellow plants to Dr. Nazir Ahmad who found that higher spinning performance was 44's in case of green plants and 40's in the case of yellow plants. The soil deficiency was the cause of the difference in counts.

Mr. Wad desired to know what soil observations had been made.

Mr. Dabral explained that the moisture percentage and the total soluble salts were ascertained and that it was found that they were more under green plants than under yellow ones. No physical constituents had been taken into account.

COTTON AGRONOMY

Paper No. 2

COTTON AGRONOMY

BY

M. U. BARAKZAI,

AGRICULTURIST, AGRICULTURAL RESEARCH STATION, SAKRAND.

Introduction.—Before describing the various aspects of cotton agronomy dealt with by the Sind Agricultural Department, it will not be out of place to give a brief historical review of the development of cotton cultivation in Sind. There is sufficient evidence to justify the statement that cotton has been in cultivation in the Province from ancient times. In Pre-British times, it was not grown as a commercial crop nor occupied extensive areas in any part of Sind. Every farmer cultivated a few *ghuntas* to an acre of his land, under cotton. The seed cotton was ginned on wooden hand gins at home, and spun on 'charkha', and the professional weavers of which a large class is yet in existence in Sind, weaved a sort of rough cloth called "Jori," which was used for making garments for the agricultural classes. The females used a similar cloth after dyeing in various colours or printing in various designs. After the British conquest of Sind, facilities of irrigation were extended to a large part of the country, by the excavation of new high level canals and remodelling of the old systems and as a result of these efforts cultivation of cotton gradually expanded. The crop became a commercial product and cotton was largely exported to foreign countries.

During this period, the agronomy of cotton received considerable attention and certain centres, *e.g.*, Bhitshah, a village situated north of Hyderabad, acquired fame for the excellence of cultivation, for the high quality of seed, and high yields. Ridge method of sowing cotton, applications of large quantities of cattle manure, top-dressing with *kalar* earth and thorough intercultural operations, were the special features of the Bhitshah tract. Selected bolls of cotton from the 2nd and 3rd pickings were

collected by advanced growers and ginned on hand gins. The seed so obtained was sold at double the price of ordinary machine ginned seed. The importance of the seed was recognised by the cultivators who came from long distances to purchase the seed at a high price. Use of this seed meant half the seed rate. The Agricultural Department was established in Sind in 1904, and with its inception, the foundation stone of agricultural research was laid. The cotton crop on account of its importance as a commercial crop received its foremost attention, and as a result, diverse improvements in various directions have since been made. Since the opening of the Lloyd Barrage and Canal Systems, the cultivation of cotton has made an unprecedented expansion in the Province, and now it occupies nearly 8 lacs of acres against about 3 lacs of acres cultivated in pre-Barrage days.

SEASON AND CLIMATE.

Cotton is essentially a *kharif* crop in Sind. It cannot stand the low temperatures of the month of January which destroy the crop almost entirely. It is also affected to a greater or less extent by the hot dry blast and high temperature (112°F. to 120°F.) of the month of May. Between these two limits, *i.e.*, from June to December, the crop grows vigorously and yields well. The limited range of the season restricts the introduction of long season varieties in Sind and only admits of the cultivation of the short season varieties. Recent successful findings as regards the advance (April) sowing of cotton under the conditions of perennial irrigation, have enhanced the season of growing cotton by 3 months, whereby the cultivation of superior stapled varieties of cotton has been made possible. The months of July and August when the climate changes for the better constitute the most favourable period for the rapid growth and profuse bearing of the plants. A heat spell is often experienced in September when temperature rises to 110°F., or 112°F., but the early maturing types do not as a rule suffer from its adverse effects, having already largely completed the sexual phase. The late maturing types however suffer from the spell, in having their flowers and recently fertilised bolls scorched.

Rain-fall is an insignificant factor in the cultivation of cotton in Sind. Cloudy weather, however, sometimes causes serious harm, when it is continuous, by delaying the bursting of bolls and encouraging diseases and pests in the crop. The normal rainfall is about 5 inches, all of which falls in July and August.

SOILS.

Sandy soils or shallow soils over-lying a deep layer of sand are absolutely unsuitable for cotton cultivation. On the other hand cotton fails almost entirely in soils excessively charged with "Kalar" which are generally very stiff and impermeable. Between these extremes, the crop can be grown on all kinds of soils. Loams are by

far the best soils for the successful cultivation of the crop. Soils charged with moderate quantities of salts, though stiff in texture under careful management and irrigation, yield heavy out-turns of cotton. Deep soils are always considered to be rich and lasting in fertility. Sandy loams are easily exhausted under ordinary conditions of cropping but with sufficiently large doses of manure they yield remarkable results.

PREPARATORY TILLAGE, SOWING AND SEED-RATE.

Under pre-Barrage conditions, water was available from June to the middle of September, and in consequence of the short season, the cultivator was obliged to resort to the most elementary and simple practice of sowing *kharif* crops in time. It consisted of cutting down and burning the scrub growth at the advent of the sowing season, applying two irrigations called "kacha" and "pucca rej," scattering seed on the irrigated field at the rate of 30 to 40 lbs. per acre and stirring the soil with a plough. Advanced growers gave two to three ploughings to the land in dry state before the advent of sowing season, crushed clods by hand or by passing wooden rollers, threw up ridges and furrows by hand or with a plough, dibbled the seed on ridges at sowing time and irrigated the furrows for enabling the crop to germinate. This type of grower used selected seed almost invariably, applied large quantities of manure to the fields and usually gathered a rich harvest. But such growers are very limited in number and are more or less confined to Bhitshah tract only.

The study of the agricultural practices, commonly followed in the cotton growing tracts of Sind, revealed a number of problems of cotton agronomy to be urgently explored. The most obvious method of increasing the fertility of soil was to test and introduce dry ploughing of lands in the off season, in order to enable the soil to weather and aerate, as also to destroy the weeds and scrub growth which usually spring up in fallow lands. Moreover the loose condition of the soil enables larger volume of water to penetrate deep down which is a distinct advantage from the point of view of irrigation economy. The operation is now adopted by the cultivators in the district and is gradually extending.

The broad-cast sowing obviously involves the minimum of tillage, and heavy seed rate to ensure a good germination. Instead, a couple of ploughings and plank rollings followed by drilling of seed was found to be the most successful method of sowing the cotton crop. The ploughings and plank rollings produced optimum conditions of soil tillage which favoured a uniform germination and healthy growth. The drill deposited the seed at the desired depth in the moist layer, whereby the seedlings developed their early growth much more vigorously than the broad-cast sown crop and demanded subsequent irrigation after long intervals. A long yoke (5ft., 6ft., or 7 ft., according to the spacing between the rows) was the only change which the cultivator had to make in his outfit to adopt the method in his practice. Due to the extension of sowing season consequent upon the availability of water from April

the drill method of sowing cotton can now be practised with ease. This method is also largely responsible for the maintenance of clean fields and destruction of weeds.

Results of experiments carried out for several years have demonstrated that sowings of cotton can be successfully carried out from April to the middle of June. The earlier sown crop no doubt receives a certain amount of set-back during the 40 hot days, but it soon recovers from its adverse effects and in the end stands taller than the later sown crop. The later sown crop (15th May to 15th June) on the other hand is moderate in height and bears as many or an even larger number of bolls than the earlier sown crop. For long season varieties, *e. g.*, Sea Island and Boss III., March sowings have been found to be advantageous. The long range of sowing season of cotton under the condition of limited supply of irrigation water enables the cultivator to take full advantage of the available water supply and also to practise advanced methods of cultivation, which were denied to him under inundation conditions for lack of sufficient time.

The problem of spacing between the rows and between the plants in the row has also been carefully studied. Bushy varieties, *e. g.*, 289F and 4F, demand a larger space in both directions. Closer planting of these varieties interferes with the normal habit of their branching and induces the plants to grow unusually tall with the ultimate disadvantage of bearing fruit towards the top only. A well spaced crop branches abundantly right from the bottom and enables the plants to carry a larger crop of fruit to maturity without assuming high stature. Three to three-and-a-half feet between the rows and one to one-and-a-half feet between the plants in the rows seems to be the most satisfactory space for this type of cotton. Sindhi and Egyptian are by habit tall growing varieties and as such $2\frac{1}{2}$ feet distance between the rows and 1 to $1\frac{1}{2}$ feet between the plants has been found to be an appropriate space for them.

The seed rate of cotton, which the cultivators generally practise, is one bag for 4 acres; *i. e.*, 30 lbs. per acre. In stiff and "kalar" lands, where germination under broadcast sowing is invariably defective or there is danger of excessive thinning by white ants, the seed rate is enhanced to 40 lbs. per acre. Broadcast sowing is mainly responsible for the higher seed rate inasmuch as many seeds fail to germinate due to lack of contact with the suitable environments or to falling under heavy clods. On the other hand, machine ginned seed, which is sold in ungraded state to the cultivators and contains from 14 to 40 per cent of crushed seed, must be proportionately heavily seeded. Grading of seed is therefore a very necessary item of work for controlling the seed rate of the crop. On the Agricultural Farms the seed rates of graded seed in vogue are 16 lbs. for *Desi* (27 W. N.), 20 lbs. for Egyptian, and 24 lbs. for 289F and 4F. This seed rate is also high and the resulting crop is generally thinned to

the extent of about 30 to 50 per cent when it is about a foot or a foot-and-a-half above ground. This problem requires still further investigation chiefly with regard to the percentage of unsound seed which is found in excess in the local seed in some years.

MANURING.

As a rule, Sind crop of cotton is not manured, though every cultivator is fully alive to the importance of manuring cotton. The exception to this rule is the Bhit-shah tract where manuring is a common feature of cotton cultivation. The reasons for this inability are diverse, but one important reason is lack of sufficient supply of manure due to absence of preservation facilities and small cattle population in the cotton tracts. Cultivation of fodder crops is now rapidly dwindling down on account of the tendency of the *Zamindars* to cultivate larger percentage of the holdings under cotton crop. This tendency is bound to reflect adversely on the future supply of the cattle manure. Experiments have, however, demonstrated that cotton crop responds to organic manuring in a remarkable manner. On the other hand, half the organic dose with 20 to 30 lbs. of nitrogen in the form of sulphate of ammonia has enhanced the yields to a considerable extent. The economic aspect of the application has also been fully studied and found satisfactory. Green manuring of cotton, by sowing juar (*Cyamopsis Psoraloides*) in the intermediate spaces of the drill sown crop and burying it after 6 weeks' growth has been successfully carried out on some farms with beneficial results.

VARIETIES.

The important varieties of cotton which have been successfully cultivated in Sind are of short to medium long stapled types. Sind N. R. (27 W. N.) is a selection from *Desi* cotton which has established itself in Sind on account of its hardiness and suitability to diverse conditions of soil, treatment, season, etc. The second and rather superior stapled variety which is largely grown in Sind is Sind-American (4 F-98), a selection from the original 4F imported from the Punjab. This variety is also fairly hardy and well suited to local conditions. The Sind *Sudhar* (289 F1) is the latest production from the Punjab 289 F and has since its introduction by the Department spread far and wide in the district. It is a longer stapled cotton but in other respects it differs little from the 4 F variety. Among the exotic cottons, the Sea Island and the Boss. III. 16 are local products of the original stuff and are being tested in various tracts for their yield and suitability. These varieties are seriously attacked by white ants and other diseases (Jassids) and demand far more careful attention than the Sind *Sudhar* (289 F) and 4 F regarding cultivation, irrigation and manuring, etc., hence their expansion in the Barrage zone is likely to be very limited for the time being.

CROP MIXTURES.

It is usual with the cultivator of Sind to sow the cotton seed mixed with a small quantity of juar or maize, and a few melon creepers along the borders. In certain localities sesame and juar are sown in light patches or along the borders. The maize and juar are cut and fed to cattle in green state, but in some cases, maize is allowed to mature cobs which are used in the dietary of the cultivators' families. Melons in the neighbourhood of towns fetch some income to the cultivators, but in other places they are locally consumed. Most of these sub-crops disappear from cotton fields by the end of August, after which cotton crop is seen occupying the whole field.

ROTATIONS.

In pre-Barrage days, cotton together with *kharif* cereals occupied 1/3rd to 1/5th of each holding, the percentage depending upon the available supply of water. As a result there was practically a compulsory system of fallowing of the land in vogue. The lands cultivated once came under cultivation after a lapse of 2 to 4 years. This system of farming did not stand in need of a rotation as the period of fallow was sufficiently long to enable the lands to recuperate their fertility under the strong sunshine of Sind. In Jamarao tract, where irrigation conditions before the Barrage were more or less perennial, a system of rotation was in force. Cotton was cropped in the 1st year after which the land received a full year's fallow and had bajri or wheat in the 3rd year. With the advent of perennial irrigation consequent upon the working of the Lloyd Barrage and canal systems, a definite system of rotation has to be adopted to ensure successful cultivation of crops. Under the project scheme, 4 crops are proposed to be cultivated in 10 seasons (*i.e.*, 5 years). Cotton and *kharif* cereals will be cropped in the 1st year in the *kharif* season, wheat in the second, third and fourth years in the *rabi* seasons and a year's fallow in the fifth year. If the lands are kept well tilled in the fallow seasons, it seems possible to maintain the land in a fairly good state of fertility under this rotation although deficiency of organic matter may be revealed by the yellowing of crops and gradual decline in the yield. The Department of Agriculture in Sind has under test a number of other rotations which promise to give better results as regards the end in view, *viz.*, the maintenance of soil fertility. The important feature of these rotations is the introduction of berseem cultivation in the *rabi* season. This leguminous crop possesses a very valuable quality of improving the fertility of the soil on which it is grown and provides a nourishing green fodder for the stock whose maintenance on the lands is one of the important means of increasing the supply of organic manure. The remarkable effects of the cultivation of berseem are realised when cotton is grown after the berseem harvest and burying down of its stubble in the land. Its cultivation is now spreading in the Barrage areas, with considerable momentum.

INTERCULTIVATIONS.

Under average conditions, the Sindhi cultivator gives one or two hoeings with the 'kharpi' (a hand tool) to his broadcast sown crop. The first hoeing is given before the first irrigation and is called "Suki Gud." It consists of merely removing the weeds which germinate on the land after the seed is sown. The second hoeing is given during the rainy season, i.e., July and August, when due to repeated waterings or rains, extraordinary growth of weeds springs up in the fields. Both the hoeings cost approximately Rs. 8/- to Rs. 10/- per acre. But these hoeings are not efficient and the soil gets hardly any stirring at all. The crop is noticed to have been stuck up and is of pale colour, lacking in vigour and freshness. The drill sown crop on the other hand can be easily intercultivated with bullock drawn implements whereby the soil is stirred to a depth of 4 to 5 inches and plants at once assume dark-green colour and grow vigorously. This interculture is a very cheap operation, which the cultivator can practise as many times as the crop permits, with the least difficulty. The introduction of this method of interculture by the Department is largely responsible for the reduction in the cost of production of the cotton crop, as also for the enhancement of the yield, obtained as a result of healthy growth arising from the deep intercultivations given to the crop during its growing period. Technically it is the aeration of the soil and larger room for root expansion which lead to the healthy and vigorous growth of the plants. This method of intercultivation is now being practised by the cultivators even in their broadcast sown crops in various localities in the Barrage areas. In practice three intercultivations have been found to be quite enough for obtaining good results. No intercultivation is given during the flowering stage of the plants.

IRRIGATION OF COTTON CROP.

The problem of irrigation of cotton crop has received a great deal of attention and numerous experiments extending over several years have been performed by the Department, partly with the financial help of the Indian Central Cotton Committee, and partly with its own resources. The normal irrigation arrangement consists of applying the initial soaking of 8 acre-inches in two doses to the land before sowing the seed. When the land dries up sufficiently, the preparatory tillage is given to the land and seed is sown. The first irrigation is applied 30 days after sowing and the subsequent irrigations are applied at intervals of 15 to 20 days until the middle of October after which no more irrigations are found necessary for the well-being of the crop. There is sufficient experimental evidence to show that irrigations beyond the middle of October are wasteful and rather tend to retard the opening of the mature bolls already borne by the crop, by stimulating undesirable fresh vegetative growth. On the other hand the late irrigations involve reduction in the acreage of *rabi* cultivation, which is an economic loss to the farmers.

Experiments on the intervals of irrigation carried out in the Physiological section have shown that waterings at longer intervals during the earlier growth period of the crop followed by frequent waterings at shorter intervals during the reproductive stage of the plants make a better programme of cotton irrigations than uniform system of irrigations applied at fixed intervals. The results of these experiments are significant and conclusive. The new system of irrigation has now been extended to large areas in order to test its practical applicability under ordinary conditions available in the country.

PESTS AND DISEASES.

The important pests of cotton crop met with in Sind are (1) Spotted Bollworm (2) Pink Bollworm, (3) Jassids and White-fly. These pests are universal all over Sind and only in bad years cause serious damage to the crop. Other diseases of which the origin is obscure and which also cause whole-sale failure of crop in certain years are (1) Red leaf in American and Egyptian cotton, (2) Tirak, *i.e.*, bad opening of bolls. The latter appeared at Sakrand in 1932 and seriously damaged the American varieties of cotton. Detailed investigations of these diseases at this time when cotton crop is rapidly extending in the Barrage areas are urgently necessary in order to prevent, if possible, sudden outbreaks and whole-sale failures.

COTTON PICKINGS AND FINAL HARVEST.

From August onwards up to about the middle of October, the activities of the plants are diverted from the vegetative growth to the reproductive phase. During this interval nothing need be done to disturb the active formation of flowers and bolls. The pickings are obtained almost at monthly intervals from October to December. The crop is usually picked, after the dewfall has dried, by women folk and collected on hessian cloth or mattings until the end of the day when it is transported to open godowns and stored. Clean picking is urgently to be impressed on the pickers who are generally careful only for the quantity of the picked material to obtain larger share for their daily wages. But the grower thereby suffers in obtaining a low price for the poor quality of his produce and so it is in his interests to see that the material is picked as clean as possible.

The last but not the least important point to note here is the cutting of the cotton sticks after harvest and ploughing up of the land to eradicate the roots of the plants. This operation is absolutely necessary to prevent carry-over of the various pests and diseases to the next year. On the other hand, the ploughed up condition of the field will enable the soil to recuperate its fertility by natural weathering processes and soil aeration.

COTTON AGRONOMY

Paper No. 3.

THE SALINE SOILS OF SIND AND THE COTTON PLANT

BY

M. A. SHAMA IYENGAR,

AG. AGRICULTURAL CHEMIST AND SOIL PHYSICIST,

AGRICULTURAL RESEARCH STATION, SAKRAND.

The Province of Sind forms the western-most part of the great Indo-Gangetic plain. The whole country is flat and has a low absolute altitude. Here the river Indus flows from North to South and divides the Province into two nearly equal halves.

It is an arid land of extremes of temperature, with its long hot summers from April to November and its cold winters when frost is almost an annual feature. The rainfall is scanty, the average being 3 inches per annum, all of which is received during the summer months in light showers.

The soils of Sind, which are both made and maintained by the river, are however very fertile. They are deep, calcareous alluviums, mostly loamy, with a low water holding capacity and are slightly alkaline in reaction. For a virgin soil, they are poor in nitrogen and organic matter. The soil profile is undefined and structureless. A striking characteristic of these soils is their lack of uniformity over any distance, the surface soils varying considerably from spot to spot.

Under these soil and climatic conditions, the agriculture in the country, in absence of rainfall, depends entirely upon irrigation. Consequently, only along the uncertain banks of the river and in certain places to which water could easily be led by canals did any serious cultivation prevail. And what cultivation did exist was extensive in nature and struggled against an irregular supply of water. Even then cotton cultivation was an important item on the cultivator's programme.

With the building of the mile-long Sukkur Barrage, however, the old conditions disappeared. With the 10 great canals, each a river in itself, with their thousands of miles of distributories reaching the farthest end of the territory, a much larger area has been brought under cultivation. The old uncertainty is replaced by a constant and regular supply of irrigation water.

This certainty of a regular water supply has given rise among others to two facts with which we are now concerned. The area under cotton which was only 2.5 lacs before has risen to 9 lacs of acres and over, within three years of the completion of the Barrage and is still rising, while the Barrage Project contemplated under 7.5 lacs of acres as the ultimate intensity to be reached in third decade and after. Further where almost all the two and odd lacs of acres under cotton were sown to the short stapled local varieties, now there are 4 lacs of acres under the local and 5 lacs of acres under the superior American and Egyptian varieties.

These facts are significant and show first that cotton cultivation, already prominent, has leaped into an amazing and incredible importance in the country, and secondly that in addition to the indigenous short stapled varieties, more favourable conditions are now available for growing the superior American and Egyptian staple cottons.

But there are two soil factors in the country which militate against the successful growing of these superior cottons. One is the white ants and the other is the presence of kalar (salts) in the soil with which we are now concerned.

Salt lands are very common in Sind. There is hardly a round acre of cultivable area which does not include some patch or other of salt land. There are also vast stretches of salt lands sometimes running into hundreds of acres. A salt content of about 1 to 2 per cent in these soils is very common but some spots there are which contain as much as 7 to even 10 per cent of total soluble salts at the surface. The salts are distributed throughout the profile with usually a higher concentration at or near the surface. These soluble salts consist chiefly of sodium chloride and sodium sulphate. Sodium carbonate is almost absent. Therefore the kalar lands in Sind are not the true alkali soils but may more properly be described as saline soils.

As the presence of salts in soil beyond certain limits is injurious and even fatal to plants, these salt lands have to be reclaimed before the ordinary crops can be successfully grown on them.

During work directed towards finding methods for the reclamation of kalar lands and subsequent growing of cotton, a few facts observed pertaining to the cotton plants grown on kalar lands under reclamation and the salts are herewith presented.

Salt tolerance of cotton.—The nature of the injury done by these salts to the various crops is not clearly understood. But it is certain that different crops as well as different varieties of the same crop exhibit differences in their capacity for tolerance of these salts in the soil.

The local varieties of all crops grown in Sind are able, presumably by adaptation, to withstand higher percentages of soluble salts in the soil. Whereas a 0.2 per cent soluble salts in the soil is generally considered to be harmful to crops, at Sakrand as elsewhere in Sind, crops like jowar, wheat and even cotton can grow fairly well in soils containing as much as 0.5 per cent of total soluble salts, mostly consisting of sodium salts. The high calcium content of the soil and the irrigation agriculture conditions seem to be responsible to an extent for this higher degree of tolerance.

The following is an interesting Table—

Crop.	% salts in soil tolerated.	% salts that are injurious.
	(Injurious)	
Cotton (<i>Desi</i>)	0.52 (.2—3)	0.78
Jowar	0.62 (.25—.35)	0.91
Wheat	1.00 (.3—.5)	1.47

The different varieties of cotton were sown on saline soils for 3 years in 5 replications. It was found that the *Desi* selection 27 W. N. grew very well and of the Americans 285-F₂ showed better results than 289-F and 4F-98.

Prompted by an experiment where some African salt bushes were found to absorb large amounts of alkali salts from saline soil, the ordinary crops grown on these soils were also analysed for the sodium salts removed by these from the soil. It was found that—

Bajri removed	193 lbs. of NaCl per acre.
cotton „	126 „ „ „ „ „
jowar „	124 „ „ „ „ „
while wheat „ only	25 „ „ „ „ „

The cotton crop as an aid to reclamation.—Of the many methods tried for the purposes of reclamation, the application of chemical correctives gave very indifferent results, while the mechanical process of leaching the salts down to the lower

layers of the soil with adequate doses of water consistently resulted in considerably reducing the salt contents of kalar soils. Then on leaving the lands fallow, the salts driven down returned to the surface and accumulated more or less to the former degree. With a view to prevent or minimise such re-accumulation of salts, a number of crops were grown on kalar soils which had just been leached. It was found that leaching resulted in greater benefit to the land if immediately followed by some crop.

And of the crops tested for this purpose, cotton was found to be superior to others (jowar, bajri, etc.) as in the plots where cotton had been grown, much less salts returned to the surface than in others. The difference in the effects is due, perhaps, first to the superior shading effect of cotton and secondly, to the greatly decreased quantity of water available to rise to the surface as the deeper and more extensive root system of cotton intercepts the water during its upward movement to a greater degree and transpires larger quantities of it through the leaves.

The water requirement of cotton on saline soils.—All the older irrigation schemes have taught that a judicious use of water is vital for the continued productivity of irrigated lands. The dangers of the misuse of water in Sind are twofold, *viz.*, the rise of the water table and the development of salinity. Hence the minimum quantities of water necessary to grow normal crops, consistent with the maintenance of the physical condition and the fertility of the soils, have been determined by carefully conducted field experiments.

These experiments were laid on both salt free soils and on saline soils which had just been given leaching doses of different intensities. The results showed that once the salts have been leached down, it is possible to obtain as good crops of cotton on the previously saline lands as on salt free soils with equal quantities of irrigation water. On the total, however, the saline soils needed more water by that amount which was required for the preliminary leaching. The actual yields of 4F-18 in lbs. of seed-cotton per acre were as follows:—

Quantity of water given	1932		1933	
	Sweet land	Kalar land	Sweet land	Kalar land
46.5	1160	1408	1840	1685
37.4	640	1120	1536	1616

There are slight indications that the cotton plant perhaps prefers a slightly saline soil to one completely free from soluble salts. The effect of these salts in soil on the quality of fibre is not yet studied.

Continuous cotton on saline soils.—A part of a kalar area which was treated to a leaching dose has been kept under continuous cotton for the last seven years and the plots are given no manure or other treatment. The effect of such a cropping with cotton after cotton without any system of rotation, on both the soil fertility constituents and the yields of cotton, are being observed.

The yields obtained are :—

In lbs. per acre of seed cotton of 27 W.N.						
1930	1931	1932	1933	1934	1935	1936
939	493	1255	1088	973	1133	

This repeated growing of cotton on the same area has not affected either the fertility constituents in the soil or the yields obtained from year to year. The variations in yields are attributable more to the seasonal fluctuations than to any diminished productivity of the soil.

SUMMARY.

Summing up, the salt lands of Sind are just saline soils and can be rendered fit to grow both the local and the superior varieties of cotton by giving an adequate leaching treatment prior to sowing. All the varieties of cotton now being grown in Sind are fairly resistant to salts in the soil, the *Desi* cotton being comparatively more resistant than the Americans, which are superior to the Egyptians. The cultivation of cotton immediately following a leaching treatment is very effective in minimising the return to the surface of the salts once washed down by leaching. The water requirement of the cotton crop is more on saline than on sweet soils by just that amount which is necessary to leach down the major part of the injurious salts in the soil. Once this leaching is done, the cotton crop thrives on the leached soil at least as well as it does on a salt free land and, perhaps, even relishes a certain amount of these salts in the soil. And lastly, a continuous cropping with cotton after cotton for seven years in succession on an originally leached saline soil has so far shown no ill effect either on the soil constituents or the crop yield.

DISCUSSION.

Mr. Ramanatha Ayyar said that in the experiments conducted on cotton-jowar rotation in the Madras Presidency he had come across an interesting observation that when cotton followed jowar the soil contained a greater percentage of sodium ion. The bad effects of that condition were remedied to a certain extent by growing the succeeding cotton thick or by applying gypsum or by leaving the land fallow till the next sowing season and then ploughing the land and sowing the crop. By these methods he was able to reduce the injurious effects of increased sodium ion content. It may be possible that if any of these methods were tried in Sind, perhaps the alkaline effect might be reduced.

Mr. Dabral explained that sodium chloride and sodium sulphate were always found along with calcium carbonate. Under these conditions sodium could not form that particular kind of bad effect. The rotation in Sind was not jowar and cotton and so the question did not arise. Mr. Shama Iyengar used to grow jowar and wheat, jowar in kharif and wheat in rabi season and the yield of wheat went down to 300 lbs. where it used to be 1000 lbs. In order to find out the cause of this the land was left fallow for one year and it was surprising that the yield in this case was much more than 1500 lbs. This was also a very interesting feature which was being investigated. The sodium content of Sind soil was not so bad as calcium was always present there.

Mr. Andrews enquired whether Mr. Dabral's reference on page 2 of his paper to the leaf crinkle disease of Egyptian cottons was the same as in the Sudan.

Mr. Dabral explained that leaf crinkle in Sind was a sort of laminae malformation and was confined to Egyptian types. During hot weather a sort of collection of the undulating folds of the laminae tissues was observed. There was nothing of the type of leaf crinkle referred to by Mr. Andrews.

Mr. Andrews pointed out that leaf curl disease was not common in India, but there was white fly in Sind. He had found the leaf curl disease on hollyhocks in the Punjab and as this disease could be transmitted from hollyhocks to Egyptian cotton, in introducing Egyptian cotton in Sind there was every possibility of introducing leaf curl disease also.

Mr. Hutchinson stated that the general subject of the introduction of diseases was raised by Mr. Richards in the Agricultural Research Sub-Committee, and if that subject was going to be considered, this disease might also be added along with that. He wished to know if there was any likelihood of introducing Egyptian seed for research purposes in Sind.

Dr. Burns said that he understood Mr. Andrews to have already located the disease in hollyhocks.

Mr. Andrews said that hollyhocks formed an alternative host. There were of course Egyptian varieties immune to this disease.

To a query from Dr. Burns whether the transfer from hollyhocks to cotton had occurred in the Sudan Mr. Andrews answered in the affirmative.

Replying to Mr. Hutchinson Mr. Andrews said that some American varieties were susceptible to leaf curl disease and some were not.

The President said the question of the extension of the leaf curl disease from hollyhock to cotton might be considered by the Agricultural Research Sub-Committee.

This was agreed to.

Subject—5. Paper on Spinning Tests Data by Mr. M. L. Patel.

Reference from the Plant Breeders' Conference held in August, 1936.

Mr. M. L. Patel introducing the discussion said that the first main question for consideration was whether or not the superiority of an improved type as found consistently at the Laboratory was reproducible, wholly or partly under prevalent mill conditions; or what difference in counts between the original and improved types would be visible under mill conditions, because the improvement in spinning performance effected by the breeders along with other economic characters was usually limited to 6 to 7 counts. If the results at the Laboratory are not reproducible under mill-conditions then the consumer should have this knowledge and be guided only by the Matunga Laboratory results. The next important question was whether it was possible that the superiority of 1027 A. L. F. over 1A. L.B. in regard to count strength product seen consistently in the Laboratory would be turned into inferiority when both were tested under similar conditions in one individual mill. Though in all cases the samples sent to the Laboratory and to the mills were identical the differences between 1027 A.L.F. and 1.A.L.B. were not visible in the mills. Such was also the case with the Punjab cottons, for the difference of 8 counts (36-28) in favour of 38F over 43F found in Matunga Laboratory was not visible in the mills, though the difference in the case of a very inferior cotton like D. C. 13 was visible. As regards Sind cottons the superiority of 289F₁ (Sind Sudhar) over 285F₂ and 4F-98 of 5 and 14 counts respectively as found in the Laboratory vanished in the mills; the count strength product for 30 counts being 1451, 1623 and 1559 lbs. for 289F₁, 285F₂ and 4F-98 respectively, according to the mill test. In fact 289F₁ (Sind Sudhar) which was a superior variety according to the Laboratory was found to be inferior to the other two in the mills. The second important point was that cottons having a staple length of 0.87" and above with moderate fineness, did not show relation with spinning value in indigenous cottons. This seemed to be true not only for Broach Herbaceum but also for Verum cottons of Jalgaon and probably also of Akola. The consumers paid price for cotton according to the staple length and fineness by hand tests. This method was also practised by the breeders in their selection work. He said that he found from the spinning results of selections made either from the local variety or from crosses, that cottons which had a staple length of 0.87" and above did not show corresponding increase in spinning value. Thus those characters for which the merchants paid a premium when translated into yarns did not give higher spinning value, and on the contrary cottons which had even shorter staple than 1027 A.L.F. sometimes spun better. Thus it will be seen, he continued, that the merchants did not pay sufficient premium for the cottons which would spin better due to the characters unknown for the time being. Thus one more difficulty was as to which characters should be selected for higher spinning because staple length and fineness, which are the usual characters made use of in selection work,

when bred into different crosses succumbed and did not give better quality. Though Surat 1027 A.L.F. was the longest Indian cotton in the whole of India and as regards fineness probably it was not inferior to other Indian cottons, it was not known exactly wherein lay the defect in his cotton whether in length of staple or in fibre maturity to make its spinning performance lower than what it should be, commensurate with its fibre characters. It had, however, been found, he said, that those cottons which were spinning 45 counts were valued at Rs. 40/- higher than Broach and at least Rs. 20/- lower than 1027 having staple characters suitable for 32's only. In other words cotton spinning 45's was valued about Rs. 20/- lower than that which had a staple only for 32's. Really if the former was not marketed at a higher price it was no good to the cultivator. This he said was his contention and the other cotton breeders might consider whether as a result of the improvements which they had effected the premium obtained over the standard basis of Broach was proportionate to the spinning value of their cottons particularly in parity with American cotton. He cited an instance of Broach-Desi 8 cotton which was reported to spin from 37 to 40 counts. Whereas Broach-Desi 8 cotton fetched a premium of Rs. 40/- to Rs. 50 on Broach which is classed as suitable for 16's to 20's only, Broach-Desi 8 actually fetched Rs. 10/- to Rs. 20/- lower than 1027 A.L.F., capable to spin 32's. In conclusion he wished to know whether it was possible to reproduce the results obtained in the Laboratory at least partly or even in some ratio when the representative samples are tested under identical conditions on the same machinery of a single mill so that if the consumers are convinced of getting higher spinning of improved cottons, they would come forward to pay the proper price.

Dr. Nazir Ahmad referring to the points raised by Mr. Patel said that he proposed to deal with them one by one, as it would help to clarify the position. The first point was a comparison of the Laboratory test results with mill test results. This was a point regarding which Mr. Patel wrote to him some time ago. When Mr. Patel compared the Laboratory tests he (Dr. Nazir Ahmad) was not sure if Mr. Patel took into consideration all the factors involved in such a comparison. The exact conditions under which a test was carried out played an important part and for purposes of comparison it was necessary that the different tests should be made under identical or nearly the same conditions. Apart from the difference in the two samples of the same cotton, a difference in the type of machinery used, the treatment given and the settings, speeds, drafts, twists employed would all have an effect on the final result. The difficulty was that whereas in the Laboratory these conditions were perfectly definite, they differed considerably from mill to mill and even in the same mill at different times. Therefore in the very first instance a certain amount of confusion would arise by inadvertently comparing two results one of which was obtained under definite conditions and the other under unknown and possibly different conditions. If Mr. Patel were to give an assurance that the same conditions were maintained in the mills as in the Laboratory the question would become a little easier to tackle. The

strength of the yarns spun from a cotton depended upon a number of factors besides the cotton itself. It depended, for instance, on the settings and twist used in the ring frames or on whether the cotton was spun from double or single roving or whether it was spun on a high draft or the ordinary system. There were a large number of processes through which the cotton underwent from the first machine in the blow-room to the spinning frame and each process was capable of exerting a certain amount of influence on the strength of the yarn. The cumulative effect of these processes might be quite large, and therefore the results of the tests in different mills might show considerable variation.

Apart from this, the mill tests usually were performed on large size samples; either a whole bale or a sample of 200 or 100 lbs. was tested in a mill; whereas in the Laboratory tests were usually made on 10 lbs. samples. Tests could be made at the Laboratory on 100 lbs. samples, but would be difficult for cotton breeders to supply so much lint of each strain and this procedure would result in a severe restriction of the number of strains which the breeders would be able to raise on the limited area at their disposal. Secondly, more time would be taken for testing a 100 lbs. sample and without considerable additions to equipment and staff he (Dr. Nazir Ahmad) would not be able to complete, in the course of a year, tests on so many samples as at present. If he were asked what effect the size of the sample had on the strength of yarns, he would say that the same attention could not be paid to a large as to a small sample. The regularity of the scutcher lap was much greater with a small sample and it was in the scutcher lap that the foundation of the yarn strength was laid. The more regular the lap the stronger the yarn ultimately spun from the cotton. Again the carding was also better with a small than with a large sample, and that factor also tended to give a higher result in the Laboratory. In these respects the Matunga Laboratory was getting similar results as the Shirley Institute which also had come face to face with the same problem. He saw from the report of the Lancashire Indian Cotton Committee for 1935 that they adjudged 289 F as capable of spinning up to 46's standard warp counts but no mill in India would spin this cotton into higher than 30's warp counts. Again, the Sind American and Cambodia were adjudged by the Shirley Institute as capable of spinning up to 46's and 30's respectively, but these estimates were higher than the actual mill practice for the reasons already explained. In the case of short stapled cotton the position might be modified by the fact that a mill might insert a somewhat higher twist while the Laboratory has to adhere to certain standard twists. The strength of yarn as will be seen from a paper which he will read at this Conference depended on the twist inserted and the effect was more pronounced with the short than with the long staple cottons. In order to maintain uniform basis of comparison certain twist standards have been adopted. In the mills, however, they sometimes use fairly high twist multipliers for coarse counts. Therefore, from cottons like Bengals, low quality Oomra or C.P. No. 1 which would spin 8's to 10's in the Laboratory a mill might spin 12's to 14's by inserting more twist. Therefore, unless all those factors

were known it was futile to make any strict comparisons. Even if all the conditions of test in a mill were known, the fact that the Laboratory tests were made on small size samples would introduce a certain amount of difference. The difficulty in estimating the magnitude of this difference was enhanced by the fact that no one or two mills could be regarded as possessing a standard equipment which would represent all. He stated that the conclusion that in all cases the mill results differed from the Laboratory results was not quite correct. He produced data which showed that while there were cases of disagreement, in other cases the Laboratory results agreed closely with the results of mill tests. In order to obviate these difficulties the procedure followed by him nowadays was to request the cotton breeder to send a large sample of the cotton and he arranged for tests with one or two up-to-date mills which possessed equipment. If these tests were carried out in a mill which had inefficient blow-room machinery or the cards or the spinning frames were not properly looked after, quite different results might be obtained.

Another point worth mentioning was that whereas in the Laboratory 50 tests of each yarn sample were made in the mills sometimes only 10 to 20 tests were made so that the mean value was less accurate. This introduced another element of difference. Still another point to be taken into consideration was that while the humidity in the spinning and testing rooms of the Laboratory was maintained between 65% and 70% R. H. during the dry season, in some of the mills sufficient attention was not paid to it while in the others it was regulated properly. The count strength of the yarn depended to some extent upon the prevailing humidity. These sources of differences between the mill and Laboratory were inherent in the nature of the tests and had not been overcome either by the Shirley Institute or by the Matunga Laboratory.

As regards the characters responsible for spinning quality, taking the whole range of Indian cottons from the Bengals up to the best quality Punjab-American cotton, it was known that as a rule the longest staple cotton was capable of spinning the highest standard warp counts. The Shirley Institute found a similar relation for the Empire cottons. The next important property was the fibre weight per inch which was a measure of the fineness of the fibre. Dr. Turner and Mr. Venkataraman analysed the results for over 100 standard Indian cottons covering nearly ten seasons. They found that in 70% cases the spinning performance of a cotton could be predicted fairly accurately from these two properties. It means that the range had now been narrowed down to 30% which is a great step forward. Experiments are being conducted at the Laboratory to solve the mystery of the remaining 30% cases by examining other properties such as wax content, maturity, etc. It was of course possible to select a small sub-range of cottons which proved the exception to a general rule. Mr. Patel had drawn attention to the fact that the correlation seemed to disappear in cottons possessing a staple length of 0.87" and above; and, as small range was important to the cotton breeder, the point deserved investigation.

As regards the third point that cottons selected on the basis of quality did not fetch sufficient premiums in the market it should be remembered that like other commodities, cotton followed the ordinary laws of supply and demand. If there was a variety which was well established in the market, there was always a certain amount of hesitancy in replacing it by another. The well-established variety had, so to say, a vested interest and it offered resistance and it was possible that if a new and better strain might not get the premium which it deserved in the first few years, as time passed the millowners were bound to recognise its merit and purchase it at a sufficient premium. Therefore, it was somewhat rash to be guided by the results of a few years. Impatience in these things did not pay in the long run. He had known cases where a new variety which was sent by him to a mill was so much liked by them that they wanted to know how much of it was available in order that they might purchase the whole lot. If the variety was really very good, it would gain an immediate market; but if the difference was small it would take time for the results to percolate to the millowners. These, he thought, were the four points raised by Mr. Patel, but if there were any points left over, he would be glad to explain or clear them.

Rao Saheb Kottur pointed out that cotton breeders were producing improved varieties of cotton but the millowners were not taking advantage of them. Also in the area under his jurisdiction there were mills in Hubli which had not got even sufficient machinery to carry out proper spinning tests. That was one of the reasons why the grower was not getting better prices for his staple cottons. If there was deterioration in cotton these millowners would raise a huge cry and condemn the Agricultural Department.

The President remarked that the Indian Central Cotton Committee had taken special steps to ensure that reports on technological tests reached as many millowners as possible, in order that the capabilities of new and improved cottons might clearly be brought before them. It had further been decided to appoint a Special Sub-Committee of the technical heads of the Spinning Departments of the various mills to discuss each report as it came out. A proposal was also under consideration for the appointment of a liaison officer on the staff of the Technological Laboratory whose function would be to keep in touch with the various mills.

Mr. Hutchinson stated that at Indore he had no difficulty in correlating the Laboratory tests of plant breeding material with mill results. He was really interested in Mr. Patel's results and would like to ask one or two questions about them. He felt that Mr. Patel's most serious trouble was not so much that the tests of the mills and the Technological Laboratory did not match, but that they did not run in the same order, that was to say, that Dr. Nazir Ahmad was convinced that 1027 A.L.F. was better than 1A whereas the millowners did not see any difference in the valuation between them. It seemed to him quite possible that with the much greater accuracy

than it could possibly be hoped to get in the mills, the Laboratory might be detecting factors which affected the spinning value which were not detectable in the mills. He enquired whether Dr. Ahmad had worked out the correlation between the fibre and spinning properties in the Laboratory data and the mill data and if so whether there was any agreement between the Laboratory and mill data.

Dr. Nazir Ahmad explained that he had not worked out the correlation between the Laboratory data and the mill results, and he doubted very much if it would prove a fruitful line of investigation. Some of the mills were outside Bombay and he did not know all the conditions under which the tests were made. As regards the second point the only satisfactory way of solving it was actually to carry out a well designed experiment by taking half-a-dozen cottons covering a fairly wide range and selecting a few mills and make tests on full bales of the same in the mills and the Laboratory. Otherwise, he feared that data randomly collected would not lead to any definite or reliable conclusions.

Mr. Hutchinson observed that it would appear that in the finer herbaceum cottons with which Mr. Patel was concerned improvements were obtained which Dr. Ahmad expressed as quite definite under Laboratory conditions, for which, however, no corresponding approval could be got in the mills; and even allowing for possible margin for mill tests, unless Mr. Patel could get a premium for the improved quality which the Technological Laboratory data confirmed, Mr. Patel could give up this line of work and go in for yield. That would be really unfortunate. He hoped that it would be possible to see some way of determining what kind of quality it was worth breeding provided it could be arranged with the mills to spin under mill conditions. There again it was a large problem. It appeared as if Mr. Patel was in a serious difficulty from the practical point of view and unless the improved quality fetched a better price Mr. Patel was wasting his time and money.

Dr. Nazir Ahmad explained that if there was a difference of about 4 counts between two cottons in the Laboratory results this would probably not be reflected in the mill test and if reflected at all it would possibly be in the fewer breakages which the mill might get. Supposing one cotton spun 26's and the other 30's in the Laboratory they would use both for spinning 24's in a mill. In one case they might get fewer breakages than in the other. Mills usually proceeded by steps of about 4 counts.

Mr. M. L. Patel asked whether the mills spun two cottons, one local and the other improved, and considered them useful for the same count. The latter would not give higher counts under the same mill conditions.

The President pointed out that there was no mill in Bombay or Ahmedabad to carry out these tests.

Dr. Nazir Ahmad, referring to the differences between 1A Long Boll and 1027 A.L.F., said that 1A Long Boll had a higher ginning percentage with a slightly higher yield than 1027 A.L.F. and the mills were also aware of the difference in the spinning quality of these two cottons. Mr. Kasturbhai Lalbhai, for instance, was definitely against 1A Long Boll. It was a question of appearance also; 1027 A.L.F. was the brighter of the two cottons. The merit of a cotton should be judged by its colour and freedom from neps also and not merely by the count-strength product of its yarn.

Mr. Hutchinson felt that plant breeders were apt to over-estimate the count-strength product and overlook a number of other very important things. Mill opinions might perhaps be reconciled more closely with the Laboratory reports on close examination of some other parts of the tables as well as the count-strength products.

Mr. Mohammad Afzal, endorsing the opinion of Mr. Hutchinson, said that it would not be of much use to go by the Laboratory tests alone. These tests should be used for the preliminary elimination of strains. When two or three best strains have been selected, the breeder should arrange for a mill test through Dr. Nazir Ahmad. The final selection of the best strain should be made from Dr. Nazir Ahmad's opinion coupled with the mill opinion. He cited his experience with Lyallpur 43F and 38F. Several new strains were tested at Lyallpur for four or five years and from these tests 43F and 38F appeared to be the most promising. At this stage Dr. Nazir Ahmad was requested to arrange for a mill test of both these cottons which he very kindly did. Final selection of 43F was made by taking into consideration both the Laboratory and mill tests. Referring to Jubilee cotton he said that he sent a small sample to Dr. Ahmad, another to the Shirley Institute and a bale to a mill. The three tests agreed quite well. What he wanted to stress was that the breeders at the end of their tests of a definite strain must always get the mill opinion.

Mr. Nanjundayya, referring to Mr. M. L. Patel's statement, that he (Mr. Patel), improved the length of cotton but did not get a proper price, wished to know how Mr. Patel had assessed the fineness.

Mr. M. L. Patel replied that it was based only on the fibre weight per unit length.

Mr. Nanjundayya explained that the fibre weight per unit length was a complex of two quantities, viz., the original cell diameter and the degree of thickening. Strictly speaking in defining fineness one had to take into account the wall-thickness in relation to the cell diameter, though it has not been possible to adopt it in routine fibre tests. It was, however, interesting to note that Peirce and Lord had found that fineness of cell was the primary determinant of yarn strength. In evolving new strains the breeders generally attach the greatest importance to the length of staple,

fineness being incidental. It had been shown that long staple cottons were more uniform in diameter and the short staple more uniform in length. In the case of both the long and short staple cottons, it would appear that breeding for fineness with due regard to maturity factor would pay at least for the latter. It was a well-known fact that of two cottons, having the same length and fibre-weight per unit length, the one with a small diameter with normal maturity was better than the one which had large cell diameter and less thickening. He suggested that Mr. Patel might try to breed for intrinsic fineness, i.e., cell diameter. It would be seen, he continued, from Dr. Turner's bulletin on the "Ginning percentage, Lint Index, etc.," that the variation in weight along the length of a single fibre was enormous for Surat 1027 A.L.F. It might be worth while for Mr. Patel to go into this point as uniformity in any fibre property would be a valuable asset.

Mr. M. L. Patel said that the breeders could not be expected to study the hair weight along the varying length of fibre. They had to go by the average fibre weight. If variation in weight along the length of a single fibre was the character which determined the spinning value of a cotton it would be of no use to breeders for selection for higher counts. When a new cotton was introduced in a tract it got a premium not in the beginning but later on when it got established. He pointed out that 1027 A.L.F. had been introduced in Surat district for the last ten years and was well known to the consumers and still in spite of the increasing production of this cotton from year to year the millowners were not paying more premium for Surat cotton. As Mr. Hutchinson had put it the point for consideration was not the sole difference between the spinning value of the mills and the Laboratory but the relative spinning capacity of the two types, the local and the improved. In one single mill the improved type B.D.8 gave consistently better results than the local one. It was capable of spinning 40's against the 14's to 16's of the local, and premiums paid for it were only Rs. 40/- to Rs. 50/- and that too with the best organisation to market it. These were the actual facts which had to be faced in introducing new cottons. There was urgent necessity to convince consumers of the real spinning value of the improved types as they would not offer good prices till they were convinced of their real value. So long as there was a particular type of cotton which spun high counts he did not understand why they bought American cotton and paid higher prices for the same counts.

Mr. Mohammad Afzal pointed out that Mr. Patel was confusing the issue when he talked of prices merely in relation to spinning performance. Several factors are responsible and the spinning performance is only one of them. He cited the case of 47F and 43F. The former would spin 50's while 43F is capable of only 40's. But 43F is a much brighter cotton and gets better prices. Sometimes, however, proper premiums could be obtained corresponding to the improvement in spinning quality. He instanced the case of Jubilee cotton which could spin 18's as compared

to 6's to 8's of Mollisoni and said that the former was selling at practically the same price as 4F. It would thus appear that proper premiums could be obtained when any spectacular improvement was shown in the spinning quality, but otherwise in the case of minor improvements it would be some time before the mills got to know of the real worth of the cotton and pay proper premiums. He continued that it took four years for the merits of 43F, which could spin 40's against 20's of 4F, to be properly appreciated. Selling at a discount over 4F two years ago, 43F was now fetching a premium of about a rupee per maund over 4F. Still the premium was not commensurate with its spinning quality.

Mr. Ramanatha Ayyar, remarking that the experience in Madras was different from that of the Punjab, said that Karunganni strains introduced about 30 years ago, which could spin 28's against 14's of ordinary Uppam, were not getting the proper price though spinners had been well aware of the improvement effected in spinning quality.

Mr. V. G. Panse, endorsing the remarks of Mr. Ramanatha Ayyar, said that in Central India the Cambodia variety which was introduced about 20 years ago, with a spinning capacity of 20's against 10's to 12's of local cotton, was not getting more than 15% premium over local cotton, though the improvement in the spinning capacity was 70 to 80%.

Mr. Hutchinson observed that it appeared to him that many breeders had got an exaggerated idea of the value of the improved quality to the spinner. He said that there was no question that Cambodia cotton in Central India was getting the full premium as based on world market rates. 15% premium was all that it was worth to the spinner because he could import cotton from America or Kampala at a cheaper rate. He thought that the cotton breeders must cut down very considerably their idea of the commercial value of an increase in the spinning performance.

Rai Sahib Kalidas Sawhney, concurring with Mr. Hutchinson, said that a difference of a few counts between local cotton and an improved type might be quite definite and marked to the breeders whereas it might not so appear to the mills. This, he explained, was due to the fact that some of the mills specialised only in spinning certain counts, say, 20's, and if cotton capable of spinning 30's was offered to them they would not pay more than what they would pay for a cotton spinning 20's, for they did not spin 30's. But that did not mean that there was any defect in the cotton. He expressed his opinion that it would be more paying to the cultivators if marked improvement was effected in the yield of cotton provided the spinner did not get any cause for complaint as to the spinning performance of that particular variety. For example, if a mill spun 24's and if an improved cotton which could spin 24's was supplied, the mills would have no complaint and the cultivators would be much more benefited by improving the yield of cotton.

Dr. Burns pointed out that the only thing that mattered was the price and if Sind or American happened to be cheaper they would be bought in preference to 1027 A.L.F., though it was a first class cotton.

Mr. M. L. Patel expressed the view that if colour or any other character of the lint would compensate for the spinning value the breeders should go in for that character. He, however, desired to know whether it would be a permanent feature that better coloured cotton would fetch a better price or would be equal to the spinning value of certain number of counts of the improved quality. In his opinion the breeders should introduce that character which would fetch a premium.

The President in summing up the discussion said that it appeared to him that cotton breeders must be careful to distinguish between the marketing of cotton and the prices quoted in a particular year from the intrinsic value of cotton as shown by actual spinning tests. This was quite distinct from the question of the difference in test results obtained in individual mills and in the Technological Laboratory. The value of any cotton for a particular year was affected by the supply of that cotton in relation to the demand for it. For example, during the last few years there had been a wide fluctuation between the price of the Broach contract and the prices of American cotton in Liverpool or New York. Merchants normally took Broach as being approximately equivalent to 90% of the quotation for strict low middling American in Liverpool for the corresponding date and took this as the export parity, but experience showed that this percentage though approximately correct on the average had varied from about 80 to 95 over a series of years. Secondly there was at present an import duty on American cotton which meant that any cotton which would spin above a certain count tended to obtain a marketed premium over cotton which would not spin quite so high a count. There was a definite gap in the relation of prices for different varieties which neither mill reports nor technological reports could entirely explain. The object of the Laboratory was to assist cotton breeders and agricultural departments generally in planning a long term policy, for cotton breeding was necessarily a slow process. Much had been said about the cotton breeder adjusting his policy to supply and demand but in point of fact it took something like fourteen years to create a new cotton and bring it into general cultivation. The Laboratory assisted cotton breeders by testing cotton under standard conditions, both to compare cottons with each other and to ascertain how individual cottons varied from year to year.

When making any comparison between the results of mill tests and tests in the Spinning Laboratory it must be borne in mind that mills differ greatly both in machinery and in efficiency and moreover mill requirements vary from year to year. Any mill manager's opinion of a cotton was apt to be biased by the state of the cotton market at the moment.

Every cotton breeder needed in the first place to know which of the many strains on which he was working were worth continuing and multiplication. As the result of many years' work directed to ascertaining which of the measurable characters of cotton were of importance in determining its spinning quality, Dr. Turner, and subsequently Dr. Nazir Ahmad, had arrived at a prediction formula. As pointed out by Dr. Nazir Ahmad, fibre weight and fibre length were of predominant importance in judging a new cotton when a large range of cottons was taken into account. Working in a narrow range other characters had to be considered and the Laboratory was now studying other characters of cotton in relation to spinning quality. There was, however, every possibility of the physical properties of Indian cottons being of great importance in distinguishing between the first and second best of a particular group. This of course was a further refinement, the first object of the Laboratory was to ensure that no cotton with unsatisfactory spinning characters was introduced into general cultivation.

Dr. Nazir Ahmad, referring to Rai Sahib Kalidas Sawhney's point about going in predominantly for yield, said that so far as prices were concerned there was a tussle between the grower and the consumer and which ever side won the Laboratory seemed to get the blame from the other side. He considered that it would be a retrograde step to neglect quality and to fix all attention on high yield and ginning out-turn and that he would require very strong arguments to change his opinion. A factor which would give an indication as to the type of cottons that would be required more and more was the trend in the manufacture of yarns of different counts. The relevant figures for India and Japan were indeed illuminating. In India during the period 1914—1935, while the production of counts 1—10's and 10—20's remained practically steady the production of 21's to 30's went up from 156 million lbs. to 287 million lbs., 30-40's from 80 million lbs. to 112 million lbs., and above 40's from 200 to 258 million lbs. The net result of disregarding quality would, therefore, be that the Indian mills would import more and more of American and African cottons to supply their needs for counts above 20's. The same was the case with Japan. During the same period the production of 1 to 20's counts increased from 534 to 634 lbs., 21 to 40's from 143 to 632 million lbs. and above 40's from 46 million to 157 million lbs. As Japan was India's best customer importing about 1½ million bales every year it would be a mistake to disregard quality as Japan would then turn to other markets for her supplies.

Rai Sahib Kalidas Sawhney, rising on a point of explanation, as his observations seemed to have been misunderstood, said that what he meant was that in improving the cotton of a particular area attention should first be concentrated on the improvement in lint yield without losing anything in the quality which was already grown. At the same time, he continued, he did not mean to say that attention should not be paid to quality. Spinning tests of the Laboratory would be helpful in

deciding the difference between the improved strain and the strain already existing. As a matter of fact improvement of quality arose at a later stage only when no other improvement could be effected. Another difficulty met with in improving the quality was that as soon as the object was achieved, say in the case of Gaorani spinning 30's, it not only lost certain of its original characters thereby but also came into competition with a very large production from America and Africa. As a result when there were fluctuations in the production of American cotton it was very difficult to ensure a proper premium for it. To put it more clearly if the spinning quality of Gaorani, whose production was about 100,000 bales, was increased to 40's it would come in competition with good cotton of other countries, probably resulting in a lower price for both.

Dr. Nazir Ahmad observed that while each case should be decided on its merits after due consideration of all the points, his opinion was that at a time when other countries were devoting considerable attention to improvement of quality this aspect of cotton breeding must not be neglected in India.

COTTON TECHNOLOGY

Paper No. 1.

INFLUENCE OF TWIST ON YARN STRENGTH

BY

NAZIR AHMAD AND V. VENKATARAMAN.

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I. INTRODUCTION.

It is a well known fact that the insertion of twist in the roving is one of the integral processes in the manufacture of yarns. As the cotton fibre itself is only about an inch or at the most two inches long, it has to depend on twist as a binding factor. The number of turns per inch in a yarn will thus determine the extent to which the hairs will adhere to one another in a roving or a yarn. In the former the twist inserted is just enough to hold the fibres together, which can therefore be pulled apart easily. In the latter, however, owing to the greater twist inserted, it is not possible to separate the fibres so easily. In other words, whereas in a roving

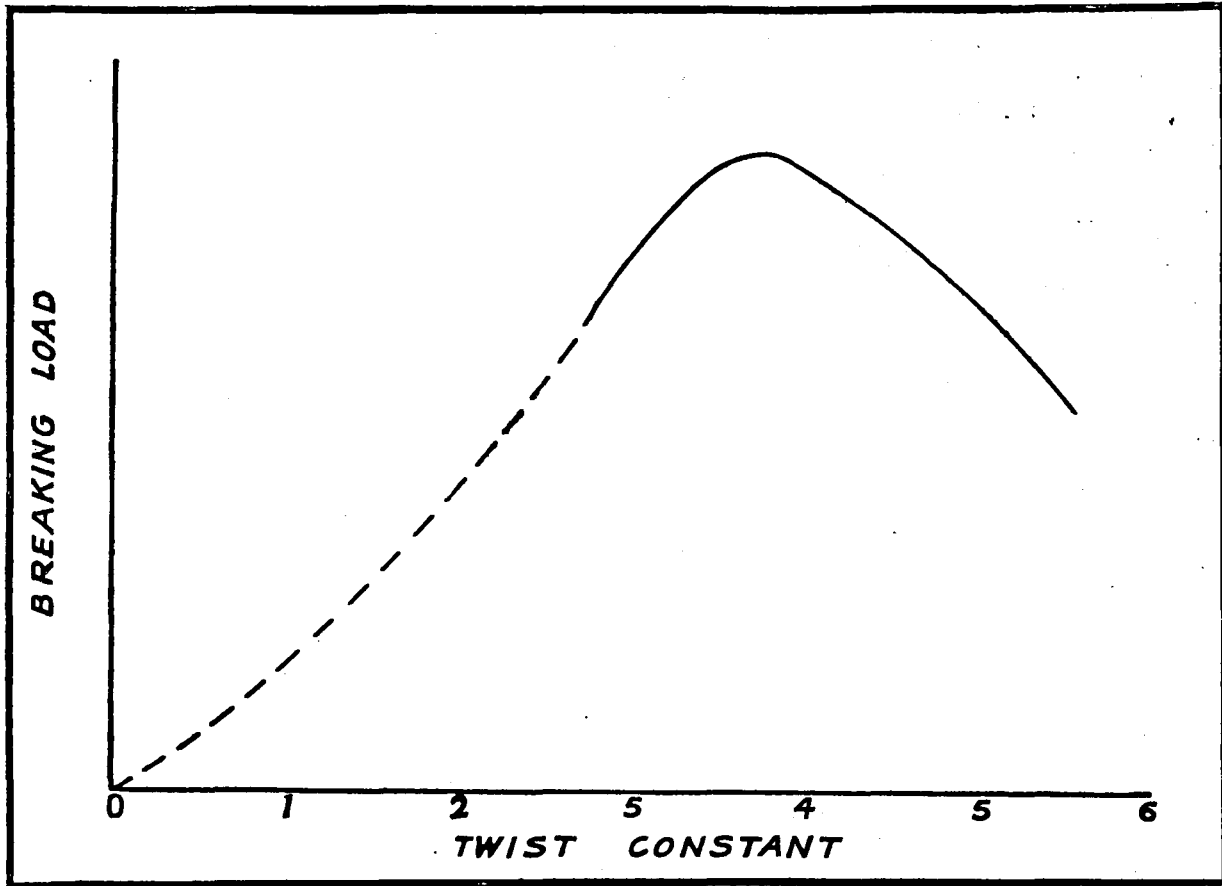
under tension most of the fibres slip, in an ordinary yarn, most of them break and only a few slip, the relative proportion of the two depending upon the twist inserted. Beyond a certain limit no fibres at all will slip and the insertion of further twist will not add anything to the grippage of the fibres in a yarn.

If very little twist is inserted in a yarn the angle made by the fibres with the axis of the yarn is nearly equal to zero and no strain is required to pull the yarn apart. When twist is inserted, the fibres are bent spirally and make an angle with the axis of the yarn, which increases with the degree of twist. The limit up to which this angle could be advantageously increased so that all the fibres in the yarn break is called the limiting angle and the number of turns per inch inserted is called the limiting twist. If the twist is increased beyond this limit the yarn begins to curl and loses its feel. Eventually the yarn-strength ceases to increase and begins to decrease. Thus, beyond a certain limit, twist has an adverse instead of a beneficial effect, and it becomes a matter of the greatest practical and theoretical importance to find out this limit for different cottons and different types of yarns.

Twist is never uniform along the length of a yarn, which breaks under tension at its weakest point. The number of turns at one point may be as much as two to three times that at another point in an ordinary commercial yarn. Thus, besides the average value, the distribution of twist along a yarn is the next important factor. The irregularity in twist is caused by several factors such as variation in the fibre-properties, the variation in the number of fibres in a cross-section of the roving, the variation in the spindle speed, etc. Some of these factors are peculiar to the cottons, while others depend upon the treatment given. Thus, the uniformity of the roving and consequently the regularity of twist can be improved by blending the fibres by combing, doubling and redoubling, etc. In a comparison of the effects of twist, therefore, it is necessary that these factors should be kept as nearly constant as possible. The results of an investigation carried out to determine the effects of twist on the properties of yarns spun from certain short-medium, medium-long and long-staple cottons is described in this report.

II. PREVIOUS WORK.

Morton¹ found by direct experiment on 15 cottons that the shape of the curve is as in Fig. 1, which represented the relation between twist and strength. It showed that the strength increased up to a certain limit and thereafter began to fall down. He² further examined the various factors which are responsible for this particular shape. He found that the pressure set up by the twist between two fibres, the clinging power and the nature of the fibre-surface including hair convolutions are some of the factors which determine the effectiveness of the binding factor. He further opined that the efficiency of spinning is also an important factor in determining the form of this curve.



(Fig. 1)

Oxley³ has also drawn similar curves and considered in some detail the nature of the relationship that exists between the number of turns per inch and the tensile strength of yarns. The effects of twist on cotton yarns of Middling cotton are shown graphically in a paper by Mercier and Schoffstall,⁴ who point out that the maximum strength in lea-test is reached at a twist-multiplier of about 4.25, whereas in the single-thread testing the maximum is reached at a twist multiplier of 5.25. This has been partially explained on the ground that the single thread result represents the average of high, low and medium values while the lea strength is an average of medium and low breaks of the threads composing the lea. Wardell⁵ found for a 20^s yarn spun from Upland cotton, 1- $\frac{1}{8}$ " in staple, that the limit twist factor was 4.75, that the elongation and contraction increased with the twist and that the yarns of maximum strength were also the most uniform. Eiben⁶ after discussing the various factors which modify the strength of yarns with the insertion of twist, gives a formula of limited application for the critical co-efficient of twist.

Thus, it will be seen that although considerable work has been done, it has not so far been possible to lay down a general formula which should give the optimum twist constant from a knowledge of the fibre-properties of a cotton and the treatment given to it. At present, this constant must be determined in each case by actual trials. That it varies with the class of the cotton is a matter of common experience. Morton² found from his tests on fifteen cottons of about 1 1/16" staple, spun into 24^s counts, that the optimum twist constant for the maximum lea test lay between 3.4 and 4.4 and between 3.4 and 3.8 for 10 out of these 15 cottons. Single thread tests showed higher optimum twist constants for the same cottons, 14 out of 15 gave values lying between 4.1 and 4.7. He also found that single thread strength irregularity increased by 43 per cent when the twist constant was increased from 4 to 7. Forseith obtained the value of about 4.5 for 13^s yarns spun from 7/8" strict Middling Uplands. Balls⁷ using a series of 13 cottons slightly longer than 1 1/16" staple, found the optimum twist constant to be of the order of 3.75 as determined by the single thread test, while Winterbottom's tests on 20^s combed yarn spun from Brown Egyptian gave a value of 5. In the Technological Laboratory⁸ the maximum strength for any one count of Cambodia cotton within the range of 20^s and 60^s, was given by using one or other of the twist constants 4.25 or 4.5, but with the shorter cotton, Mollisoni, spun within the range 6^s and 16^s, the strength went on increasing up to the twist constant 5, which was the highest used.

There is one aspect of the effect of twist on yarn strength to which a reference should be made here. Probably in a majority of cases, such fabric properties as appearance, feel, uniform dye absorption, durability, etc., are more important than mere strength. Thus, a stronger cloth need not necessarily be a better cloth and the stronger yarn does not always give a stronger cloth. Corser and Turner⁹ found that, in certain structures of cloth, single as well as double yarns should be soft twisted

to produce the strongest fabric. In many cases, the twist which gives the strongest yarns does not necessarily yield the strongest cloth while mere tensile strength in cloth may be incompatible with other desirable properties. For instance, in some cases, extensibility is more important than strength itself, while in others softness may be more desirable. While a full discussion of these points is beyond the scope of this investigation, it is necessary to bear in mind the fact that there are other qualities besides tensile strength which also constitute criteria for assessing the merit of a yarn or a fabric.

III. SCOPE AND OBJECTS OF THE PRESENT WORK.

In the present tests, the cottons have been divided into three classes: (i) short-medium staple, (ii) medium-long staple, and (iii) long staple. They were spun into suitable counts with varying twist constants in order to find out whether it would be possible to demarcate the optimum twist constant for each class; bearing in mind the other properties such as fibre-weight, convolutions, hair-friction, hair-strength etc.

We should also state here that effects due to twist are somewhat different for the carded and the combed yarns. We know that the combed yarns are more regular, their fibres are better arranged, they lie more nearly parallel and straighter, are more uniformly mixed and contain a smaller percentage of shorter fibres. Thus the combed yarns may be expected to require less twist for attaining the maximum strength. In order to study the effects of twist on combed yarns as well, the two long-staple cottons, Egyptian Giza 7 and Sind Sea Island, were spun both into carded and combed yarns with varying twist constants.

The primary object of this investigation is to find out the limiting twists for the different counts of (i) short-medium staple, (ii) medium-long staple, and (iii) long staple cottons which would yield the best strength results. The investigation is restricted to the variation of twist in the ring-frames only, and is thus an extension of an earlier work done on two cottons, Cambodia and Mollisoni, which is described in a previous bulletin.⁸ Furthermore, in the case of two cottons, yarns were also spun with the same twist into different counts to estimate the slippage factor.

IV. COTTONS USED IN THE TESTS.

The first series of experiments, an account of which was published in *Technological Bulletin*, Series A, No. 17, were carried out on the two Indian cottons Cambodia Co. 1 (295), which is a fine medium-long staple cotton from Madras Presidency, and Mollisoni which is a coarse and short-staple *Desi* type of Northern India. In the present series of experiments, P. A. 4F and Superfine Oomra were chosen to represent the short-medium staple varieties; A. R. Kampala, A. R. Busoga and A. R.

Jinja to represent the medium-long staple varieties, and Sind Sea Island and Egyptian Giza 7 to represent the long staple varieties. The results of the fibre tests on these cottons are given below.

TABLE I.
Fibre Particulars.

1. Fibre-Length Distribution (Balls Sorter):							
Mean group-length in eighths of an inch.	Percentage.						
	SHORT-MEDIUM		MEDIUM-LONG			LONG	
	P. A. 4F	Super- fine Oomra.	A. R. Kampala	A. R. Busoga	A. R. Jinja	Sind Sea Island.	Egyptian Giza 7
2	1.3	..	0.1	..	..	0.9	..
3	3.0	3.2	0.8	1.6	0.9	1.4	0.9
4	6.5	9.2	1.8	2.4	1.6	2.8	2.4
5	15.8	28.0	3.3	3.0	2.2	4.3	3.6
6	28.5	39.7	5.5	4.9	4.0	6.0	4.7
7	31.5	16.0	11.5	9.8	6.8	8.5	7.3
8	10.8	3.9	21.9	18.6	13.7	11.4	12.5
9	2.6	..	25.9	26.1	24.9	15.6	18.9
10	..	..	18.2	20.8	24.6	17.9	24.8
11	..	..	8.0	9.6	14.6	15.9	15.6
12	..	..	3.0	3.2	5.4	9.9	6.9
13	..	..	..	..	1.3	4.0	2.4
14	..	..	..	..	..	1.4	..
2. Mean Fibre-Length (inch):							
(a) By Balls Sorter	0.77	0.71	1.07	1.08	1.14	1.14	1.14
(b) By Baer Sorter	0.78	0.73	1.07	1.08	1.12	1.16	1.14
3. Mean Fibre-Weight per inch (millionth of an ounce)							
	0.143	0.219	0.142	0.142	0.135	0.118	0.135
Mean Fibre-Strength (oz.)	0.144	0.224	..	..	..	..	..
Clinging power (oz.)	0.00736	..	..	..	..	..	..

It will be seen that the short-medium cottons are about $3/4$ " long, those in the medium-long group are from $1\ 1/16$ " to $1\ 1/8$ " long, the Jinja cotton being somewhat longer than the other two cottons, while those in the long staple group are longer than A. R. Kampala and A. R. Busoga. Thus, these cottons cover a range of $3/4$ " to $1\ 1/6$ ". The range of fibre-weight per inch, excluding Superfine Oomra and Sind Sea Island, is much narrower, all these cottons possessing values of about $.140 \times 10^{-6}$ oz. Superfine Oomra is much coarser, while Sind Sea Island is somewhat finer than the others.

V. EXPERIMENTAL DETAILS.

The details of the machinery employed in these tests are given in another bulletin.¹⁰ The blow-room treatment was different for some of the cottons than for others as follows: The samples of 4F and Superfine Oomra were passed through Lattice Feeder, Crighton Opener (twice), Hopper and Scutcher (3 times), those of the three African cottons were passed through Hopper bale opener, Horizontal cleaner, Crighton, Gridded dust trunks, Cage exhaust, Hopper feeder and Scutcher (twice), while the long staple cottons were passed through the Hopper bale opener, Horizontal cleaner, Gridded dust trunks, Cage exhaust, Hopper feeder and Scutcher (once only). The samples of short-medium, and medium-long cottons were given two heads of drawing and spun from single hank roving, while those of the long staple cottons were given three heads of drawing and in 60's and higher counts were spun from double hank roving. The comber loss for each of these two cottons was about $15\frac{1}{2}\%$.

The procedure adopted was as follows: The 35 lbs. sample of 4F was divided into four portions behind the slubber to give four nominal hank rovings, *viz.*, 3.5, 4.3, 4.8 and 5.4. These were spun into counts ranging from 20's to 36's with twist constants varying from $3\frac{3}{4}$ to $5\frac{1}{2}$. A similar sample of Superfine Oomra was divided into five nominal hank rovings, *viz.*, 1.7, 1.9, 2.4, 2.5 and 3.1 and spun into counts ranging from 8's to 16's with twist constants varying from 4 to $5\frac{3}{4}$. The three African cottons were spun into 40's counts only using the twist constants, $3\frac{1}{2}$, $3\frac{3}{4}$ and 4, while Giza 7 and Sea Island were spun into 50's and 60's carded and 60's and 70's combed yarns with twist constants varying from 3 to 4. Thus, it will be seen that as regards the cottons, counts and twists, a fairly wide range has been covered. Furthermore, 4F and Oomras were spun with a constant number of turns per inch into different counts in order to study the variations in strength, etc., due to a variation in counts alone.

VI. DISCUSSION OF RESULTS.

The yarns obtained were examined for evenness,lea breaking strength, single-thread strength and ballistic work of rupture. The methods employed in these tests are described in another bulletin.¹⁰ We shall now discuss these results according to each yarn characteristic.

(1) *Yarn Breakages.* [Table II.]

(i) *Short-medium staple cottons, 4F and Superfine Oomra.*—Yarn breakages in the ring frame would be expected to increase with the counts and decrease with twist. These effects are more strongly marked with Superfine Oomra than P. A. 4F. In the latter cotton, the breaks are comparatively few up to 26's counts, but are fairly numerous in 30's and the insertion of twist up to a twist multiplier of 5 does not reduce their number. In the 36's, however, higher twist is associated with fewer breaks. Both 30's and 36's are beyond the spinning capacity of this cotton, and the use of hard twist does not apparently bring the number of yarn breaks within the economic limit. With Superfine Oomra the number of yarn breaks is quite small in 8's and 10's counts. In 12's counts the breaks are fairly numerous up to a twist multiplier of $4\frac{1}{2}$, but there is a gradual decrease until for twist multiplier $4\frac{3}{4}$ and higher for which they are quite few. Thus $4\frac{3}{4}$ may be considered as a suitable constant for spinning this cotton into 12's/14's counts. In 16's counts the number of breaks also shows a decrease with increasing twist, but even with the highest twist multiplier used, the number is outside the limit of economic spinning.

(ii) For the three medium-long staple cottons A. R. Kampala, A. R. Busoga and A. R. Jinja, the use of any of the three twist multipliers $3\frac{1}{2}$, $3\frac{3}{4}$ or 4, for spinning 40's counts did not make any appreciable difference to the number of yarn breaks in the ring frame, which were few in each case.

(iii) When we examine the number of yarn breakages in the ring frame for the long staple cottons, Giza 7 and Sea Island, we find that there is a downward trend both for carded and combed yarns as the twist constant is gradually increased from 3 to 4. However, the rate of decrease is very small for twist multipliers beyond $3\frac{1}{2}$ which may, therefore, be regarded as a suitable constant from this point of view.

(2) *Yarn Evenness.*

In considering the results for evenness class it should be remembered that the estimate of evenness is based upon a hand and eye examination of the yarn and therefore cannot be so accurate as the determination of other yarn characteristics which is done with the help of suitable instruments. These results of yarn examination for evenness are given in Table III. It will be seen that in 26's Punjab-American 4F gave fairly even yarns up to a twist multiplier of $4\frac{3}{4}$, but that with higher twist multipliers the yarns became fairly even to uneven. Although the 30's yarns were fairly even, yet the 36's yarns again were fairly even to uneven no matter which twist multiplier was employed. Thus, the use of an excessively high twist multiplier tends to reduce the evenness of yarns of this cotton or at least

TABLE II.

Ring Frame Yarn Breakages per 100 spindles per hour.

Cotton.	Counts.	Twist Multipliers.											
		3	3½	3½	3¾	4	4½	4½	4¾	5	5½	5½	5¾
P.A. 4F	20	..	..	..	0	16	0	..	10	..	..	..	..
	26	..	..	..	..	12	4	20	12	24	8	4	..
	30	..	..	..	..	..	36	17	53	50	..	..	..
	36	..	..	..	..	..	..	55	42	23	47	..	..
Superfine Oomra	8	..	..	..	..	0	11	..	..	0	..	..	..
	10	..	..	..	..	9	27	0	..	..	..	..	..
	12	..	..	..	..	65	51	36	0	29	15	15	29
	14	..	..	..	..	..	..	36	15	22	..	..	..
	16	..	..	..	..	..	..	..	206	182	91	..	..
A. R. Kampala	40	..	..	4	15	5	..	..	..	..	..	..	..
A. R. Busoga	40	..	..	2	0	0	..	..	..	..	..	..	..
A. R. Jinja	40	..	..	7	12	10	..	..	..	..	..	..	..
Giza 7	<i>Carded</i>	50	32	18	14	13	5	..	..	..	..	..	..
	..	60	64	55	23	16	14	..	..	..	..	..	..
	<i>Combed</i>	60	27	6	18	14	15	..	..	..	..	..	..
	..	70	25	27	18	14	12	..	..	..	..	..	..
Sea Island	<i>Carded</i>	50	50	42	10	8	9	..	..	..	..	..	..
	(Sind)	60	50	52	18	15	23	..	..	..	..	..	..
	<i>Combed</i>	60	27	23	12	3	18	..	..	..	..	..	..
	..	70	15	22	15	12	21	..	..	..	..	..	..

does not bring about any improvement. Unlike P. A. 4F, Superfine Oomra did not show these effects to an equally marked extent. It gave even to fairly even 8's, but fairly even 10's and 12's, no matter which twist multiplier was used. In the two higher counts the yarns were fairly even to uneven, showing that even if they attain sufficient strength by the use of excessive twist, they are undesirable on account of their poor evenness class.

For the medium-long staple cottons, the yarns spun with twist-multiplier 4 appear to be somewhat more even than those obtained with the other two twist multipliers. Between the other two twist multipliers there is not much to choose as with A. R. Busoga $3\frac{3}{4}$ gave more even yarns than $3\frac{1}{2}$ while with A. R. Kampala, the lower twist multiplier gave the more even yarns. Thus, within the small range of twist multipliers employed for these cottons, the yarn evenness is only affected to this extent that the twist multiplier 4 gives slightly more even yarns than the others.

The two long staple cottons, Giza 7 and Sea Island, gave equally even yarns in each count irrespective of the twist constant employed between the range 3-4. This holds both for the carded as well as the combed yarns.

(3) *Lea Strength.*

The values of the lea strength corrected for actual counts and humidity are given in Table IV for the short-medium, medium-long and long staple cottons.

(i) *Short-medium staple cottons, P. A. 4F.*—It will be seen that in 20's counts the strength increases by about 10 per cent when the twist constant is raised from $3\frac{3}{4}$ to $4\frac{1}{4}$. But with a twist constant of $4\frac{3}{4}$ the strength has suffered a decline. Thus $4\frac{1}{4}$ or $4\frac{1}{2}$ may be taken as the optimum twist constant for spinning this cotton into 20's counts. In the higher counts of 26's, however, the strength varies within the small range of 3 lbs. when the twist constant is gradually raised from 4 to $5\frac{1}{2}$, with a peak value at $4\frac{1}{2}$ or $4\frac{3}{4}$. Similarly, in the 30's and 36's counts the peak value is obtained with a twist constant of $4\frac{1}{2}$, while the variation in strength is again very small. Now both 30's and 36's are definitely outside the spinning capacity of this cotton, while under mill conditions it is extremely doubtful if it would spin satisfactory 26's. We thus find that, if this cotton is spun above its spinning capacity, the insertion of extra twist beyond that given by a twist factor of $4\frac{1}{2}$ does not appreciably increase its lea strength, while for the counts for which it is ordinarily regarded suitable a twist multiplier of $4\frac{1}{4}$ to $4\frac{1}{2}$ gave the peak value of lea strength.

TABLE III.

Mean values of "Evenness Class."

Cotton.	Counts.	Twist Multipliers.											
		3	3 $\frac{1}{2}$	3 $\frac{1}{2}$	3 $\frac{3}{4}$	4	4 $\frac{1}{4}$	4 $\frac{1}{2}$	4 $\frac{3}{4}$	5	5 $\frac{1}{4}$	5 $\frac{1}{2}$	5 $\frac{3}{4}$
P. A. 4F	20	..	..	..	4	4	4	..	3	..	..	..	..
	26	..	..	..	..	5	5	5	5	6	6	5	..
	30	..	..	..	..	..	5	5	5	5	..	..	..
	36	..	..	..	..	..	..	6	6	6	6	..	..
Superfine Oomra	8	..	..	..	..	4	4	..	..	4	..	..	..
	10	..	..	..	..	5	5	5	..	..	..	..	..
	12	..	..	..	..	5	5	5	5	5	5	5	5
	14	..	..	..	..	..	..	6	6	6	..	..	..
	16	..	..	..	..	..	..	..	6	6	6	..	..
A. R. Kampala	40	..	..	5	6	5	..	..	..	..	..	..	..
A. R. Busoga	40	..	..	6	5	5	..	..	..	..	..	..	..
A. R. Jinja	40	..	..	6	6	5	..	..	..	..	..	..	..
Giza 7	<i>Carded</i>	50	5	5	5	5	5	..	..	..	..	..	..
	"	60	6	6	6	6	6	..	..	..	..	..	..
	<i>Combed</i>	60	3	3	3	3	3	..	..	..	..	..	..
	"	70	4	4	4	4	4	..	..	..	..	..	..
Sea Island (Sind)	<i>Carded</i>	50	4	4	4	4	4	..	..	..	..	..	..
	"	60	4	4	4	4	4	..	..	..	..	..	..
	<i>Combed</i>	60	3	3	3	3	3	..	..	..	..	..	..
	"	70	4	4	4	4	4	..	..	..	..	..	..

Superfine Oomra.—Unlike 4F, in Superfine Oomra the lea strength registers an increase at almost every step as we proceed from the twist multiplier 4 to $5\frac{3}{4}$, the only exception being the 12's yarns spun with $5\frac{1}{2}$ and $5\frac{3}{4}$ twist multipliers. In 8's counts there is an increase of 17 per cent when the twist multiplier is raised from 4 to $4\frac{1}{2}$ and an increase of 80 per cent when it is raised to 5, in the 10's counts an increase of about 60 per cent from 4 to $4\frac{1}{2}$ twist multiplier; while in 12's counts the increase is about 80 per cent with a change in twist multiplier from 4 to $4\frac{1}{2}$ and a maximum increase of 130 per cent when a twist multiplier of $5\frac{1}{2}$ is used. It will be seen that the lea strength increases very rapidly at first, but more slowly as we go higher up in the scale of the twist multipliers until after $5\frac{1}{4}$ it is practically constant. Evidently, at this point the slippage tendency of the fibres has been stopped. In the 10's counts a twist multiplier of $4\frac{1}{2}$ may be regarded as sufficient to give yarns of satisfactory strength, but if this cotton should be spun into 12's a twist multiplier of at least 5 is necessary. In the higher counts of 14's and 16's even a twist multiplier of 5 to $5\frac{1}{2}$ does not give sufficiently strong yarns, although the yarn strength continues to increase. These counts are evidently beyond the capacity of this cotton, and the use of excessive twist would probably introduce certain undesirable features.

We will now discuss the results obtained for the yarns which were spun into different counts, keeping the number of turns per inch constant for each count. These yarns ranged in counts from 20's to 32's with 21.25 turns to the inch for P. A. 4F, and from 8's to 14's with 14 turns to the inch for Superfine Oomra.

When the rupture of a yarn at a point takes place, a certain fraction of the fibres present in the cross-section break, while the others merely slip past one another. The relative proportions of the fibres which snap and those that slip depend principally upon twist, type of cotton and actual count. The force required to break a yarn is, therefore, spent partly in breaking a certain fraction of the fibres and partly in pulling the remaining fibres apart. If

N = Total number of fibres in the cross-section at the point of rupture of the yarn

p = the fraction of fibres which break

S = the strength of individual fibre

T = the single thread strength of the yarn, then

$$T = p \cdot N \cdot S + (1-p) N \cdot f \quad (1)$$

where f = the force required to pull apart the fibres which do not break.

At ordinary twists the force required to break the fibres will far exceed that required to pull them apart. Consequently the first term on the right hand side of

TABLE IV.

Lea Strengths (lbs.) corrected for humidity and counts.

Cotton.	Counts.	Twist Multiplier.											
		3	3 $\frac{1}{4}$	3 $\frac{1}{2}$	3 $\frac{3}{4}$	4	4 $\frac{1}{4}$	4 $\frac{1}{2}$	4 $\frac{3}{4}$	5	5 $\frac{1}{4}$	5 $\frac{1}{2}$	5 $\frac{3}{4}$
P. A. 4F	20	..	..	..	72.4	75.8	79.1	..	76.4	..	..	..	..
	26	..	..	..	..	51.7	52.2	53.2	53.4	52.1	52.3	50.0	..
	30	..	..	..	..	..	41.2	42.9	40.6	40.6	..	..	..
	36	..	..	..	..	..	..	32.2	31.5	31.5	30.4	..	..
Superfine Oomra	8	..	..	..	..	94.6	110.1	..	..	169.5	..	..	..
	10	..	..	..	..	66.8	85.7	104.2	..	..	..	..	..
	12	..	..	..	..	41.1	57.5	75.2	88.5	91.7	93.0	94.7	94.2
	14	..	..	..	..	..	..	50.7	64.9	73.4	..	..	..
	16	..	..	..	..	..	..	..	42.2	57.1	63.2	..	..
A. R. Kampala	40	..	..	38.3	39.8	42.7	..	..	..	..	..	..	..
A. R. Busoga	40	..	..	40.1	42.6	44.5	..	..	..	..	..	..	..
A. R. Jinja	40	..	..	39.0	39.6	42.5	..	..	..	..	..	..	..
Giza 7	<i>Carded</i>	50	32.9	38.8	40.9	40.8	41.4	..	..	..	..	..	..
	..	60	27.0	29.2	31.8	31.0	31.9	..	..	..	..	..	..
	<i>Combed</i>	60	30.0	34.6	36.6	37.2	36.7	..	..	..	..	..	..
	..	70	22.9	27.2	29.1	30.1	27.9	..	..	..	..	..	..
Sea Island	<i>Carded</i>	50	35.3	37.2	39.0	39.1	38.5	..	..	..	..	..	..
	..	60	25.5	30.2	30.8	31.7	31.3	..	..	..	..	..	..
	(Sind) <i>Combed</i>	60	34.9	36.7	37.8	38.1	38.5	..	..	..	..	..	..
	..	70	27.0	28.3	29.0	29.1	28.9	..	..	..	..	..	..

equation (1) will be more important. At very low twists, however, the slippage factor may become comparable to the grippage factor. By inserting the values of the various constants in the right hand side of equation (1) we can calculate the yarn strength and compare it with the actual value. The number of fibres in the cross-section may be calculated from actual counts and fibre-weight per inch, the fibre-strength was actually determined, the slippage factor 'p' for P. A. 4F was taken from the work of Turner and Gulati¹¹ described in another bulletin, while as a first approximation we can take 'f' equal to the clinging power of the cotton. On doing so we obtain the values for single-thread strength which are given in the following Table together with the values found by direct test.

TABLE V.
P. A. 4F cotton.

Count	Number of fibres.	Single-Thread Strength (actual) (oz.)	Single-Thread Strength (calculated) (oz.)
32	116	5.45	7.49
28	132	7.16	8.36
25	148	8.61	9.87
22	168	10.28	11.75
20	185	11.66	13.34

It will be seen that the two sets of values lie fairly close to one another showing the fundamental soundness of the line of reasoning adopted by us. It will, however, be noticed that the calculated values are in all cases a little higher than the actual values as if a constant factor were operating which has not been taken into consideration.

Since in these yarns the number of turns per inch has been kept constant, we may assume that the binding force due to twist alone will remain practically constant. The other binding force between the fibres is that due to their mutual lateral pressure which will depend upon the number of fibres present in the cross-section and which is represented by 'f' in equation (1). In order to make a rough estimate of its value, we may assume that 'p' is the same for the different yarns, *i.e.*, the same fraction of fibres is broken in each case. The value of 'p' is taken from the 32's yarns as giving the best agreement between the observed and the calculated value of single thread strength and comes out equal to 33, which is in good agreement with that found by Turner and Gulati. Substituting this value in equation (1),

we find the following values for the binding due to the lateral pressure exerted by the fibres on one another:

Count.	Number of fibres.	f.
32's	116	....
28's	132	0.89
25's	148	1.58
22's	168	2.30
20's	185	2.87

It is remarkable that 'f' is found to vary linearly with the number of fibres and the straight line giving the best fit enables us to calculate the value of the binding force on a single fibre. This comes out to be equal to .0372 oz. Now the clinging power of this cotton is .007 oz. which is roughly 1/5 of the value found here. It must, however, be remembered that the clinging power is found by pulling a fibre through a pad without any twist, while here the fibres are pulled apart in a bundle which is twisted and in which consequently the cohesion of the fibres will be several times greater than in a pad. Furthermore, for the sake of calculation it has been necessary to assume that the binding due to the lateral pressure of fibres was zero in the 32's yarns—the finest yarn spun in this series. This assumption is not strictly justified, and if we had inserted some figure higher than zero for this binding, it would have reduced the values for the other yarns.

We could apply a similar treatment to the results obtained for Superfine Oomra, provided its clinging power was known. Since the value of its clinging power was not available at the time of writing this bulletin, we may calculate the factor 'f' in a way similar to that adopted for the P. A. 4F cotton. In this case, the percentage of fibres which break is taken as 16.5. This is about half of that taken for 4F, but it must be remembered that twist in these yarns is 14 turns per inch as against 21.2 for 4F. Turner and Gulati¹¹ found that f or 13.3 turns to the inch the average percentage of broken fibres in 5 cottons was 16.9 in 20's counts and thus our value is in reasonably good agreement with theirs, though for the lower counts into which this cotton has been spun this percentage would probably be less than 16. On substituting these values, we obtain the following values for 'f':

Counts.	Number of fibres.	'f'
14	173	....
12	201	2.54
10	242	6.48
8	302	12.61

which gives 0.1 as factor accounting for the binding due to the lateral pressure of the fibres. This is considerably higher than that obtained for 4F, but we should expect it to be so in view of Oomra being a shorter and coarser cotton.

(ii) *Medium-long staple cottons.*—The lea strength, the ballistic work of rupture and the single thread strength show a progressive increase with twist in the twist multiplier range of $3\frac{1}{2}$ to 4 for all the three cottons, A. R. Kampala, A. R. Busoga and A. R. Jinja spun into 40's counts. The yarns spun with a twist multiplier 4 gave about 3-4 lbs. higher lea test and about 2-3 inch-lbs. higher ballistic test than those spun with a twist multiplier of $3\frac{1}{2}$, while the difference between these and the yarns spun with a twist multiplier of $3\frac{3}{4}$ was generally quite small. Thus, so far as the criterion of strength alone is concerned, a twist multiplier of 4 appears to be better for these cottons than a lower one, though it is possible that other considerations such as the appearance and production of yarn, etc., may favour the selection of a lower twist multiplier. Furthermore, judging from the small rate of increase of yarn strength with twist in this region, it seems highly probable that the peak value of strength has very nearly been attained. There is thus a marked difference between these and the Superfine Oomra cotton for which the strength increased rapidly in the region of twist multiplier 4 and the peak value was reached only with a twist multiplier of $5\frac{1}{2}$.

(iii) *Long staple cottons. (a) Carded and (b) Combed.*—The results for these cottons are given in Table IV while in Table VI the percentage differences in lea strength classified according to treatment (carded or combed), cottons (Giza 7 or Sind Sea Island) and counts (50's-60's or 60's-70's) are shown. A study of these Tables yields several interesting results.

TABLE VI.

	Percentage Variation			
	3 to $3\frac{1}{2}$	$3\frac{1}{2}$ to $3\frac{3}{4}$	$3\frac{3}{4}$ to 4	$3\frac{1}{2}$ to 4.
I. Treatment.				
(i) Carding	+12.4	+ 5.3	+ 0.1	+ 0.4
(ii) Combing	+11.0	+ 4.6	+ 1.5	- 2.1
II. Cottons.				
(i) Giza 7	+15.0	+ 6.8	+ 0.6	- 1.0
(ii) Sind Sea Island ..	+ 8.4	+ 3.1	+ 1.1	- 0.6
III. Counts.				
(i) 50's carded and 60's combed	+11.0	+ 4.8	+ 0.6	- 0.1
(ii) 60's carded and 70's combed	+12.5	+ 5.1	+ 1.0	- 1.6

It will be seen that there is a sharp increase in yarn-strength when a twist multiplier of $3\frac{1}{2}$ is employed instead of 3 and a less sharp increase when a twist multiplier of $3\frac{3}{4}$ is used instead of $3\frac{1}{2}$, the increase being greater for the carded than for the combed yarns and greater for Giza 7 than for Sind Sea Island. Now, these two cottons have practically the same mean fibre-length, but Giza 7 possesses a somewhat higher fibre-weight per inch. It would, therefore, appear that for these long staple cottons the influence of twist increasing the yarn-strength is more marked with the cotton possessing a higher fibre-weight per inch. This would probably be due to the coarser cotton possessing either greater ribbon width or more convolutions per inch and consequently the binding effect of twist would be greater in it than in a finer cotton. Furthermore, it will be seen that if the twist multiplier is raised from $3\frac{1}{2}$ to $3\frac{3}{4}$, the yarn-strength increases by only a small amount, and that the insertion of further twist with a twist multiplier of 4, actually pulls down the lea strength by a small amount in all cases except one. Thus, although the peak value of lea strength is reached with a twist multiplier of $3\frac{3}{4}$ both for carded and combed yarns, the difference between these and the values obtained with a twist multiplier of $3\frac{1}{2}$ is so small that the latter may be used with practically equally good strength results and the further advantages of higher production and softer yarns. We saw above that the twist multiplier for peak value of lea strength which stood at $5\frac{1}{4}$ for the short staple Oomra was reduced to about 4 for the medium-long staple African cottons while for the long staple cottons it is further brought down to $3\frac{1}{2}$. The use of a lower twist constant, $3\frac{1}{2}$ or 3, however, pulls down the yarn-strength by an appreciable amount, while if a twist multiplier of 3 is used, the lea-breaking strength may, on the average, be 12 to 18 per cent less than the peak value.

So far as the two ranges of counts (50's to 60's or 60's to 70's) are concerned, the effects are practically the same, as shown by the last two rows of Table VI.

(4) *Single Thread Strength.* [See Table VII.]

(i) *Short-medium staple cottons.* As for the lea test results, the single thread strength also increases steadily with the increase in twist constant from 4 to $5\frac{3}{4}$ in the 12's counts spun from Superfine Oomra. For P. A. 4F, however, the rise occurs only up to a twist constant of 5 in the 26's counts after which a decline in single thread strength sets in. Thus, the optimum twist constant according to the single thread test results for 26's counts of P. A. 4F cotton is found to be 5.

TABLE VII.

Single Thread Strength (oz.) corrected for humidity and counts.

Cotton.	Counts.	Twist Multiplier.											
		3	3 $\frac{1}{2}$	3 $\frac{1}{2}$	3 $\frac{3}{4}$	4	4 $\frac{1}{4}$	4 $\frac{1}{2}$	4 $\frac{3}{4}$	5	5 $\frac{1}{4}$	5 $\frac{1}{2}$	5 $\frac{3}{4}$
P. A. 4F	20	..	..	..	9.50	9.98	10.46	..	11.67	..	..	..	..
	26	..	..	..	..	6.75	7.30	7.55	8.01	8.53	8.17	8.36	..
	30	..	..	..	..	..	6.39	6.82	6.61	7.06	..	..	..
	36	..	..	..	..	..	..	5.23	5.52	5.41	5.14	..	..
Superfine Oomra	8	..	..	..	..	15.35	17.50	..	..	23.77	..	..	..
	10	..	..	..	..	10.70	14.16	16.15	..	..	..	..	..
	12	..	..	..	..	9.97	11.32	12.10	13.99	14.36	14.34	14.38	14.54
	14	..	..	..	..	..	..	9.81	12.13	11.86	..	..	..
	16	..	..	..	..	..	..	..	9.47	10.04	10.92	..	..
A. R. Kampala	40	..	..	5.78	6.31	6.09	..	..	..	..	..	..	..
A. R. Busoga	40	..	..	5.93	6.35	6.55	..	..	..	..	..	..	..
A. R. Jinja	40	..	..	5.98	5.93	6.60	..	..	..	..	..	..	..
Giza 7	<i>Carded</i>	50	4.66	4.89	5.52	5.60	5.76	..	..	..	..	..	..
	"	60	3.67	4.12	4.09	4.20	4.44	..	..	..	..	..	..
	<i>Combed</i>	60	4.17	4.82	5.33	5.18	5.35	..	..	..	..	..	..
	"	70	3.65	3.68	4.18	4.32	4.01	..	..	..	..	..	..
Sea Island	<i>Carded</i>	50	5.02	5.57	5.96	5.95	6.58	..	..	..	..	..	..
	(Sind)	60	4.07	4.49	4.51	4.82	4.68	..	..	..	..	..	..
	"	60	4.99	5.03	5.19	5.57	5.58	..	..	..	..	..	..
	<i>Combed</i>	70	3.92	4.03	4.50	4.40	4.28	..	..	..	..	..	..

(ii) *Long staple cottons.*—It was observed from the lea tests for these cottons that either $3\frac{1}{2}$ or $3\frac{3}{4}$ can be regarded as the optimum twist constants. The single thread strength results show that this holds good for the combed yarns from both cottons and for carded yarns of Sind Sea Island. Only in the 50's and 60's carded yarns of Egyptian Giza 7 the single thread strengths are found to increase steadily up to 4 twist constant. This slight departure, however, is not important and $3\frac{1}{2}$ can be considered as suitable twist multiplier for these cottons, especially when they are combed.

(5) *Ballistic work of rupture.* We shall now consider the results of this test which is a joint measure of both strength and extension. [See Table VIII.]

(i) *Short-medium staple cottons.*—The change in the ballistic work of rupture of the P. A. 4F yarns spun with different twists is generally small, being only about $5\frac{1}{2}$ per cent. in the 26's yarns with a change in twist multiplier from 4 to $4\frac{1}{2}$. Thereafter a slight decline in the ballistic test is noticed showing that $4\frac{3}{4}$ may be considered as giving the best ballistic results for this cotton in the 26's counts.

Unlike the lea test results, the rise recorded in the ballistic results of 12's counts of Superfine Oomra cotton is small, the maximum occurring with $4\frac{1}{2}$ twist constant, while the increase from 4 to $4\frac{3}{4}$ twist multiplier gives a percentage increase of only 7 per cent. Thus, both for 4F and Superfine Oomra, $4\frac{3}{4}$ twist multiplier gave the best ballistic test results in 26's and 12's counts respectively.

(ii) *Medium-long staple cottons.*—The results of the ballistic tests for these cottons vary in the same manner as observed for the lea test results, the twist multiplier 4 giving the maximum value. It is not possible to state definitely from these results whether we should expect a further increase with a higher twist multiplier, but in view of the fact that the increase observed for the change in twist multiplier from $3\frac{1}{2}$ to 4 is very small, the twist multiplier 4 may be regarded as giving the best ballistic test results for these cottons.

(iii) *Long staple cottons.*—In the 50's carded yarns of both cottons, the ballistic strength increases steadily as the twist constant was raised from 3 to 4. But, in 60's carded yarns the twist multipliers $3\frac{3}{4}$ and 4 gave practically the same results so that the former can be regarded as optimum for this count.

For the combed yarns of Sind Sea Island cotton, there is a steady tendency for the ballistic strength to increase up to the twist multiplier 4. For 60's of Egyptian Giza 7, however, the ballistic strength falls after the twist multiplier $3\frac{3}{4}$, while in 70's $3\frac{3}{4}$ and 4 gave practically the same results. Thus for Sind Sea Island combed yarns, the twist multiplier 4 may be regarded as giving the best ballistic test results while for Egyptian Giza 7 a lower constant, namely $3\frac{3}{4}$, is sufficient to serve the same purpose.

TABLE VIII.

Ballistic Work of Rupture (inch-lbs.) corrected for counts and humidity.

Cotton.	Counts.	Twist Multiplier.											
		3	3 $\frac{1}{4}$	3 $\frac{1}{2}$	3 $\frac{3}{4}$	4	4 $\frac{1}{4}$	4 $\frac{1}{2}$	4 $\frac{3}{4}$	5	5 $\frac{1}{4}$	5 $\frac{1}{2}$	5 $\frac{3}{4}$
P. A. 4F	20	..	..	..	143.1	150.7	151.5	..	154.4	..	..	..	..
	26	..	..	..	..	98.8	102.6	103.2	104.4	102.2	103.8	104.0	..
	30	..	..	..	..	..	89.5	90.6	91.1	90.8	..	..	..
	36	..	..	..	..	..	..	72.8	72.4	72.6	71.1	..	..
Superfine Oomra	8	..	..	..	..	293.4	316.5	..	..	346.5	..	..	..
	10	..	..	..	..	210.3	226.3	233.4	..	..	..	..	..
	12	..	..	..	..	180.3	181.6	186.9	192.7	187.0	189.5	192.2	190.8
	14	..	..	..	..	..	..	155.5	162.4	166.4	..	..	..
	16	..	..	..	..	..	..	..	136.5	145.2	148.5	..	..
A. R. Kampala	40	..	..	73.2	74.8	76.6	..	..	..	..	..	..	..
A. R. Busoga	40	..	..	78.4	80.0	80.2	..	..	..	..	..	..	..
A. R. Jinja	40	..	..	77.2	78.1	80.8	..	..	..	..	..	..	..
Giza 7 <i>Carded</i>	50	60.7	61.9	65.9	67.1	68.6	..	..	..	..	..	..	..
" <i>Combed</i>	60	50.2	50.8	51.3	52.6	52.6	..	..	..	..	..	..	..
" <i>Combed</i>	60	54.4	56.3	58.9	60.4	59.9	..	..	..	..	..	..	..
" <i>Combed</i>	70	48.7	49.3	50.3	51.7	51.7	..	..	..	..	..	..	..
Sea Island <i>Carded</i>	50	59.7	61.7	65.4	67.1	69.4	..	..	..	..	..	..	..
(Sind) " <i>Combed</i>	60	50.2	50.5	52.9	54.2	54.1	..	..	..	..	..	..	..
" <i>Combed</i>	60	54.2	55.5	57.4	60.6	62.8	..	..	..	..	..	..	..
" <i>Combed</i>	70	48.1	48.0	49.2	49.7	50.3	..	..	..	..	..	..	..

VII. SUMMARY.

The object of the tests described in this report was to study the influence of twist on yarn strength and to find, if possible, the optimum twist constant for each cotton. The cottons selected covered a wide range of staple length, extending from the short stapled Oomra to the long stapled Sind Sea Island. The long staple cottons were spun both into carded and combed yarns, while the short staple cottons were also spun with the same number of turns per inch into different counts to estimate the slippage factor as distinct from the grippage factor. The following conclusions are drawn from the results of these tests.

(1) *Yarn breakages.*—In the counts which are definitely beyond the spinning capacity of P. A. 4F, the use of hard twist does not appreciably reduce the number of yarn breaks. For the medium-long staple cottons, yarn breakages in the ring frame in 40's counts spun with $3\frac{1}{2}$ twist multiplier gave satisfactorily few breakages which did not decrease by using a higher twist multiplier. In the case of the long staple cottons the yarn breakages decreased up to a twist multiplier of $3\frac{3}{4}$ after which they were sensibly constant.

(2) *Yarn Evenness.*—The use of a high twist in the P. A. 4F yarns either failed to cause any improvement in evenness or had a deleterious effect. On the other hand, Superfine Oomra gave equally even yarns with the different twist multipliers in 8's, 10's and 12's counts. In the higher counts, the yarns became uneven and the insertion of twist even if it increased their strength, could not pull up their evenness class. With the medium-long stapled cottons, the yarns spun with twist-multiplier 4 were found to be somewhat more even than those obtained with the two lower twist multipliers.

The two long staple cottons gave equally even yarns in each count irrespective of the twist multiplier employed within the range 3-4. This held both for the carded and the combed yarns.

(3) *Lea Strength.*—A twist-multiplier of $4\frac{1}{2}$ or $4\frac{1}{4}$ may be taken as optimum for P. A. 4F spun into 20's counts while in the higher counts such as 30's and 36's even the insertion of high twist does not give sufficient strength. For Superfine Oomra, a twist multiplier of $4\frac{1}{2}$ may be regarded as suitable for spinning it into 10's counts, while a twist multiplier of 5 is necessary for spinning it into 12's counts. The higher counts 14's and 16's are beyond its spinning capacity and high twist fails to impart sufficient strength.

It is noteworthy that the force required to pull apart the slipping fibres in a yarn is found to be directly proportional to the number of fibres in the cross section. The value of the binding force on a single fibre for P. A. 4F cotton was estimated to be 0.0372 oz. which is roughly 5 times the value of its clinging power. We should ex-

pect this difference owing to the fact that in a yarn the fibres are in a twisted bundle. The value of the binding force on a single fibre for Superfine Oomra was estimated as 0.1 oz. This is higher than that obtained for P. A. 4F, but one should expect it in view of the latter cotton being a longer and finer one.

For medium-long staple cottons a twist multiplier of 4 gave the best results in 40's counts, but the difference in strength between this and the lower twist multiplier of $3\frac{3}{4}$ was small and other factors such as the appearance and production of yarn, etc., should also be taken into consideration.

With the long staple cottons it was observed that the influence of twist, as an aid to increasing yarn strength, was more marked with a coarser than with a finer cotton. The peak values of yarn strength were obtained with $3\frac{3}{4}$ twist multiplier after which there was a small decrease in most cases. But the difference between these values and those obtained with $3\frac{1}{2}$ twist multiplier was so small that the latter multiplier may be used with equally good results and the further advantages of a higher production and softer yarns.

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DISCUSSION.

Dr. Nazir Ahmad, summarising the results of the paper under consideration, said that twist generally increased the strength of yarns. In the preparation stages in the fly frames a very small amount of twist was inserted in the roving in order to keep the fibres together, for at that stage if more than the barely minimum twist was inserted, it interfered with the drafting process which did not take place smoothly and efficiently. This applied to the three fly frames, the slubbing, the inter and the roving frame. In the spinning frame where the yarn was spun sufficient twist was inserted so that the yarn might have the requisite strength, the twist inserted depending on the count of yarn and consequently on the type of cotton used. The twist inserted in the spinning process was measured in terms of a factor called the 'twist multiplier.' The actual number of turns per inch inserted in a yarn was given by the twist multiplier multiplied by the square root of the count of the yarn. For instance, in spinning 16's with a twist multiplier of 4, the number of turns per inch inserted was 4×4 , i.e., 16. For medium staple cottons it was customary, although there was no standard practice, to employ the twist multipliers of 4 and $4\frac{1}{2}$, for long staple cottons a twist multiplier of $3\frac{1}{2}$ or 4, and for still longer cottons like Sakel and Sea Island a twist multiplier of $3\frac{1}{2}$ and even $3\frac{1}{4}$ was employed. The reason why, so far as possible, the twist should be kept low was that high twist reduces the softness and evenness of yarns besides lowering the production. If, for instance, 20's yarn were spun with the multiplier $3\frac{1}{2}$, about 8 ozs. would be obtained per hour per spindle. If the twist multiplier was increased from $3\frac{1}{2}$ to 4, the production would fall down to about 7 ozs. It should be noted in considering the performance of an improved variety that a mill may not spin it into as high a count as it could be spun, as for special reasons the mill might sacrifice strength for the sake of production. For instance, if a cotton of 15/16" long staple is capable of spinning 30's a mill might decide to spin only 24's from it and get higher production. The main object before a mill manager was to make profits either by producing finer yarns or by increasing production.

He continued that this paper was in the nature of an effort to stimulate discussion on the results of some tests given on page 5 which were carried out on three types of cotton, short-medium, medium-long and long staple cottons. For short-medium Punjab-American 4F and Superfine Oomra were selected, for medium-long three African cottons (Kampala, Busoga and Jinja) and for long staple Sind Sea Island and Egyptian Giza 7 were spun with different twists. The mean fibre-lengths of these were:—4F: 0.77," Superfine Oomra: 0.72," Kampala: 1.07", Busoga: 1.08," Jinja: 1.13", Sind Sea Island: 1.15" and Egyptian Giza: 1.14". The various twist multipliers used in spinning were shown in Table II on page 8. Punjab-American 4F was spun in counts from 20's to 36's with different twist multipliers ranging from $3\frac{1}{2}$ to $5\frac{1}{2}$ Superfine Oomra in 8's to 16's with twist multipliers ranging from 4 to $5\frac{1}{2}$; the three Africans in 40's with twist multipliers

ranging from $3\frac{1}{2}$ to 4 and the long staple cottons were spun with twist multipliers ranging from 3 to 4. Discussing the effect of twist on spinning behaviour he said it would be seen from p. 7 that with short staple cotton when higher twist was inserted, it definitely reduced the number of breakages up to a twist multiplier of $4\frac{1}{2}$ but beyond that the breakages remained fairly constant. As regards the effect of twist on yarn evenness the results summarised on pages 7 and 9 show that when Oomra was spun in 12's, 14's and 16's by inserting extra twist, although the yarn strength increased up to a limit, the yarns became progressively uneven, which was an undesirable feature. The results of strength tests given in Table IV show that the lea strength of 8's yarns spun from Oomras with a twist multiplier of 4 was 95 lbs. but with a twist multiplier of 5 the lea strength rose to the high figure of 170 lbs. It was this large increase in strength with twist which was a special feature of the short staple cottons. In 12's counts, spun with the medium twist multiplier of 4, the lea strength was 41 lbs. but with the twist multiplier of 5 it increased to 92 lbs. Thus it was possible to spin Oomras up to 12's counts by inserting sufficient twist in it, though the evenness and production of the yarns would be reduced. With Punjab-American 4F the strength in 20's count went on increasing slowly from twist multiplier $3\frac{3}{4}$ to $4\frac{1}{2}$, while in 26's and 30's counts there was hardly any change in the yarn strength. With Sea Island and Egyptian cottons the maximum strength was reached at a comparatively very low twist multiplier of $3\frac{1}{2}$ and beyond that there was a decline in strength. Some yarns were spun in different counts with the twist multiplier so adjusted that the number of turns per inch was the same. It meant that the binding force of the twist was the same on the fibres in the various yarns. A simple formula from single-thread strength, given on page 11, was then developed from the following considerations, namely that when the yarn broke the force required to break it was partly spent in breaking a certain fraction of the fibres and partly in pulling the remaining fibres apart. Taking the value of the latter as approximately equal to the clinging power of cotton and the value of the percentage of broken fibres from a previous investigation of the Laboratory, the strength of the yarn could be calculated as shown on page 13. A fairly good agreement between the calculated and actual single-thread values was observed which was most encouraging. This was only a beginning and if the proportion of fibres which broke in yarns of different counts spun with different twists was known and also the manner in which 'f' was related to the clinging power of the cotton the breaking strength of the yarns could be calculated.

Mr. M. L. Patel said that a similar experiment carried out at the Shirley Institute in the case of Dhollerás, the results of which were given in his paper No. 5 (Supplementary Note)* showed that the twist factor of 4 and 5 gave almost the same strength in 16's and 20's. As a result of these tests the opinion was expressed that the cotton tested was suitable for spinning into warp counts from 20's to 24's, which

* Not Printed.

appeared to be rather high for Dholleras. Further, Wagad cotton spun in Matunga Laboratory was adjudged suitable for spinning 12's to 16's while at the Shirley Institute with a twist factor of 4 to 5 it was found suitable for 20's to 24's and the yarns spun with twist factor "5" being in every case better than the corresponding yarns spun with twist factor "4".

Dr. Nazir Ahmad said that yarn evenness was judged by the eye and was therefore subject to errors of personal judgement.

Mr. Hutchinson wished to know whether there could be any comparison between the spinning value on the peak of the twist strength curve and the highest standard warp counts.

Dr. Nazir Ahmad said that the gradient of the curve from strength at the highest standard warp count and the strength at the peak value would probably be different for different cottons. At present sufficient data was not available, but he would bear in mind the suggestion made by Mr. Hutchinson and would look into the point raised by him when sufficient data were available.

Mr. Hutchinson dealing with the difference between the results of the Shirley Institute tests and those of the Laboratory said that for purposes of comparison Dr. Ahmad had laid down strict conditions to be observed in all tests as otherwise they would not serve their purpose, whereas the Shirley Institute tests were probably done with a view to seeing how far Indian cottons could meet Lancashire needs and how by special adjustment in processing, cottons which were not normally considered in the Lancashire range could be brought into the Lancashire range. In comparing the Shirley Institute figures with the Technological Laboratory figures for Indian cottons, it should be borne in mind that the same figures of the Institute were not available and it was found very difficult to compare them with the Matunga tests. In short, he said that the Shirley Institute tests were carried out rather to determine what was the top level economic spinning with all suitable adjustments that could be made, whereas the Matunga tests were carried out to determine what was the top level economic spinning under certain rigidly specified conditions.

COTTON TECHNOLOGY

Paper No. 2.

THE DETERIORATION OF BROACH PALEJ COTTON ON STORAGE

BY

A. N. GULATI,
INDIAN CENTRAL COTTON COMMITTEE
TECHNOLOGICAL LABORATORY,
MATUNGA, BOMBAY.

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INTRODUCTION.

In the course of an investigation into the causes of deterioration of Broach Palej cotton at the Technological Laboratory, Matunga, among other tests, Bright's congo-red test for damaged fibres was also carried out. The results of this test

showed conclusively that micro-organisms played an important role in the deterioration of this cotton while it was stored at Bombay. An attempt was, therefore, made to isolate the different fungi and bacteria present on this cotton. The relative abundance of each organism was estimated and it was further determined which of the most prevalent forms were known cellulose decomposers. The present report thus deals with (1) the results of the congo-red damage test; and (2) the systematic study of the fungi and bacteria present on the cotton.

PART I.

(i) *The Congo-Red Damage Test.*

The application of Bright's congo-red test enables one to distinguish the nature of damage to cotton fibres resulting from fungi, machinery, heat and sulphuric acid. The degree of damage in each of the four types is also detectable as slight, moderate and severe. The distinguishing features of the test, after Bright, are tabulated below.

Degree of damage.	Appearance of Hairs.			
	Attacked by fungus.	Exposed to Heat.	Damaged by mechanical means.	Treated with sulphuric acid.
1. No damage	Stained pink	Stained pink.	Stained pink	Stained pink
2. Slight damage.	Narrow multiple red spiral bands.	Broad simple red spiral bands.	Surface bruises.	..
3. Moderate damage.	Stained evenly red.	Narrow multiple red spiral bands.	Deep cuts.	Irregular red patches.
4. Severe damage.	Stained red and cracked.	Stained red and cuticle singed.	..	..

The damaged fibres seen in this cotton could be referred to two categories only, viz., mechanical and fungal, because the cotton in question was raw and had been subjected only to machine-treatment in the gin and the baling press. Table

I. summarises the results of this test carried out on the original sample in the month of April 1934; and two samples after storage for six months in October. The two stored samples consisted of material from the top and the middle of the same bale.

It will be seen from Table I below that the original sample had 69% undamaged hairs and 31% damaged hairs. Out of the latter only 4% were damaged by fungi. In the stored samples the number of undamaged hairs fell to 48% and 46% in the top and the middle samples respectively, while the number of damaged hairs increased to 52% and 54%. This increase, it will be noted, was wholly due to a remarkable rise in the number of fibres showing fungal damage. Apart from the nature and appearance of damage indicated by the congo-red technique, fungal mycelia and spore-heads growing on the fibres were actually observed. A direct evidence of fungi attacking the cotton fibres was thus available.

TABLE I.
Damage Test Results.

Samples.	Undamaged fibres.	Damaged fibres.	
		Mechanically.	By fungi.
1. Original	.. 69%	27%	4%
2. Stored :			
(a) Top of bale	.. 48%	23%	29%
(b) Middle of bale	.. 46%	19%	35%

Note.—300 fibres were tested for each set of values.

The gradual fall in the number of hairs showing mechanical damage from original to the "middle" material of the stored bale is somewhat anomalous. In the absence of any difference in machine-treatment, the fall in these values could only be explained on the basis of the limitations of the technique. Fibres showing two types of damage, i.e., mechanical as well as fungal, had to be classified only in one of the two categories. If the mechanical damage was more pronounced than the fungal, the fibre was classed as mechanically damaged; and in case it was more fungal than mechanical the fibre was classed under fungal damage. Since the mechanically injured fibres are known to attract the micro-organisms more than the intact fibres, it was no wonder that the fungal attack masked the mechanical damage; and thus led to the classification of fibres, originally placed under mechanical damage, among those showing fungal damage.

The difference in the values of top and middle material of the stored bale is not significant in the case of undamaged and mechanically damaged hairs; but it appeared to be a little too much for fibres showing fungal damage. Obviously it is due to richer growths of fungi in the middle of the bale. Thaysen² (1924) also found that "heart-damage" in the bale originated from microbiotic action.

(ii) *The Temperature and Moisture Conditions at Bombay.*

The remarkable increase in the hairs damaged by fungi in this cotton at Bombay indicates that the moisture and temperature conditions were conducive to fungal growth. The moisture^{2*} content of this cotton as observed in April (1934) was a little over 4%. During the monsoon it rose to 8%. The average temperature during April was 85°F. which gradually came down to 80°F. in September. This combination of moisture and heat resulted in fungal damage to an additional 20% of the fibres. Armstead and Harland³ (1923) observed that 7.8% moisture content produced but slight growth of fungi on cotton in England. The trade people in Bombay seem to be aware of the fact that Broach cotton does not deteriorate so rapidly in England. Although the moisture condition is the same in the two countries, yet the deterioration seen in Bombay is lacking in England. The explanation appears to lie in the temperature conditions. In England it is usually 45°F. in April, and it gradually rises to 60°F. in August and September. These values and the range of temperature are decidedly lower than those prevailing at Bombay. It may therefore be concluded that the temperature and moisture conditions which are favourable for fungal growth are as much to blame for the deterioration of the cotton at Bombay as the fungi.

The optimum conditions of temperature and moisture approached in a sample stored over water (not touching it) in a closed jar during the months of November and December at Bombay. The cotton which was lying in almost saturated humidity, at a temperature varying from 85°F. to 78°F., had completely changed its colour in two months, was exceedingly tender and was full of fungal growths.

PART II.

(i) *The Systematic Study of Fungi and Bacteria.*

This study involved careful microscopical examination of the cotton and the micro-organisms grown in cultures from the cotton. The cotton was examined in (1) its ordinary state; and (2) after storage of a two gramme sample for a month over water in a closed jar. The examination of the ordinary cotton showed the presence of a large variety of organisms and also revealed their association with "stained" and matted parts of the lint. The sample stored over water proved useful in detecting the fungi which are capable of rapid growth on increase in the moisture content of cotton. The change in the colour of the cotton on such storage became

more and more pronounced as the fungal growths advanced. Culturing of the fungi on special media was resorted to for isolating the different species for the purpose of identification.

This procedure of the study was considered necessary because not only did the findings at each step reveal different stages of the very complex life history of different fungi, but also served as checks on each other. In fact, any local contaminations could not be excluded otherwise; and some of the many forms discovered might not have been detected at all. The findings of this study are summarised in Tables II., III. and IV.

(ii) *Discussion of Results.*

(a) *The ordinary stored sample.*

Table II shows the results of microscopical examination of stored cotton from the top and middle of the bale. Ten preparations, each containing 50 to 100 fibres were systematically examined from each sample. In either case fibres for the first five slides were taken from "stained" and matted lint; while for the remaining five slides, they were picked at random from clean lint.

TABLE II.

Showing the estimated abundance of different micro-organisms detected in microscopical examination of Broach Palej cotton.

Names of morphological units of fungal stages.	Top Material.		Middle Material.		Remarks.
	Matted and "stained."	Clean white.	Matted and "stained."	Clean white.	
1. Mycelia	On 94% fibres.	On 24% fibres.	On 70% fibres.	On 40% fibres.	They were mainly of two types, septate and aseptate; each comprising colourless and yellow forms.
2. Spore-heads	20 on one slide only.	Nil.	1 on one slide only.	3 on one slide only.	They were of the type of conidia borne on conidiophores as in <i>Aspergillus</i> spp.

TABLE II. contd.

Names of morphological units of fungal stages.	Top Material.		Middle Material.		Remarks.
	Matted and "stained."	Clean white.	Matted and "stained."	Clean white.	
3. Spores.					
(a) round.	Numerous	Few.	Rare.	Numerous on one slide and rare on another.	<i>Aspergillus</i> and <i>Penicillium</i> type.
(b) oval.					
(c) Long spindle shaped.	Few	<i>Nil.</i>	Numerous.	Numerous.	<i>Nematospora</i> sp.
(d) ellipsoidal 4-celled.	<i>Nil.</i>	Rare	Rare	<i>Nil.</i>	<i>Stemphylium</i> -like.
(e) contained in flask-shaped Asci.	Rare.	<i>Nil.</i>	<i>Nil.</i>	<i>Nil.</i>	<i>Ascomycetes.</i>
(f) very small, round, hyaline, growing on short and fine branching mycelia.	<i>Nil.</i>	Numerous on one slide only.	<i>Nil.</i>	Few on one slide only.	<i>Actinomyces</i> sp.
(g) Zygospor.	Rare	<i>Nil.</i>	<i>Nil.</i>	<i>Nil.</i>	<i>Mucor</i> sp.
(h) Oogonia (Resting).	Rare.	<i>Nil.</i>	<i>Nil.</i>	Rare.	<i>Phycomycetes.</i>
(i) Yeast-like cells.	<i>Nil.</i>	<i>Nil.</i>	<i>Nil.</i>	Numerous.	<i>Moniliaceae.</i>
Amoeboid markings on the fibres (possibly bacterial growths).	<i>Nil.</i>	Few.	Few.	Few.	

Mycelia, spore-heads, and spores of different shape and size were met with in varying numbers. The mycelial threads were differentiable into two groups, namely (1) Septate and (2) Aseptate. Each one of these types was further divisible into (i) yellow coloured and (ii) colourless varieties. The spore-heads were only of the type met with in the genus *Aspergillus*. In all nine types of spores were seen. With the exception of oval and round spores, the other types were only rarely met with. One of these types was exclusively seen in the top material and another one was met with only in the middle material. As the spores are easily detachable, it is no wonder that they were thrown off the fibres in the process of mounting them for microscopical examination. Their numbers, therefore, are not of much consequence in estimating the abundance of a fungus from a material like cotton. It was possible to identify them to some extent on the basis of their colour, shape and size—such identification is shown in the above Table.

Mycelial growths of fungi are the only structures which can adhere to the fibres. It is from them only that the harmful enzymes probably get excreted and which degrade the cellulose. As pointed out by Galloway⁴ (1930) in the study of cotton fungi and Waksman⁵ (1931) in the study of soil forms, exact numerical estimates of the abundance of fungi, species by species, is an impossible task. However, without differentiating the types of fungi it is possible to denote such infections numerically by the number of infected fibres. Such values have been given in Table II. They show that whereas the infection is present in both "stained" and clean lint, it is distinctly of a more intense order in the stained lint; and that clean lint from the middle of the bale has again more abundant infection than that from the top of the bale.

The "stains" seen in the matted lint were cream, yellow, brown and pinkish. Possibly they represented different combinations of fungal infections. The mattedness is obviously induced by the presence of fungal growths in one of two ways. Either it is due to the binding effect of mycelial threads or it results from the action of gummy^{5a} secretions of the fungal growths. Some amount of mattedness is also associated with immaturity of fibres. Possibly here too it is due to the presence of fungi which are said to find better food materials⁶ from the immature fibres in the form of dried up protoplasm and hence thrive on them. This discussion leads to a question: Is it the immature hairs which attract the micro-organisms or is it the micro-organisms which corrode the fibres internally and make them look like immature hairs? It is shown by Gulati⁷ (1936) by discussing all the evidence in hand that the latter too is possible at least in some portion of the fibre.

(b) *The sample stored over water.*

The data on this sample are given in Table III. The fibres for this study were picked up at random because the whole sample had turned brownish and distinction of "stained" and clean lint was not possible. In this case of storage over

water, it was noticed that black mildew appeared on the third day on the surface of lint facing water. The black spore-heads gradually diffused into the mass of cotton. After a week some blue growths of *A. ruber* and dark green growths of *Penicillium* sp. were also observed; the former round leaf bits, and the latter on the lint. The cotton ultimately assumed a dirty brownish tint with numerous tiny dark spots, and also dirty greenish specks of a distinctly larger size. The former were spore-heads and the latter were perithecia.

TABLE III.

showing fungi thriving in excess of moisture on a sample of
Broach Palej Cotton stored over water for one month.

Fungal Structure.	Estimated number of fibres attacked and other fungal structures in 10 slides.										Remarks.
	1	2	3	4	5	6	7	8	9	10	
1. Mycelia.											Represent <i>Ascomycetes</i> <i>Deutromycetes</i> <i>Phycomycetes</i> and <i>Actinomycetes</i> all mixed together.
(a) Septate											
(i) colourless											
(ii) coloured											
yellow.	Seen on cent per cent fibres.										
(b) Aseptate											
(i) colourless											
(ii) yellow											
2. Spore-heads.											
(a) Conidia on conidiophores.											
(i) <i>Aspergillus niger</i>	2	7	..	5	..	..	..	..	..	..
(ii) <i>Penicillium</i> sp.	398	..	..	..	10	5	200	56	15	..	
(b) Sporangia of Mucor type.	5	2	..	..	10	2	12	6	5	1	
(c) Perithecia											
(i) with tubular											
(ii) Asci with long paraphyses.	..	1	1	..	40	10	28	18	22	5	

TABLE III—contd.

Fungal Structure.	Estimated number of fibres attacked and other fungal structures on 10 slides.										Remarks.	
	1	2	3	4	5	6	7	8	9	10		
3. Spores.											<i>Aspergillus</i> ,	
(a) round coloured	}	Numerous on every slide.										<i>Penicillium</i> and
(b) oval												<i>Mucor</i> spp.
(c) Long spindle-shaped.		..	..	..	..	..	..	..	..	..	<i>Nematospora</i> sp.
(d) Ellipsoidal, 4-celled.	21	..	1	..	..	..	..	..	..	..	<i>Stemphylium</i> -like.
(e) Asci containing 6 or more spores.	..	..	1	..	..	..	1	..	..	..	<i>Ascomycetes</i> .
(f) Hyaline, round, very small spores.	..	..	..	..	..	..	..	..	..	..	<i>Actinomyces</i> .
(g) Zygosporos	2	..	..	..	..	..	..	..	..	..	Mucors.
(h) Oogonia resting and active.	1	..	300	15	300	..	10	..	..	..	<i>Phycomycetes</i>

Bacterial forms were either spirillae, bacilli, or oval flagellated.

As shown in the above table all the fibres were attacked by mycelial growths. The spore-heads too were distinctly numerous. Spores of round and oval type were also numerous on every slide. The spores of *stemphylium* sp. and the oogonia of the *Phycomycetes* were also more frequent than in the ordinary sample. Spores of *Nematospora* and those of *Actinomyces* were strikingly absent. These forms appear to be adversely affected by the excess of moisture.

The black mildew consisted of *Aspergillus* spp. and *Mucor hygrophilus*. The dark green specks were conidial heads of *Penicillium* sp. and perithecia of two types. One of the perithecia containing tubular Asci having eight spores in each

ascus, had a mouth and neck. It was later on identified as *Chaetomium* sp. The second type of perithecium was a dark round structure, had no opening, and had long and coiling paraphyses. This form remained unidentified.

Out of the thriving fungi, *Penicillium* sp. had the most abundant growth, and its spore-heads were the most numerous. *Mucor hygrophilus* came next on the basis of the number of sporangia. *Aspergillus niger* and *A. ruber* spores too were quite numerous. The oogonia of *Phycomycetes* were also seen frequently in this material. They usually grew from septate, yellow mycelia which clustered round spherical or oval perithecia. The latter contained innumerable spores which when mounted in water turned dark purple in 24 hours. This material thus led to the identification of forms flourishing in excess of moisture.

Besides the fungi noted above spirillae and bacteria were also seen in this sample. Bacteria were of two types, (i) rods, and (ii) oval flagellated types.

(c) Cultures of fungi and bacteria.

The information available from the study of cultures is summarised in Table IV. Plain Agar and Czapek's solution agar as modified by Prindle⁸ were the media used. Whole fibres, cut fibres, and the latter shaken with sterilized water were used for inoculation. The cut fibres shaken with water yielded the largest number of colonies, some 13 different types, on Czapek's solution agar. Dry inoculations of whole and cut fibres on Czapek's medium brought forth only 4 species of fungi. The reason apparently was that only fungi growing on the surface of cotton fibres found access to the medium. Some of them grew fast and covered up the available surface and further did not let other forms show up in distinct colonies. In the case of cut fibres shaken with water even the forms found in the interior of the fibre bits were probably exposed and so had a fair chance of establishing contact with the culture medium, and therefore grew out in independent colonies. As the control with sterilized water did not show any growth, there was no reason to suspect that some of the 13 fungi were extraneous infections.

It will be noted that only four species of fungi grew on Plain Agar. They were three species of the genus *Aspergillus*, namely *A. niger*, *A. sydowi* and *A. ruber*; and a *Mucor*, *M. hygrophilus*.

Three types of bacterial colonies were also obtained on this medium. They were all three bacilli. Type 19a was derived from white colonies; type 19b from

yellow colonies, and type 19c from brown colonies. All the three were Gram negative. With the exception of type 19b, the other two readily stained with Gentian violet.

The thirteen species of fungi grown on Czapek's medium are shown in Table IV, and the number and character of their colonies are also described. It will be noted that some species seen on ordinary cotton, namely, *Actinomyces* sp., *Nematospora* sp. and *Chaetomium* sp. did not grow on either of the two media. It is also interesting to note that the three bacterial types also did not grow on Czapek's medium. This medium, however, revealed the presence of three fungi which were not recognised otherwise from the examination of ordinary cotton. They are two species of *Dema-tiaceae* and one of *Tuberculariaceae*.

Judging from the number of colonies of the different fungi the outstanding frequency of *A. niger* is noteworthy; *Moniliaceae*, 5 of Table IV ranked second, and *Mucors* came third, while *Penicillium* sp. merited the fourth place.

Out of a total of 18 fungi, only five were completely identified because they happened to belong to the common genera described at some length in the Textile literature. For want of good descriptions, suitable illustrations, and authentic specimens for comparison, the identification work could not be carried any further than the naming of family groups. Identification work is often risky without getting in touch with experts dealing with systematic mycology. Records of all the species of fungi were, however, made in the form of Photo-micrographs.

(d) *The decomposing power of fungi.*

Reference to the literature shows that some of the fungi found on Broach Palej cotton have well known powers of decomposing cellulose. Thaysen and Bunker⁹ state that the genera *Aspergillus*, *Penicillium*, *Stemphylium* and *Chaetomium* have positive powers of decomposing cellulose. They are all present in this material. Galloway (1930), however, remarked, that such generalizations are not quite safe, and he found that different species and strains of various genera behave differently towards cellulose decomposition. *A. niger* and *A. sydowi* which were also observed on Broach Palej cotton are stated to have moderate decomposing power, while *A. ruber* has no such power according to Galloway. In the present case, the only safe conclusion that can be drawn from the preliminary identification work, is that among the fungi found there is no dearth of forms capable of decomposing cellulose. Further work is necessary for fuller identification of the species detected and for determination of their role towards decomposition of cellulose.

TABLE IV.

A List of organisms isolated from Broach Palej cotton showing the organisms grown on culture media, the character of their colonies and their power of cellulose decomposition.

Names of fungi.	Number of colonies.		Character of colonies on Czapek's medium.	Power of cellulose decomposition.	
	Plain Agar.	Czapek's solution Agar modified by Prindle.		After Galloway	After Thays and Bunke
<i>Aspergillus niger</i> .	8	221	Black spore-heads, mycelial growths; Reverse crumpled sheet.	Moderate.	} Positive.
„ <i>sydowi</i> .	1	..	.....	„
„ <i>ruber</i> .	3	3	Grey blue spore-heads, velvety growth; Reverse blood red.	Nil.	
<i>Penicillium</i> sp.	..	4	Greyish green spore-heads, overgrows <i>A niger</i> .	Not known.	„
Ioniliaceae, Hyalosporeae macronemae, yeast-like spores.	..	18	Pink round, gelatinous colonies.	„	Not know
Thomaceae.	..	1	Dirty cream, overgrowing a colony of Dematiaceae.	„	„
Dematiaceae, <i>Stemphylium</i> sp.	..	1	Dark dirty purplish, watery colony.	„	Positive.
„ Amerosporae, macronemae, round or oval spores, single or in chains.	..	1	Dark brown in the centre, edges pale.	„	Not know
Dematiaceae, Dictyosporae, macronemae, 6 to 8 celled spores.	..	1	Dark brown tending to black watery.	„	„

Names of fungi.	Number of colonies.		Character of colonies on Czapek's medium.	Power of cellulose decomposition.	
	Plain Agar.	Czapek's solution Agar modified by Prindle.		After Galloway.	After Thays and Bunker
Tuberculariaceae having hard round astomatous sporodochia.	..	2	White, dense web-like colony bearing hard tubercle-like sporodochia which are transplantable.	..	..
<i>Nematospora</i> sp.	..	..	....	..	..
<i>Mucor hygrophilus</i> .	1	5	Rhizoid colony, cottonymycelial growth rising 1 cm.	..	..
„ <i>racemosus</i> .	..	1	„ rather low-lying.	..	..
Phycomycetes.	..	1	Light brown, tubercular	..	..
Endomycetaceae.	..	1	Light brown, powdery	..	..
<i>Actinomyces</i> sp.	..	..	....	Strong.	Positive.
<i>Chaetomium</i> sp.	..	..	....	..	..
Perithecia with long coiling paraphyses.	..	..	....	Not known.	Not know
<i>Bacteria.</i>					
a. White colonies.	8	..	....
b. Yellow colonies.	1	..	....
c. Brown colonies.	2	..	....

CONCLUSIONS.

1. Fungi are largely responsible for the deterioration of Broach Palej cotton.
2. Bombay conditions of moisture and heat are conducive to growths of fungi in the monsoons, and therefore these environments are as much to blame as the infection of fungi for the deterioration of this cotton.
3. For the study of fungi growing on cotton, it is necessary that they should be studied extensively from the cotton itself first, before attempting to grow them in cultures.
4. The stained and matted parts of lint were discovered to be seats of heavier infection of micro-organisms than the clean lint. The middle of the bale also seemed to be a more favoured site than the top.
5. In view of the well-known cellulose decomposing powers of some of the fungi detected and their abundance on this cotton, their role towards deterioration cannot be doubted.
6. Further experiments are necessary to study the decomposing powers of all the different fungi observed in this study.
7. The fungi and bacteria detected in this cotton after storage over water and on special culture media, are listed below. The identification of some of these forms could not be carried beyond the family groups:

.....

FUNGI.

- | | |
|-----------------------------|------------------------------|
| 1. <i>Aspergillus niger</i> | 10. Dematiaceae type |
| 2. <i>A. sydowi</i> | 11. Dematiaceae type 3 |
| 3. <i>A. ruber</i> | 12. Moniliaceae |
| 4. <i>Penicillium</i> sp. | 13. Phycomycetes |
| 5. <i>Mucor hygrophilus</i> | 14. Endomycetes |
| 6. <i>M. racemosus</i> | 15. Actinomyces sp. |
| 7. <i>Nematospora</i> sp. | 16. Unidentified Perithecium |
| 8. <i>Chaetomium</i> sp. | 17. Tuberculariaceae |
| 9. Dematiaceae type | 18. Phomaceae |

BACTERIA.

1. Oval bipolar bacilli forming white colonies.
 2. Bacilli forming yellow colonies.
 3. Bacilli forming brown colonies.
8. In the course of this work a new type of fungal attack on the fibre has been observed which forms the subject of a separate paper.

ACKNOWLEDGMENT.

The writer has great pleasure in recording his thanks to Dr. Nazir Ahmad, M.Sc., Ph.D., F. Inst. P., for the facilities provided, and the keen interest taken in the progress of this work.

Dated the 19th January 1937.

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DISCUSSION.

Mr. Gulati introducing his paper said that Broach Palej cotton was examined before and after storage with a view to detecting any deterioration of fibre structure induced by storage. Congo-Red Damage Test was employed for this purpose. It was found that while there were 69% undamaged hairs in the original sample, there were only 48% undamaged hairs in the stored cotton. It was in the course of this study that a new type of damage, hitherto unrecorded, was found. It was of the nature of internal corrosion of fibres and was the subject of a separate paper.

The results further showed a tendency to increased damage in the heart of the bale. A study of the conditions of moisture and temperature during the period of storage revealed that 7.8% moisture content, which was found by Armstead and Harland in 1923 to be capable of very slight growth of fungi on cotton in England, seemed to provide suitable conditions for such growth in Bombay. This resistance to fungi in England in the corresponding period could be ascribed to the lower temperature in England than in Bombay. While Bombay showed a variation in temperature from 85° in April to 80°F. in September, England recorded 45° and 60°F. during the corresponding months. It might, therefore, be concluded that the temperature and moisture conditions which were favourable for fungal growth were as much to blame for the deterioration of cotton in Bombay as the fungi. The fungi and bacteria present in this cotton were studied (1) directly from the cotton (2) after storing the cotton over water for a month in a closed jar and (3) in cultures grown on special media. The identification of some of these forms could not be completed for want of requisite apparatus and literature. Fuller identification of these forms could be only possible in a well equipped Laboratory with the help of expert systematists.

Mr. Gulati then illustrated his paper by exhibiting lantern slides.

Dr. Likhite while appreciating the very interesting paper presented by Mr. Gulati on the fungi found in bales of stored cotton expressed his opinion that most of the fungi found in the list were not limited to cotton only. For instance the *Aspergillus niger* was found in cotton soils everywhere. It was also found in onions so also *Pencillium* sp. and several of the fungi mentioned in the list were also soil fungi. Most probably they were carried along with the bolls and stored there and when they found suitable conditions in the heart of the bales they started decomposition. But from this point of view he did not know how it could be checked by other methods. He referred to a recent theory that a certain fungus could be kept under control by the presence of certain other fungi and enquired whether Mr. Gulati had tried any reactions of the kind.

Mr. Gulati explained that reactions of that kind were not tried, but said that he knew that some of these fungi were checked by nematodes in the soil. They kept the growth of these fungi under control. Cotton, when open, being a sort of stuffy sub-

stance was liable to infection not only by contact with the soil but also by air. Cotton was a very good recipient for catching infection while hanging on the plant or when stored in a heap. Apart from that, handling by the people who pick cotton was another source of infection. Insects infesting bolls, pass their faeces over them resulting in the infection of the bolls. Even in closed bolls the fungi get in along with the insects and the cotton is infected even while it is inside the boll. Thus the infection came from four sources, viz., through (1) insects (2) handling by the workers (3) air and (4) soil.

Mr. Hutchinson asked what the extent of the damage was commercially and what deterioration in terms of price took place.

Mr. Gulati answered that while he did not know the exact deterioration in price, he found that the colour of the cotton was affected making it yellow or brownish.

Mr. Wad wanted to know whether the fungi weakened the fibre and whether the checking organism was likely to save the fibre or in addition to the original organism might further affect the fibre. He pointed out that in the latter case that check would not save the cotton. A cotton bale contained a mixture of mature and immature fibres and as there was thus sufficient food in it for the organisms as well as moist and warm conditions, discoloration must follow.

Mr. Gulati answered that the fungi and bacteria weakened the fibres in several ways. They were capable of boring from the surface to the lumen of the fibre and also from inside out. Again they were capable of eating all cellulose matter from inside the fibre leaving only thin and weak cuticular tubes.

Whether the checking organism when introduced would further weaken the fibre depended upon the power of cellulose destruction of the organism. If it happened to be of the destructive type, its introduction in the bale to check other fungi cannot be beneficial in its effect. The growth of micro-organisms discoloured the cotton.

Dr. Likhite wished to know whether the internal fungi itself weakened the heart.

Mr. Gulati asserted that internal infection of micro-organisms weakened the fibres by eating away the cellulose matter.

Mr. Wad pointed out that there was also a likelihood of chemical deterioration when mature and immature fibres were incubated under humid and moist conditions, which might create a favourable medium for the growth of fungi. Because, immature fibres contained chemicals sensitive to such environments yielding products which may chemically weaken the mature fibres in the bale so that they also become suitable for the attack of the organisms. He enquired whether this had been tested as mature fibres not subjected to such a deterioration would resist chemical deterioration while immature fibres might be more readily decomposed.

Mr. Gulati explained that it was a sort of biochemical deterioration caused by the presence of the fungi which decomposed the cellulose of the fibres resulting in the formation of some organic acids.

Dr. Likhite asked if Mr. Gulati found the fungi more in watered bales so that by reducing the water in the bales the fungi could be checked.

Mr. Gulati answered that water also carried infection.

Dr. Likhite remarked that the water was introduced into the bales by vapour.

The President (Dr. Burns) enquired if no experiment had been carried out about infection through water in the cotton.

Mr. Gulati admitted that he had not attempted it.

Dr. Likhite recalled his own experience that almost all the soils of Gujarat had been affected by nematodes. These nematodes did not check the growth of the fungi, on the contrary the fungi grew almost side by side with the nematodes in the Gujarat soil.

Mr. Gulati said that this was due to their common association. The nematodes fed on these fungi though the fungi were not annihilated.

Mr. Nanjundayya referring to Mr. Wad's statement that immature fibres were open to chemical decomposition said that immature fibre contained practically no secondary thickening of cellulose, and as such was not liable to be chemically decomposed more than the mature fibre unless it was bio-chemical decomposition.

Mr. Gulati said that immature fibres carried more nitrogen content, and were, therefore, more heavily infected with micro-organisms than the mature fibres.

Dr. Nazir Ahmad explained that the usual method of distinguishing between the mature and immature fibres was to swell them in caustic soda, but once this treatment was applied it was not possible to separate one type of fibres from the other for chemical analysis, etc.

The President (Dr. Burns) referring to the explanation that nematodes lived on fungi asked if this bacteria was in any way similar to that found by Professor Dastur.

Mr. Gulati said that as he had not seen Professor Dastur's organisms he was unable to answer the query.

COTTON TECHNOLOGY

Paper No. 3

SPINNING TESTS WITH NEW STRAINS OF HYDERABAD-GAORANI

(GOSSYPIUM INDICUM, LAMK.)

COTTON GROWN IN SUCCESSIVE SEASONS OR IN

DIFFERENT LOCALITIES

BY

K. SAWHNEY,

COTTON RESEARCH BOTANIST, PARBHANI.

Cotton improvement work in any area may have one or several objects in view. The production of a type giving higher yield than the existing variety is perhaps the commonest and the primary object. It benefits the grower directly, provided, of course, the new strain is not inferior to its predecessor in ginning out-turn and spinning qualities. The breeding of strains with higher ginning out-turn, earlier maturation, more resistance to diseases and pests, greater capacity to stand heavy or late rains or vagaries of other environmental factors, and better spinning performance than the existing varieties, are some of the other ends to which the cotton improvement may be directed. But as a very large part of the crop is destined for spinning, it will be readily conceded that while improvement is being effected in other characters, no deterioration should be allowed to take place in spinning properties. For a

correct appreciation of the possibilities of the new strains, it is necessary to possess an accurate knowledge of their spinning properties as compared with those of the varieties that they are intended to replace. We should know definitely that when their produce reaches the manufacturer, the new types will give him no cause for complaint or incur his displeasure. Comparative spinning tests conducted by the Cotton Committee's Technological Laboratory in Bombay or by the Shirley Institute in Manchester are the best existing means of judging the spinning value of new strains. However, cotton plant is very sensitive to changes in environment and often shows pronounced reactions to them. It is, therefore, neither possible nor desirable to base one's considered judgements on the spinning results of one season or of samples grown in only one locality. Comparative experimental spinning has to be done in several successive seasons and on samples grown in a number of places.

Work for the improvement of Hyderabad-Gaorani has been in progress for the last six years. Of the numerous selections made and tested for yield and spinning performance, two strains, Gaorani 4 and Gaorani 6, have now reached a stage when a final choice has to be made between them for extensive cultivation. The results of their spinning tests for the last four years and for six localities in one year are summarised in Tables I and II. The results of their spinnings in specified counts in successive seasons are given in Table III. From a study of the data presented in these tables, it will be seen that although the magnitude of variation in spinning performance is great, yet the new strains retain their superiority over local Gaorani in all the seasons and in most of the places. However, the spinning performance of both the new strains for one place (*i.e.*, Latur) shows a marked falling off as compared with other sites. It is difficult to judge from one season's results how far this fall is due to the unsuitability of the new types to the conditions normally obtaining at this place. Leaving Latur aside for the present, it does seem that in Gaorani 6 we have a strain which can safely be considered as somewhat superior to the local variety.

The question needing a decision is whether on the available evidence the final selection of Gaorani 6 as a better cotton is justified or not. It must be stated clearly that Gaorani 6 has the other attributes of greater yield, higher ginning out-turn and earlier maturity than the local.

TABLE I.

Results of spinning tests with Hyderabad-Gaorani, Gaorani 4 and Gaorani 6 grown at Parbhani in successive years from 1932-35.

Strain or variety.	Year.	Fibre-length (inch)		Fibre weight per inch. (Millionth of an ounce.)	Waste percentage.		Yarn breakages per 100 spindles per hour.	Turns per inch.	Counts actual.	Lea strength. (lbs.)	Neps per yard.	Highest standard warp counts for which adjudged suitable.
		Ball's sorter	Baer's sorter		Blow Room.	Card Room.						
Hyderabad-Gaorani	1932	0.83	0.81	0.162	6.9	8.7	55	19.73	23.7	59.3	2.0	24's
	1933	0.84	0.82	0.173	4.1	8.3	23	19.73	24.0	57.1	1.5	24's
	1934	0.81	0.82	0.181	4.1	7.8	5	19.73	23.6	72.6	1.0	26's
	1935	0.79	0.82	0.162	6.2	8.2	50	19.73	23.9	56.2	2.0	23's
Gaorani 4	1932	0.86	0.86	0.165	4.4	6.7	13	21.86	29.4	45.8	1.8	28's
	1933	0.86	0.86	0.164	4.5	8.0	14	19.73	23.9	65.3	3.0	26's
	1934	0.86	0.86	0.178	3.13	7.2	15	23.26	33.0	46.0	1.5	34's
	1935	0.86	0.86	0.151	4.8	7.4	20	21.86	30.1	43.7	3.0	27's
Gaorani 6	1932	0.85	0.84	0.157	4.4	7.0	41	25.28	39.8	37.9	1.8	38's
	1933	0.87	0.84	0.151	4.5	6.7	20	21.86	29.8	48.8	1.8	30's
	1934	0.85	0.85	0.154	3.6	6.7	12	25.28	40.0	39.9	2.0	41's
	1935	0.82	0.78	0.147	6.6	6.9	19	25.28	40.5	36.7	2.2	38's

TABLE II.

Results of spinning tests with Hyderabad Gaorani, Gaorani 4 and Gaorani 6 grown at six localities in 1934-35.

	Hyderabad-Gaorani.						Gaorani 4.						Gaorani 6.					
	Parbhani	Nanded	Umri	Medhol	Loha	Latur	Parbhani	Nanded	Umri	Medhol	Loha	Latur	Parbhani	Nanded	Umri	Medhol	Loha	Latur
Fibre length (inch.)																		
Ball's sorter ..	0.81	0.84	0.85	0.79	0.82	0.84	0.86	0.88	0.88	0.87	0.83	0.80	0.85	0.86	0.86	0.88	0.82	0.82
Baer sorter ..	0.82	0.81	0.84	0.80	0.82	0.82	0.86	0.84	0.86	0.86	0.80	0.80	0.85	0.83	0.86	0.86	0.82	0.80
Fibre weight per inch (Millionth of an ounce)	0.181	0.177	0.172	0.189	0.168	0.180	0.178	0.183	0.175	0.187	0.163	0.192	0.154	0.166	0.166	0.188	0.162	0.179
Blow Room loss (%) ..	4.1	4.4	10.0	7.8	9.8	8.4	3.3	4.4	6.9	5.8	5.6	5.0	3.6	3.1	5.8	4.1	4.7	4.4
Card Room loss (%) ..	7.8	6.9	8.0	8.1	8.4	8.7	7.2	7.0	7.3	6.8	7.4	8.1	6.7	6.8	6.6	6.8	6.6	7.5
Yarn breakages per 100 spindles per hour ..	5	10	13	20	20	14	15	7	..	6	17	27	12	5	29	19	13	20
Turns per inch ..	19.73	21.86	21.86	21.86	21.86	19.73	23.16	21.86	23.26	23.26	21.86	19.73	25.28	25.28	25.28	25.28	21.86	21.86
Counts actual ..	23.6	29.5	29.6	29.7	30.9	24.3	33.0	30.4	34.4	33.7	29.5	24.1	40.0	39.0	39.5	40.9	29.8	29.6
Lea strength (lbs.) ..	72.6	52.3	53.0	46.7	42.9	57.8	46.0	52.4	47.4	46.1	54.5	59.6	39.9	40.9	38.5	31.5	58.4	52.7
Neps per yard ..	1.0	0.8	1.5	1.8	1.8	1.8	1.5	1.5	2.5	1.8	2.0	1.0	2.0	1.5	0.8	2.0	1.0	1.0
Highest standard warp counts for which adjudged suitable ..	26's	21's	32's	28's	28's	25's	34's	34's	37's	35's	33's	25's	41's	40's	38's	36's	35's	31's

TABLE III.

*Results of spinning tests with Hyderabad-Gaorani, Gaorani 4 and Gaorani 6
in specified counts in successive seasons.*

Variety or strain.	Counts nominal.	Year.	Yarn break-ages per 100 spindles per hour	Turns per inch.	Counts actual.	Lea strength lbs.	Neps per yard.	Highest standard warp counts for which adjudged suitable.
Hyderabad-Gaorani	20	1932	21	17.98	19.4	79.8	2.2	
		1933	47	"	20.0	74.1	2.0	
		1934	0	"	20.3	78.1	0.8	
		1935	21	"	20.1	73.4	1.8	
	24	1932	55	19.73	23.7	59.3	2.0	24
		1933	23	"	24.0	57.1	1.5	24
		1934	5	"	23.6	72.6	1.0	26
		1935	50	"	23.9	56.2	2.0	23
	30	1932	50	21.86	29.5	38.7	2.2	
		1933	53	"	29.8	37.5	1.8	
		1934	13	"	30.2	41.0	1.2	
		1935	36	"	30.3	34.9	1.2	
Gaorani 4	20	1932	47	17.98	19.4	92.1	0.8	
		1933	36	"	20.2	78.9	2.8	
		1934	0	"	20.3	89.9	1.5	
		1935	21	"	20.1	81.4	2.5	
	24	1932	36	19.73	24.1	69.6	1.5	
		1933	14	"	23.9	65.3	3.0	
		1934						
		1935	9	19.73	23.9	65.0	3.5	
	30	1932	13	21.86	29.4	45.8	1.8	28
		1933	60	"	30.2	38.5	3.0	26
		1934	13	"	30.2	54.0	1.0	34
		1935	20	"	30.1	43.7	3.0	27
34	1934	15	23.26	33.0	46.0	1.5		

TABLE III.—contd.

*Results of Spinning tests with Hyderabad-Gaorani, Gaorani 4 and Gaorani 6
in specified counts in successive seasons.*

Variety or strain.	Counts nominal.	Year.	Yarn break- ages per 100 spindles per hour	Turns per inch.	Counts actual.	Lea strength lbs.	Neps per yard.	Highest standard warp counts for which adjudged suitable.
Gaorani 6	20	1933	31	17.98	19.9	89.5	1.5	
		1934	36	„	20.0	116.6	2.5	
		1935	0	„	20.0	102.7	2.5	
	30	1932	20	21.86	30.1	60.1	2.0	38
		1933	20	„	29.8	48.8	1.8	30
		1934	0	„	30.4	63.8	3.0	41
		1935	33	„	29.2	63.3	3.0	48
	40	1932	41	25.28	39.8	37.9	1.8	38
		1933	68	„	39.4	27.1	1.5	30
		1934	12	„	40.0	39.9	2.0	41
		1935	19	„	40.5	36.7	2.2	38
	44	1932	34	26.75	45.3	30.7	2.5	

DISCUSSION.

Rai Sahib Kalidas Sawhney said that this was not a record of original research in the technique of spinning tests but was merely an attempt to collate the results of comparative spinning tests carried out on samples supplied to the Technological Laboratory. His aim in bringing forward this subject was merely to invite the opinion of people who were more conversant with technological research and finding out if he had reached a stage to select a good strain. The second point on which opinion was invited was the greater variation from season to season in the spinning performance of new strains as compared with the seasonal variation in the spinning performance of the local variety. Table I showed the spinning records of the local Gaorani for four years. All these samples were grown at one place under controlled conditions so that the results could be compared with the results of different varieties. In that table the results for Hyderabad Gaorani, Gaorani 4 and Gaorani 6 were arranged in order. From the last column giving the highest standard warp counts, it would be seen that the range of variation for Hyderabad Gaorani during these four years was very narrow as compared with the range of variation for the other two types, Hyderabad Gaorani being suitable for 25's to 26's, Gaorani 4 for 26's to 34's and Gaorani 6 for 30's to 41's. In all seasons it was interesting to note that the relative position of the three varieties remained unchanged in regard to spinning quality. As regards the range of variation for the same three varieties for one season but grown in different localities scattered over the Gaorani area, he found that it was 25's to 32's for local Gaorani, 25's to 37's for Gaorani 4 and 31's to 41's for Gaorani 6. The leaf strength for specified counts in different areas also showed a similar variation.

Dr. Nazir Ahmad said that the question raised by Rai Sahib Kalidas Sawhney at the bottom of page 2 of his paper could be answered by an analysis of the data. He could have done so had he known that this question was coming up for discussion. If Rai Sahib Sawhney would supply him with all the data available with him, he would gladly assist him in coming to a conclusion on this important point.

Mr. Hutchinson considered that a good enough consistent improvement as compared with the local variety had been recorded at least in parts of the Gaorani area. In the area where the local spun the lowest the improved strains showed little or no improvement so that it looked as though the improved strains were quite likely to be better in the better parts of the area and would not improve in the inferior parts of the area and that would probably involve a very careful enquiry as to the relative local adaptation. The interesting point was that the new strains varied considerably more from season to season and from place to place in the same season than the local type. He referred to the Report of the Hyderabad Cotton Survey Scheme and said that the most important fact which might be correlated was that Hyderabad Gaorani as normally marketed contained not only -Bani but 30% of hirsutum and it was worth while studying the data from the point of the relative uniformity

of behaviour of pure strains and mixtures. It was quite possible that though a mixture might not give as good a result as a selected pure strain, a properly designed mixture might give a regular behaviour from season to season. He expressed his view that the properties of mixtures were very important in cotton growing in India. There were two cotton producing areas in India of Upland and deshi mixtures—the Gaorani tract and the Malwi tract of Central India. At least in Central India the local mill people were sufficiently familiar with the mixture to be quite content to maintain it. They knew the mean behaviour and paid the full premium for the mixed quality grown, so that any irregularity in the mixture did not arise. It would be worth investigating whether a more uniform behaviour could not be obtained from season to season and from place to place with the mixed grown type than the pure type, and if this were done measures could be taken to grow types which would behave uniformly. It was also worth noting that an enquiry recently made into the relations of botanical species and varieties to spinning value brought out the fact that the *G. Arboreum* cottons like Karungannis and Northernns were much less variable from season to season than the Northern arboreum cotton. He was aware at the time of the enquiry that Bani was a mixture. The other types were pure strains and there seemed to be some evidence in literature that the South Indian cottons did not vary so much from season to season as some of the North Indian cottons.

Dr. Nazir Ahmad, referring to the growing of mixtures advocated by Mr. Hutchinson, said that the opinion of the consumers should be ascertained as he felt that they would be definitely against such tendency as it would open the door for certain mal-practices. Watering on the one hand and mixing on the other formed two very great drawbacks to the reputation of Indian cottons, one in the Central Provinces and the other in the Punjab, and a policy of the kind suggested by Mr. Hutchinson should be recommended only after deep and mature consideration. As regards the behaviour of different strains there was a good deal in what Mr. Hutchinson said. If a mixture was made of two components A and B and it gave a uniform behaviour, it could only be possible either by the two components behaving in a uniform manner, or the variation in A in one direction being neutralised by the variation in B in the opposite direction. So far as purely theoretical considerations were concerned, it would be worth while studying such mixtures in which one of the two components was kept constant.

Mr. Mohammad Afzal, referring to the fact the local Gaorani had always been spinning less than the improved Gaorani said that this was probably due, apart from greater length of lint of the improved Gaorani, to its low fibre weight. But low fibre weight might have been induced by the presence of a greater proportion of immature hairs. He instanced the case of Punjab Cottons where variation in spinning performance of improved types was more than in the case of deshi. It would thus appear that the variation in spinning performance of the improved Gaorani types was

probably due to the presence of a greater proportion of immature hairs which varied from year to year.

Mr. V. G. Panse said that variation in spinning value was related to the degree of adaptation of a type to a tract. In Central India the local mixture was made up of Upland and deshi components which gave less percentage of variation over a series of years. Another type was Malwi 9, a pure selection obtained from the mixture. The local mixture gave about 2% and the Malwi 9 about 3% error, and Cambodia which was the most ill-adapted type gave as high as 9% standard error.

Rai Sahib Kalidas Sawhney explained that the point raised by Mr. Hutchinson that some of the new strains might not be as well fitted to the different parts of the Gaorani area had been brought out in his second paper, where he had stated that Gaorani 4 and Gaorani 6 did not seem to be well adapted to the south-western part adjoining the Sholapur district where the spinning performance of the local variety was the lowest. In that area Gaorani 6 had given slightly higher performance as compared with the local but Gaorani 4 had not given any improved performance. Regarding the second point relating to mixture of new strains, he said that an experiment with improved strains and their mixtures was already being conducted. For this purpose Gaorani 4 and Gaorani 6 were grown in small replicated plots alongside a mixture consisting of Gaorani 4 and 6, half and half, and another containing 40 per cent of each of the two pure strains and 20 per cent of American. The local variety was also included in this test. Lint samples from this experiment would be sent to the Committee's Technological Laboratory shortly. Thus results of fibre tests would be available for the local variety, for pure Gaorani 4 and 6, for half and half mixture of the two and for 40 per cent mixture of each of the two pure strains with 20 per cent. of American. This experiment would be repeated for a number of years. The idea at the back of the experiment was to find whether or not, in a given locality, mixtures of pure strains gave more uniform spinning performance over a series of years than the pure strains themselves. Regarding Mr. Mohammad Afzal's point that the greater variation in the spinning performance of the new strain might be due to the higher variation in the percentage maturity of fibres from season to season in the new types as compared with the local variety, he said that he had had no opportunity of examining this point till then, but that he would make a study of the data collected by the Technological Laboratory.

COTTON TECHNOLOGY

Paper No. 4.

EFFECTS OF RAINFALL ON THE QUALITY OF INDIAN COTTONS

BY

R. S. KOSHAL & NAZIB AHMAD.

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 - VII. Influence of rainfall at different periods of the season on the quality of cotton
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I. INTRODUCTION & SUMMARY.

It has been known for a long time that cotton is one of those crops which are susceptible to considerable variations in quality under different soil and climatic conditions. Since the very inception of the Technological Laboratory in 1924, tests on the spinning value and fibre properties have been carried out, year after

year, on a number of standard Indian cottons, which are grown in different parts of India. The importance of these tests was early recognised by Turner¹ (1927), and later stressed by one of us, Nazir Ahmad² (1931). In course of time these records will form an excellent material for the study of weather factors on the quality of cotton. In this respect the work of the Laboratory relating to tests, under known and reproducible conditions, on the same varieties grown from pure seed for which full agricultural details are available, is unique among the sister institutions of the world. For the present, data to the extent of 13 years only are available, and these have been examined with a view to finding out (a) the secular change in quality, (b) the influence of rainfall in causing the annual variation. Fisher's method³ of fitting polynomials has been employed for the analysis of the data. Fifth degree polynomials are fitted to the weekly totals of rainfall every year. These provided six constants, which specified the average and the distribution of rainfall throughout the season. The secular trend in the rainfall distribution values as well as in the quality data was eliminated by fitting polynomial of the second degree, and on the residuals thus obtained the multiple regression equation was worked out. On account of the small number of years for which the quality data are available, each cotton could not be treated separately, but certain cottons were grouped together in accordance with the locality of growth and distribution of rainfall. The following four groups of cottons are discussed in this paper :—

- (a) Verum 262, Nagpur and Akola, C. A. 9.
- (b) Wagad 8, and Surat 1027 A. L. F.
- (c) Jayawant, and Nandyal 14.
- (d) Hagari 1 and Gadag 1.

From the results curves have been drawn to show at any particular period of the year, the benefit or harm to cotton of an additional inch of rain over the average.

From the analysis of the results the following conclusions can be drawn :—

(i) Rainfall is an important weather-element controlling the quality of cotton. It accounts for about $\frac{1}{3}$ to $\frac{1}{2}$, the total annual variation (obtained after removing the effect of secular change) in quality.

(ii) Rain in the last stage of ripening, *i.e.* 'the picking period' is harmful.

(iii) In the maturation period, additional rain is beneficial. Rainfall during this period is associated with higher temperature, and it is probably the moist heat that is useful for the proper thickening of the fibres.

(iv) In the case of cottons, Verum 262, C. A. 9, Wagad 8 and Surat 1027 A. L. F., the growing period may be divided into two parts—in the first half *i.e.* in July and August additional rain is beneficial, while in the second half *i.e.* in September and

October it is definitely harmful. On the other hand for cottons like Jayawant, Nandyal, Hagari I, and Gadag 1 additional rain is harmful throughout the growing season. This is due to the fact that most of the rain falls prior to sowing and during the sowing period; consequently the soil is saturated with moisture due to the residual effects of previous rain. It is suggested that well designed field experiments should be carried out at Dharwar and Nandyal Agricultural Stations with a view to finding out the optimum conditions of sowing.

(v) The 'Rainfall curves' in fig. 12-15 provide a useful index to the application of water by irrigation in any year of partial failure of rain. In cottons which are partly rain-fed and partly irrigated, irrigation water should *not be* given in equal amounts and in equal intervals of time, but should be properly adjusted with the amount and distribution of rainfall.

II. METHOD OF INVESTIGATION.

A.—*Introductory*.—The prediction of the quality of cotton from weather elements presents a very complex problem due to (a) difficulty of specifying weather (b) lack of comparable data. The environmental conditions of a growing plant can be satisfactorily expressed in terms of instrumental observations (such as rainfall, maximum and minimum temperature, soil temperature, hours of bright sunshine, dew point, direction and force of the wind) of a modern meteorological station. Although long records of some of these instrumental observations are available, at some of the cotton growing centres,* equally long records of values specifying quality of cotton crop are not available to make full use of them for prediction purposes. Consequently, we are compelled for the present, to select one or two important factors from the weather sequence. Of the various weather elements which might be expected to influence the growth and quality of cotton, rainfall and temperature may be regarded as the most important ones. The average values of rainfall (as published in the official records) are of little help in the study of crop-weather relationship, for it is the distribution of rainfall in a specified period that has a more pronounced effect in determining the good or bad quality of a crop.

Since a set of annual values generally show a trend in one direction or the other, before any crop-weather relationship is attempted, the crop data must be examined with a view to eliminating slow changes that might have taken place in the course of time. This will be more fully discussed under 'Secular change', but it should be sufficient to state here that the residuals, obtained after eliminating the slow changes, if any, in a crop record, are the proper values suitable for correlation with weather factors.

*The Indian Central Cotton Committee Technological Laboratory was established in 1924, and since then accurate records of quality of cotton grown in the principal cotton centres of India are available.

Of the weather elements, we will first consider rain, which provides a sufficiently complex sequence in our climate. The general distribution of rainfall could be represented by a few monthly or bi-monthly averages, if the rainfall were approximately evenly distributed in successive weeks. But rainfall in India is generally concentrated in short spells, separated by variable rainless periods. Consequently, the values for different periods in successive years are not necessarily equivalent. The great importance of this point will be appreciated more fully from the following table giving the values of rainfall totals for 4 and 8 week periods and commencing from 1st July each year, for the Agricultural Research Farm, Nandyal.

TABLE 1. A.

Four-weekly totals of rainfall—Nandyal.

Period	1924-25	25-26	26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35
1	8.07	6.89	4.57	6.85	12.98	1.44	2.75	1.93	1.62	4.24	3.43
2	3.19	5.69	1.87	4.27	4.77	2.90	2.08	2.09	5.31	9.46	6.05
3	4.87	5.16	9.67	6.20	3.57	1.48	5.28	7.89	2.59	6.20	4.77
4	2.81	11.86	1.97	5.19	5.35	8.40	4.32	7.16	0.72	3.82	2.08
5	2.10	0.42	..	2.22	0.84	0.79	3.18	2.65	3.97	0.62	2.44
6	0.23	0.88	0.10	..	0.13	..	0.34	..	0.44	2.25	..
7	..	0.26	..	..	0.05	..	0.01	0.05	..	0.62	..
8	..	0.40	..	1.10	0.19	..	..	..	..	..	..
9	..	..	..	..	..	0.13	..	0.24	0.40	..	..
10	0.81	0.05	..	0.26	..	0.50	0.05	..	..	..	1.35

TABLE 1. B.

Eight-weekly totals of rainfall—Nandyal.

Period	1924-25	25-26	26-27	27-28	28-29	29-30	30-31	31-32	32-33	33-34	34-35
1	11.26	12.58	6.44	11.12	17.75	4.34	4.83	4.02	6.93	13.70	9.48
2	7.68	17.02	11.64	11.19	8.92	9.88	9.60	15.05	3.31	10.02	6.85
3	2.33	1.30	0.10	2.22	0.97	0.79	3.52	2.65	4.41	2.87	2.44
4	..	0.66	..	1.10	0.24	..	0.01	0.05	..	0.62	..
5	0.81	0.05	..	0.26	..	0.63	0.05	0.24	0.40	..	1.35

The four-weekly totals are combined to give eight-weekly totals of rainfall and these are given in Table 1 B. In this manner we get 5 values for each season and these could satisfactorily represent the whole season if the distribution of rainfall within the corresponding eight-weekly period were similar from season to season. We find, however, that this actually is not the case. Thus, although the 1st eight weekly period in 1926-27 and 1932-33 gave approximately the same values, yet the values for the four-weekly totals for these years are different. For instance the first four-weekly period in 1926-27 recorded about $2\frac{1}{2}$ times as much rain as the second four-weekly period, while in 1932-33 the position is reversed and the second period gave more than three times the rain than the first period. Thus, in 1926 heavy rain fell in the first four-weekly period, while in 1932 the order is reversed which cannot be supposed to have similar effect on the growing plant. This clearly shows the necessity of dividing the season into finer subdivisions, *e.g.*, weekly values if possible. But we cannot use weekly values directly for correlation purposes, for sufficiently long records of crop data are not available. Even if sufficiently long records were available, the immense labour involved in the solution of regression equations would prevent us from adopting such a method. We have consequently adopted an ingenious method devised and used by Fisher in the study of 'The Influence of rainfall on the yield of wheat at Rothamsted'.⁴

B. *Fisher's method of fitting Polynomials.* - In this method the relevant information is contained in a number of 'rainfall distribution values' obtained by fitting orthogonal polynomials to the weekly totals of rainfall for each season—thus making full use of the meteorological data and yet reducing the constants to a small number. Thus, if we fit polynomial of the fifth degree to the weekly totals of each season, we get six constants which specify the average value and the distribution of rainfall throughout the season. These rainfall distribution values serve two purposes:— (1) to give the secular variation of rainfall from season to season (2) form a set of independent variables for evaluating the regression equation between the yield or quality and rainfall sequence. It may be mentioned, however, that before using them for correlation purposes, the secular change (as in the crop data) should be eliminated. The regression coefficients thus obtained enable us to determine the change of regression function *with time* which is a special feature of *this method*. In this manner curves can be drawn showing the benefit or loss to the crop of an additional inch of rain over the average. Thus if $r_1, r_2, r_3 \dots r_{31}$ are the quantities of rain (*i.e.*, weekly totals) for the 31 weeks during which the crop cycle may be completed, the linear regression of fibre-length upon rainfall would take the form—

$$L=c+a_1 r_1+a_2 r_2+a_3 r_3 \dots +a_{31} r_{31} \dots \dots \dots (1)$$

where $a_1, a_2, a_3, \dots, a_{31}$ are the regression co-efficients. If infinitely small subdivisions of time be taken, the regression equation would be replaced by the regression integral—

$$L=c+\int_0^T ardt \dots \dots \dots (2)$$

where rdt is the rain falling in the time element dt . a is now the continuous function of time, and represents an 'objective physical quantity'—namely the average increase or decrease in length due to an additional inch of rain in the time limit considered.

If time is measured from the mid-point of a series of terms, a is given by :—

$$a=A+Bt+C(t^2-n_2)+D(t^3-\frac{n_4}{n_2}t)+E(t^4-\frac{n_6-n_4n_2}{n_4-n_2^2}t$$

$$+\frac{n_2n_6-n_4^3}{n_4-n_2^2})+F(t^5-\frac{n_2n_8-n_4n_6}{n_2n_6-n_4^2}t^3+\frac{n_4n_8-n_6^2}{n_2n_6-n_4^2}t)$$

.....(3)

where

$$n_2 = \frac{1}{12}(n^2-1)$$

$$\frac{n_4}{n_2} = \frac{1}{20}(3n^2-7)$$

$$\frac{n_6-n_2n_4}{n_4-n_2^2} = \frac{1}{14}(3n^2-13)$$

$$\frac{n_2n_6-n_4^3}{n_4-n_2^2} = \frac{3}{560}(n^2-1)(n^2-9)$$

$$\frac{n_2n_8-n_4n_6}{n_2n_6-n_4^2} = \frac{5}{18}(n^2-7)$$

and

$$\frac{n_4n_8-n_6^3}{n_2n_6-n_4^2} = \frac{1}{1008}(15n^4-230n^2+407)$$

The six co-efficients A, B, C, D, E and F are obtained from the six partial regression coefficients $b_1, b_2, b_3, b_4, b_5,$ and b_6 , evaluated by correlating the quality residuals with the rainfall distribution value residuals by dividing them by factor

of the form $\frac{(r!)^2}{(2r)!} n(n+1) \dots \dots (n+r)$
(r=0, 1, 2, 3, 4 and 5)

TABLE 2.

Secular Change in Bombay Cottons.

Cotton	Variance due to	Degrees of freedom	H. S. W. C.		Fibre-length.		Fibre-weight.	
			Sum of squares.	Mean square.	Sum of squares.	Mean square.	Sum of squares.	Mean square.
Jayawant	Deterioration ..	1	2.40	2.40	.000882	.000882	.000829	.000829*
	Slow changes ..	1	2.31	2.31	.001860	.001860	.000835	.000835*
	Residual ..	6	21.51	3.59	.004547	.000758	.000928	.000155
	Total ..	8	26.22		.007289		.002592	
Gadag 1	Deterioration ..	1	13.83	13.83	.000328	.000328	.000045	.000045
	Slow changes ..	1	0.62	0.62	.000303	.000303	.000006	.000006
	Residual ..	8	128.46	16.06	.006642	.000830	.000754	.000094
	Total ..	10	142.91		.007273		.000805	
Surat 1027 A. L. F.	Deterioration ..	1	28.48	28.48*	.000159	.000159	.000456	.000456
	Slow changes ..	1	2.89	2.89	.003834	.003834	.000047	.000047
	Residual ..	10	61.71	6.17	.007976	.000798	.001289	.000129
	Total ..	12	93.08		.011969		.001792	
Wagad 8	Deterioration ..	1	0.08	0.04	.000058	.000058	.000036	.000036
	Slow changes ..	1	2.15	3.92	.000057	.000057	.000010	.000010
	Residual ..	8	23.95	3.32	.004376	.000547	.005967	.000746
	Total ..	10	26.18		.004491		.006013	

* Indicates significance for 5 per cent point.

** " " " " 1 " "

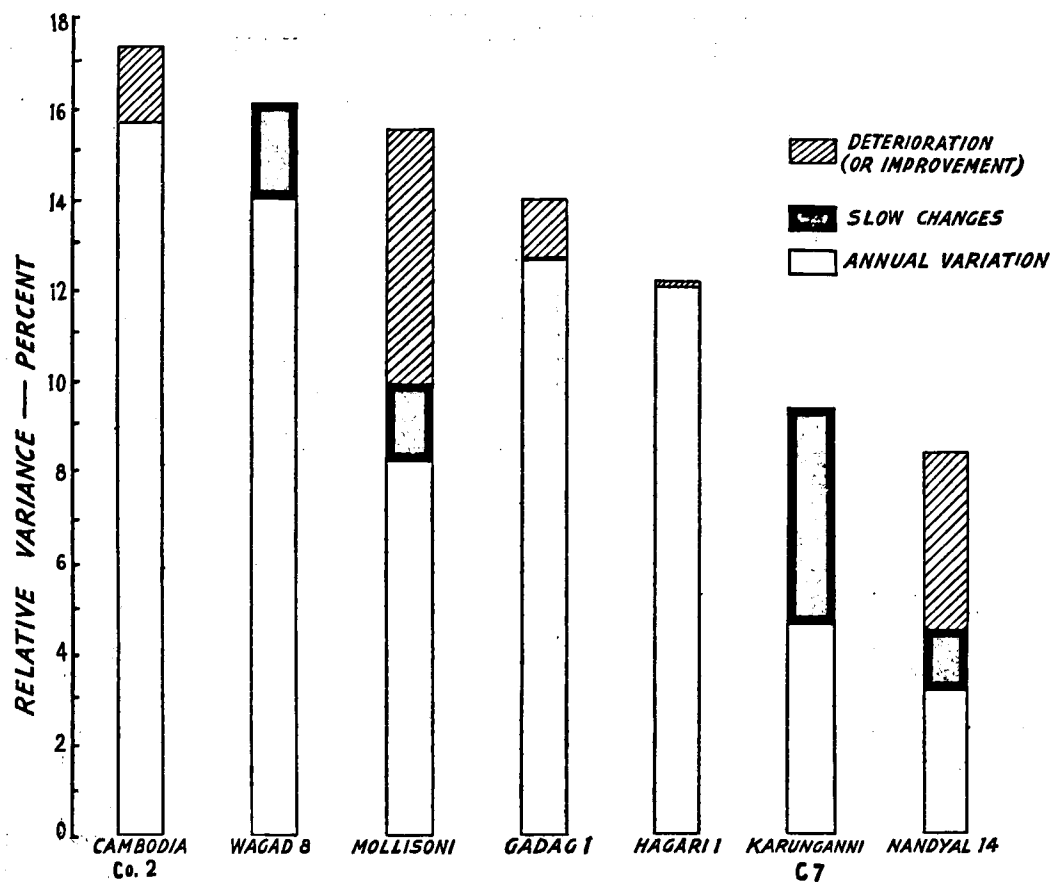


Fig. 1.—Causes of Variation in the Quality of Standard Indian Cottons.
A.—Cottons for which data for 11 years are available

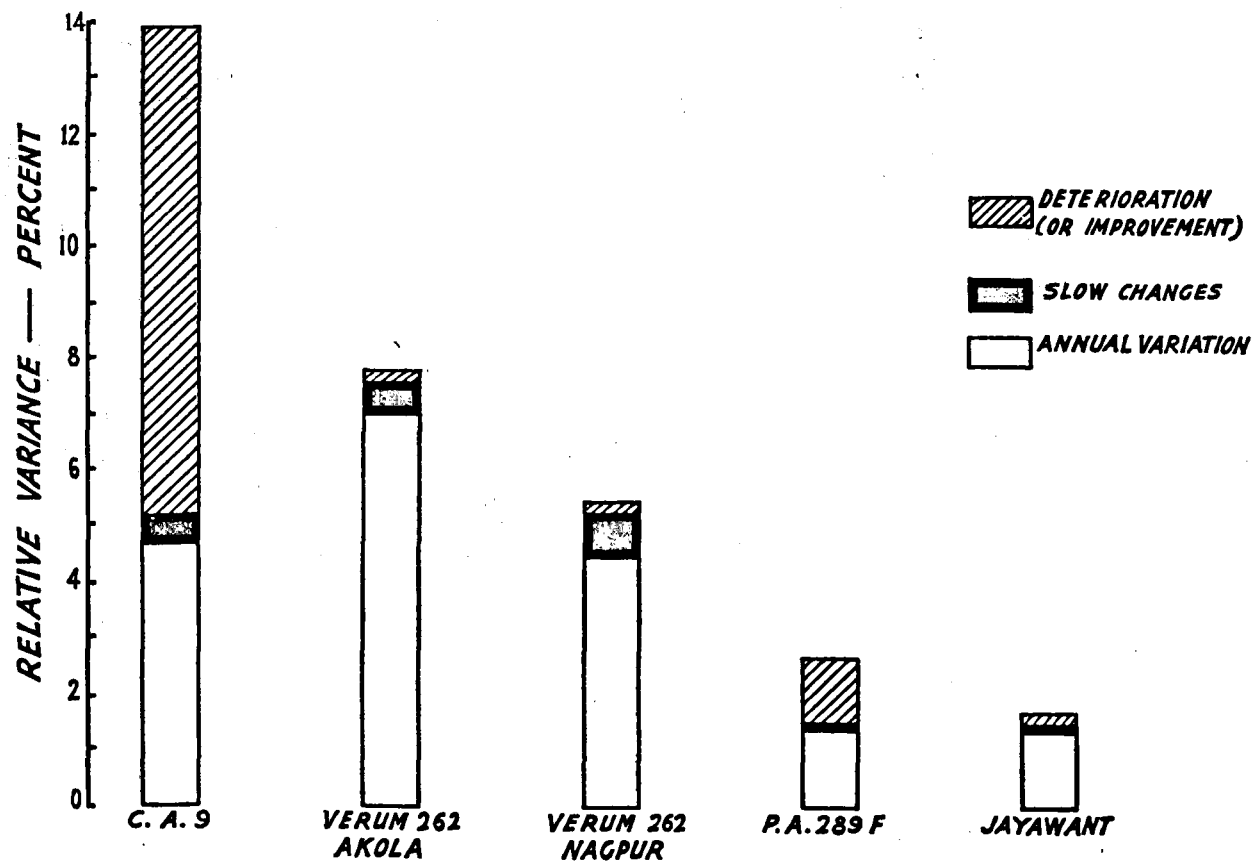


Fig. 1.—Causes of Variation in the Quality of Standard Indian Cottons.
 B.—Cottons for which data for 9 years are available.

TABLE 3.

Secular change in Punjab Cottons.

Cotton	Variance due to		H. S. W. C.		Fibre-length.		Fibre-weight.		
			Degrees of freedom.	Sum of squares.	Mean square.	Sum of squares.	Mean square.	Sum of squares.	Mean square.
289F.	Deterioration	..	1	126.59	126.59**	.005531	.005531**	.000250	.000250
	Slow changes	..	1	9.44	9.44	.000746	.000746	.000320	.000320
	Residual	..	8	52.70	6.59	.005487	.000686	.001744	.000218
	Total	..	10	188.73		.011764		.002314	
4F.†	Deterioration	..	1	0.94	0.94	.000027	.000027	.001837	.001837*
	Slow changes	..	1	27.78	27.78	.000748	.000748	.000874	.000874*
	Residual	..	6	129.78	21.63	.007825	.001304	.002025	.00038
	Total	..	8	158.50		.008600		.004736	
Mollisoni	Deterioration	..	1	3.64	3.64**	.000663	.000663	.0001265	.000126
	Slow changes	..	1	1.05	1.05	.001188	.001188	.0000002	.000002
	Residual	..	8	5.31	0.69	.004313	.000539	.0030400	.000380
	Total	..	10	10.00		.006164		.0031667	

† Effect of climate on lint samples has been used.

The arithmetic of the evaluation of 'rainfall distribution values, with special reference to Indian conditions' is given in Appendix I.

III. SECULAR CHANGE IN QUALITY OF INDIAN COTTONS.

Each of the standard Indian cottons (which provided the material for this investigation) has been grown from year to year on the same farm and has been tested for quality at the Technological Laboratory. When the annual figures for highest standard warp counts and fibre-properties are examined it is found that the nature and extent of variation is different for the different cottons. Part of this variation may be due to the progressive changes brought about by the gradual exhaustion of the soil in certain essential plant nutrients, weed infestation of the field, the adaptability of the seed to the special soil condition, etc., etc. Allowance should therefore be made for this variation before we study the effect of weather factors. This 'secular change' in a set of annual figures can be represented adequately by a polynomial whose degree is small compared to the number of observations in the series. In the present investigation as we do not possess more than 13 values for any one cotton, we have used polynomial of the second degree only. The total variance is thus analysed into 3 factors (1) deterioration or improvement, (2) slow changes, (3) annual causes. The results are given in tables 2, 3, 4 and 5, classified in accordance with the province in which the cotton is grown.

TABLE 2.

(See page 210)

Of the four Bombay cottons, only Jayawant and Surat show any appreciable secular trend. In Jayawant, both deterioration and slow changes are significant for 5 per cent point for fibre-weight. The values of X'_2 and X'_3 (given in Appendix) are both negative—showing the tendency towards the development of finer fibres. This is probably due to the exceptionally low values of fibre-weight in the years 1933-34, 34-35. For Surat cotton the mean square for 'Deterioration' is more than four times the residual (based on 10 degrees of freedom) and it is significant. Since the sign of X'_2 is +ive, there appears to be a tendency for improvement which may show up when larger number of annual values become available. Both Gadag I and Wagad 8 have indicated no secular change in their lint properties—length and weight or in the spinning values of the yarns spun from them.

TABLE 3.

(See page 211)

All the Punjab cottons have shown progressive change during the period under investigation. More than 65 per cent. of the total variance in highest standard warp counts of 289F is accounted for by a single degree of freedom—improvement (since

the sign of X'_2 is +ive). This is largely due to the two very low values 34 and 32; but even when these are excluded and the results are analysed for the remaining nine years, this effect (*i.e.*, slow improvement) is significant.

289F (9 years. 1926-27—1934-35)

excluding the years 1924-25, 1925-26.

Source of variation	Degrees of freedom.	Sum of squares	Mean square	Z
Improvement:	1	21.60	21.60	
Slow change:	1	71.67	25.96	3.7085.8815
Residual	6	24.29		
Total	8	47.56		

For the tests of significance the degree of freedom for slow change is combined with residual—5% value of Z is .860; the observed value .8815 being greater, shows that there is a definite tendency for the development of better quality of cotton with the progress of time in spite of the fact that fibre-length values have indicated a slow deterioration. There appears to be slight improvement in 4F as reflected from the fibre-weight values; X'_2 is $-.04286 \pm .018$, showing the development of fine staple. Mollisoni has also indicated a slight improvement in quality—the mean square for 'Deterioration' is significant; $X'_{2..}$ ($=1.9069 \pm .83$) is +ive and more than twice its standard error.

TABLE 4.

(See page 214)

Like 289F, the U. P. cotton C. A. 9 has indicated a remarkable improvement in the spinning performance as reflected by the highest standard warp counts values for the different seasons, and likewise a deterioration in the fibre-length values. The large sum of squares—both for a single degree of freedom—deterioration (101.40) and for the total (162.00) are due to the two very low values 28 for each of the two seasons 1924-25 and 1925-26. Both the Verum cottons have shown a slight tendency for the decrease of staple length, X'_2 for Nagpur variety is $-.055 \pm .028$, and for Akola variety it is $-.0387 \pm .018$. The effect of this tendency, however, is not reflected in the highest standard warp counts. It may be noted, however, that these results are based on only 9 annual values, consequently very definite conclusions cannot be arrived at with regard to secular change in quality.

TABLE 4.

Secular Change in U. P. and C. P. Cottons.

Cotton.	Variance due to	Degrees of freedom.	H. S. W. C.		Fibre-length.		Fibre-weight.	
			Sum of squares	Mean square	Sum of square.	Mean squares.	Sum of squares.	Mean square.
C. A. 9	Deterioration ..	1	101.40	101.40**	.002160	.002160	.000002	.000002
	Slow changes ..	1	6.29	6.29	.000070	.000070	.000456	.000456*
	Residual ..	6	54.31	9.05	.001126	.000188	.000671	.000110
	Total ..	8	162.00		.003356		.001129	
Verum 262 Nagpur	Deterioration ..	1	1.07	1.07	.003081	.003081	.000015	*.000015
	Slow changes ..	1	4.52	4.52	.000126	.000126	.000001	.000001
	Residual ..	6	27.97	4.66	.004482	.000747	.000820	.000137
	Total ..	8	33.56		.007689		.000836	
Verum 262 Akola	Deterioration ..	1	1.07	1.07	.001500	.001500*	.000010	.000010
	Slow changes ..	1	2.31	2.31	.000267	.000267	.000407	.000407
	Residual ..	6	31.51	5.25	.001789	.000298	.000571	.000095
	Total ..	8	34.89		.003556		.000988	

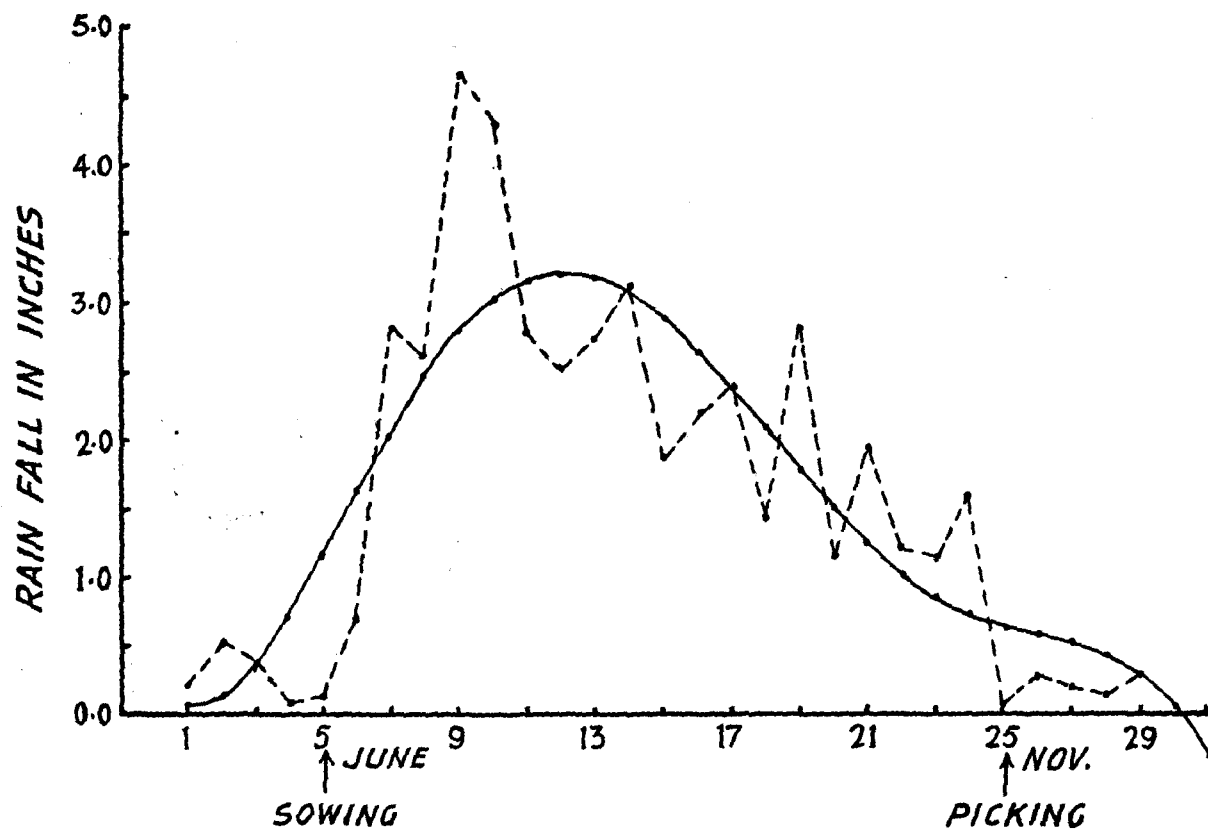


Fig. 2.—Distribution of Rainfall (Weekly totals) for the Government Farm, Nagpur.

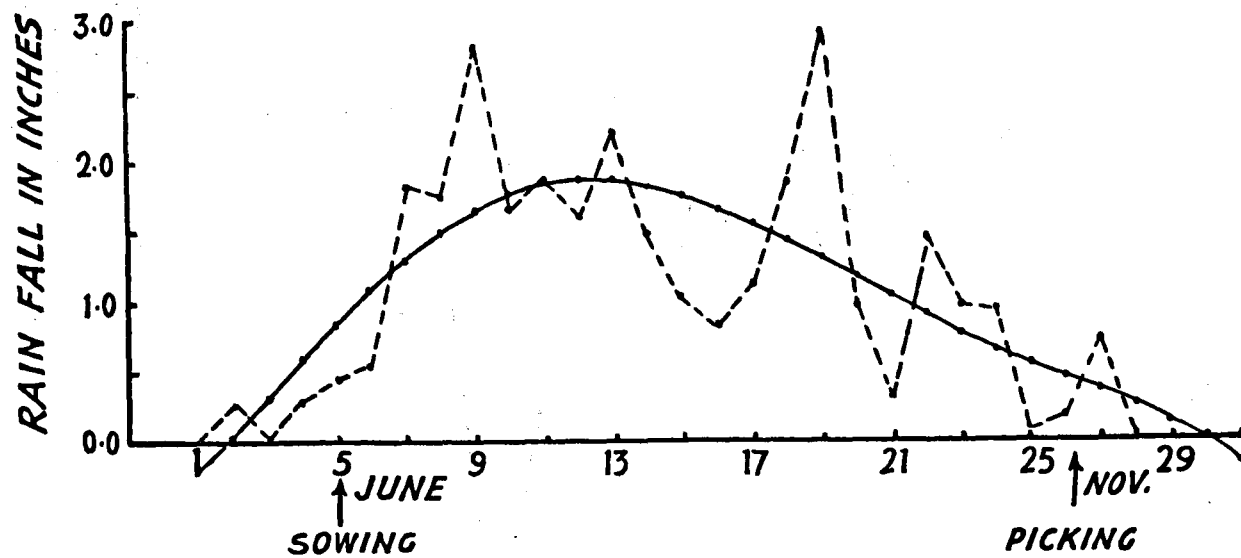


Fig. 3.—Distribution of Rainfall (Weekly totals) for the Government Farm, Akola.

TABLE 5.

Secular Change in Madras Cottons.

Cotton.	Variance due to	Degrees of freedom.	H. S. W. C.		Fibre-length.		Fibre-weight.	
			Sum of squares.	Mean square.	Sum of squares.	Mean square.	Sum of squares.	Mean square.
Cambodia Co. 2.	Deterioration ..	1	13.83	13.83	.000294	.000294	.000738	.00738**
	Slow changes ..	1	0.03	0.03	.000105	.000105	.000092	.000092
	Residual ..	8	128.87	16.11	.003092	.000386	.000588	.000074
	Total ..	10	142.73		.003491		.001418	
Hagari I.	Deterioration ..	1	0.23	0.23	.000178	.000178	.000269	.000269
	Slow changes ..	1	0.34	0.34	.001118	.001118	.000541	.000541
	Residual ..	8	99.98	12.50	.007395	.000924	.001533	.000192
	Total ..	10	100.55		.008691		.002343	
Nandyal 14	Deterioration ..	1	45.83	45.83**	.000058	.000058	.000014	.000014
	Slow changes ..	1	14.88	14.88	.000447	.000447	.000104	.000104
	Residual ..	8	37.29	4.66	.008665	.000108	.000633	.000079
	Total ..	10	98.00		.009170		.000751	
Karunganni C. 7.	Deterioration ..	1	.08	.08	.000131	.000131	.000166	.000166
	Slow changes ..	1	27.99	27.99	.000004	.000004	.000328	.000328*
	Residual ..	8	27.57	3.45	.001938	.000242	.000461	.000058
	Total ..	10	55.64	5.56	.002073		.000955	

TABLE 5.

(See page 215)

Table 5 gives the results obtained by fitting polynomial of the second degree to the 11 year data (from 1924-25 to 1934-35) for H. S. W. C., length and fibre-weight of each of the four Madras cottons. It will be noticed that Cambodia and Hagari I have shown practically no secular change in the period under consideration (although such a change may become noticeable if data extending over a longer period become available), while the other two cottons Nandyal 14 and Karunganni C 7 have indicated a distinct change—the former indicating a definite “improvement” in quality, while the latter shows a marked tendency towards a slow change. Both these trends are found to be significant when tested by Fisher’s Z test. Their importance can be seen easily from Fig. 1A, where the values of relative variance* for all the cottons for which 11 year data is available have been plotted. Thus about one half of the total variation observed in the values of H. S. W. C. for N. 14 is accounted for by a single degree of freedom—Deterioration, while for Karunganni C. 7 more than half of the total variance is covered by a single degree of freedom—slow changes. Reference to Table I in the Appendix will show that the value of X'_1 for the former and X'_2 for the latter are both positive and significant. Thus X'_1 for Nandyal 14 is $6.769+2.15$, and X'_2 for Karunganni C. 7 is $5.2907+1.91$ indicating an improvement in quality in both the cases. This improvement in quality may be due to the adaptability of the seed to the soil conditions, but it is difficult to assign definite reasons for this change. It is interesting to observe that the secular change, so prominent in H. S. W. C. values of Nandyal 14, is not shown by either of the fibre-properties—length and weight, although for Karunganni the significant “slow change effect” in H. S. W. C. values is associated with a significant change in the fibre weight values. The value of X'_3 is $-.0181+.0075$, indicating that there is a tendency for the development of finer staple.

It may be emphasised that no definite conclusions can be obtained for the nature and extent of the secular change in quality from the short series of values available at present but since slow changes are suspected, we have eliminated their influence from the crop record in order to obtain a more homogeneous material for correlation with weather factors.

It should also be noted that the data analysed in this paper relates to sample grown from pure seed under the supervision of highly qualified officers on Government farms. These results, therefore, are not strictly applicable to the trade crop which is grown under vastly different conditions, and in which an improvement or deterioration may take place owing to factors not envisaged in this paper.

* Relative variance = $\frac{100 \times \text{sum of square due to each cause}}{(\text{Mean})^2}$

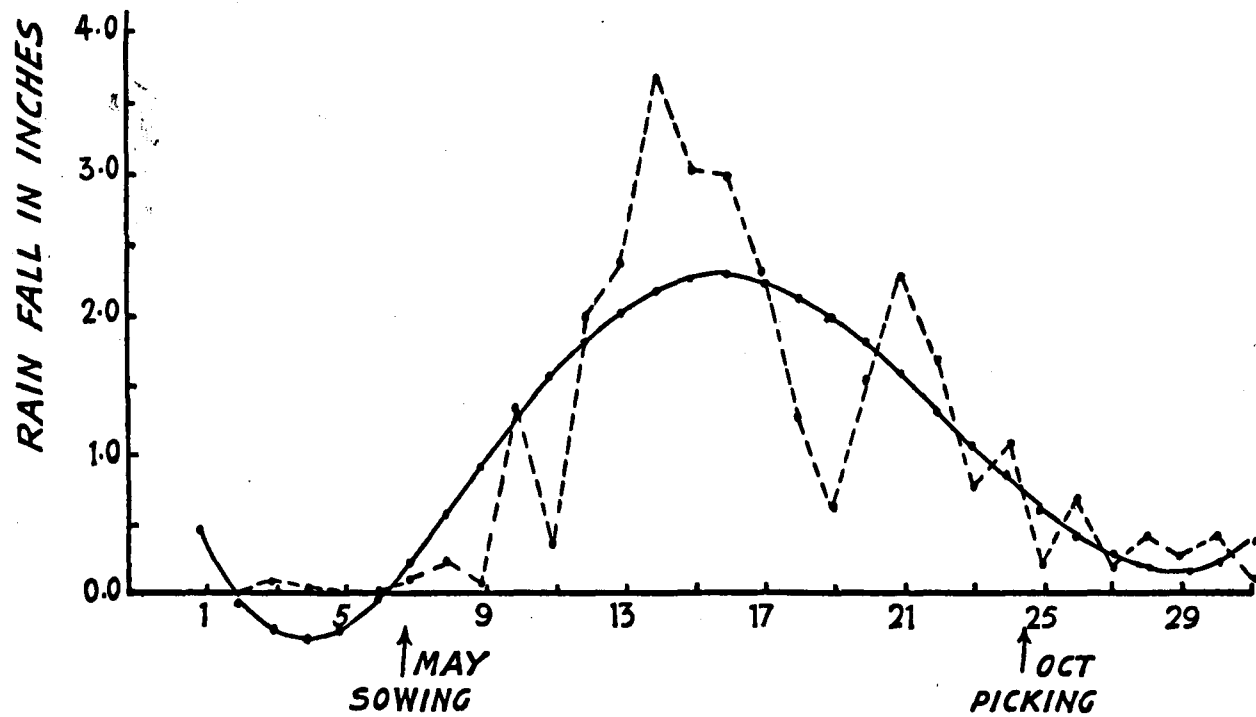


Fig. 4.—Distribution of rainfall (Weekly totals) for the Government Farm, Kallianpur, Cawnpore.

IV. DISTRIBUTION OF RAINFALL IN THE COTTON GROWING DISTRICTS OF INDIA.

The area under cotton cultivation in India approximates some 30 million acres. This area, huge as it is, is not concentrated in one 'belt' like the U. S. of America, but is distributed over a vast country in which the incidence, intensity and duration of rain is widely different in different provinces, and sometimes considerable variations occur in the various districts of the same province. Consequently, it is to be expected that with a crop like cotton, which depends so much upon the rain, the sowing and picking periods would be different in the different cotton-growing districts. It is necessary, therefore, to select an area sufficiently small to ensure reasonable uniformity as regards these factors. A study of the nature and distribution of rainfall in the principal tracts where the standard Indian cottons are grown is a necessary prologue to the investigation of the effect of weather on the quality of cotton. Its purpose is two-fold.—

- (a) It gives a bird's eye-view of the incidence, intensity and duration of rainfall and may be used by farmers and investigators as a rough guide for any crop grown in that district.
- (b) The more immediate purposes from our point of view is that, owing to the paucity of data relating to quality of cotton, any single cotton cannot at present be used for the study of effect of weather; consequently we have to combine a few cottons, and the distribution of rain in the different tract gives a clue as to which cottons are suitable for this purpose.

In order that the distribution of rain in different tracts or in different years of the same tract may be comparable, the time of incidence of rain is reckoned from a definite stage in the life history of the plant. The commencement of rainfall in the cotton season (for the purpose of this investigation) is taken to be about 5 weeks before the sowing of the seed. This procedure is all the more necessary as we have to combine two or more cottons, which may have different sowing and picking periods.

In order to obtain the distribution of rain in any tract, polynomials of the fifth degree were fitted to the weekly means for various years for which the figures for quality were available. The values of the polynomial together with the observed mean values for each week are plotted in figures 2—11 for the ten standard Indian cottons. It will be noticed that the 'cotton season' which may be regarded as lasting from the sowing to the picking period, is very different for the cottons C. A. 9 and Verum 262 (Nagpur and Akola) as compared to the others for which it is consider-

ably longer. Consequently, we may divide these cottons primarily with respect to the length of the cotton season into two groups:—

- (1) C. A. 9, Verum 262, (Nagpur), Verum 262 (Akola) for which the total effective period may be taken as 31 weeks.
- (2) Nandyal 14, Hagari 1, Karunganni C. 7, Jayawant, Gadag I, Surat 1027 A. L. F., Wagad 8,—for which the total period may be taken as 41 weeks.

Now, with regard to the second group it may be seen from the general shape of the curves that the distribution of rain, and consequently its effect upon the crop is very different for the different cottons. Hence further sub-division is necessary. It will be noticed that there is very little rain in the sowing season of Surat 1027 A. L. F. and Wagad 8 while there is plenty of rain during this period of Nandyal and Jayawant. Consequently, these pairs of cotton must be placed in separate groups, otherwise the effect of one will be neutralised by the other. This is made clearer if we calculate from the polynomial curves the rain in the first five 4-weekly periods expressed as the percentage of the total rain. The results are given in Table 6.

TABLE 6.

Percentage distribution of rain in 4-Weekly periods of different cottons.

4-weekly period.	Surat	Wagad 8	Jayawant	Nandyal 14	Hagari I	Karunganni C. 7.	Gadag I.
1	4.92	6.87	21.36	24.69	8.57	8.84	13.66
2	29.26	32.38	17.58	24.16	17.06	21.70	26.68
3	30.08	31.85	18.16	21.50	25.57	19.92	24.15
4	21.01	15.11	17.21	16.02	24.97	12.70	15.70
5	10.57	8.63	13.00	8.98	16.50	6.10	7.19
Above 20th week	4.16	5.16	12.68	4.65	7.33	30.74	12.62

From table 6 it is evident that of the four Bombay cottons, Surat and Wagad 8 registered 5 to 7 per cent of the total rain in the first four-weekly period, while in the case of Jayawant over one fifth of the total rain of the season fell in this period; consequently it is not advisable to lump all Bombay cottons in one group for investigating the effect of rainfall on the quality. Furthermore examination will show

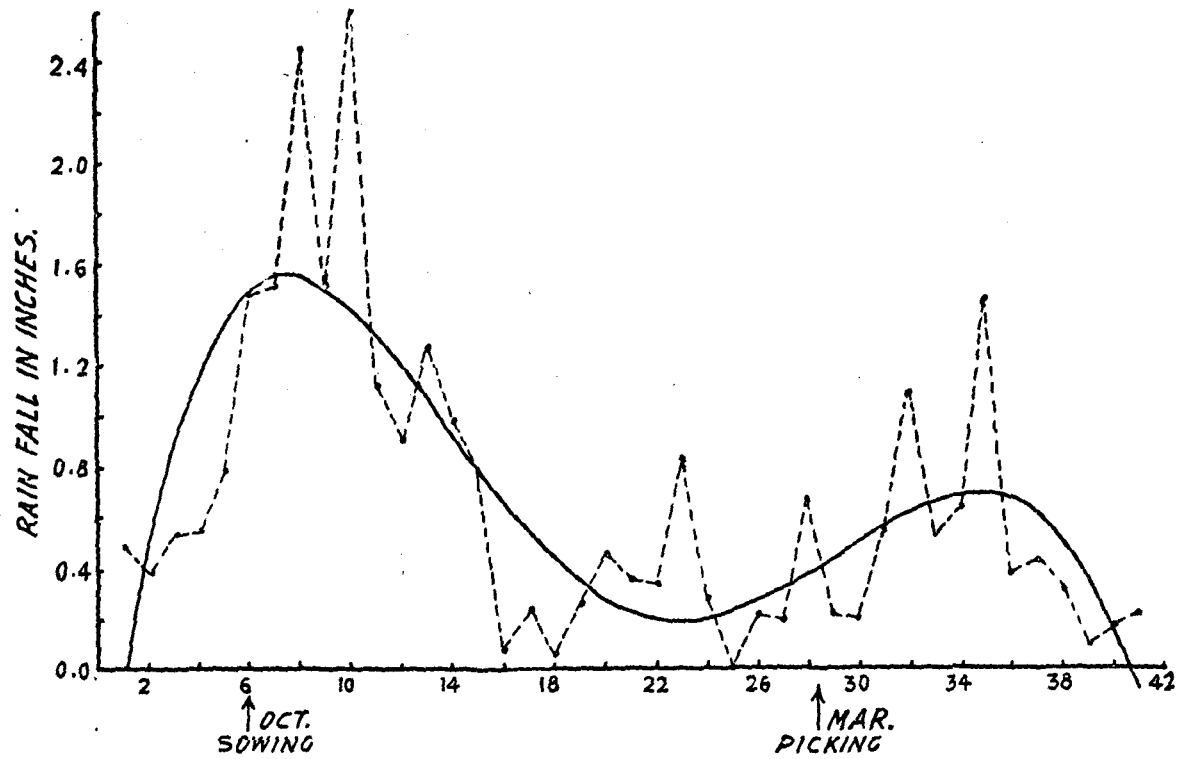


Fig. (5).—Distribution of Rainfall (Weekly totals) for the Government Farm, Virangam.

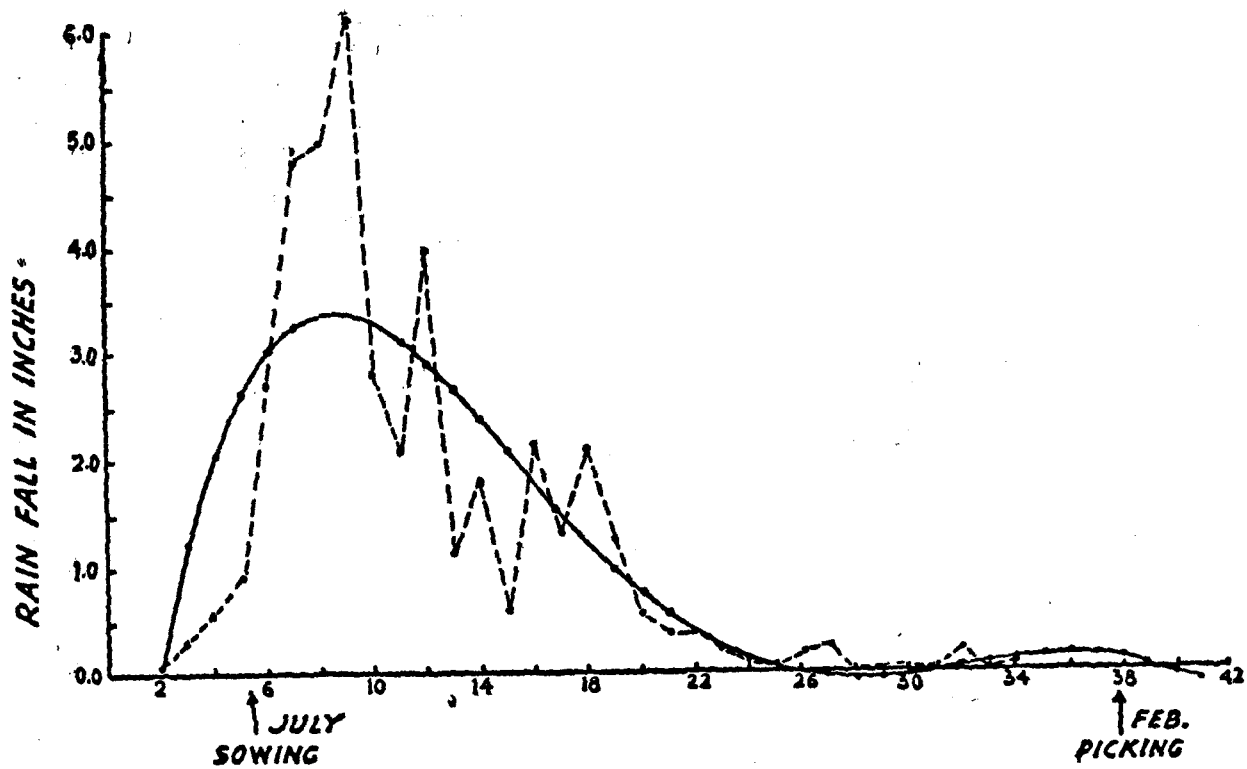


Fig. 8.—Distribution of Rainfall (Weekly totals) for the Government Farm, Surat.

that Jayawant is more analogous in this respect to Nandyal 14, where as much as one quarter of the total rain fell in the first four-weekly period. The most suitable combinations, therefore, are :—

(a) Wagad 8 and Surat 1027 A. L. F.

(b) Jayawant and Nandyal 14.

In both groups the percentage distribution of rainfall for all the 5 four-weekly periods are closely similar for each of the two cottons. We further note that the percentage rainfall distribution for Gadag I is similar to Hagari 1 and accordingly these two cottons may form a separate group.

Karunganni C7 has provided a remarkably different distribution and stands by itself. It should be particularly noted that about 30 per cent of the rain falls in the period after the 20th week. This is due to the bursting of the North East monsoon which occurs late in the season. Since this cotton is usually received at the Technological Laboratory for testing in the months of April or May, it is highly probable that the stock received consists mainly of the first picking only. Consequently we can regard the cotton season for it as extending over 31 weeks, thus eliminating the pseudo-effect of high rainfall in the picking period. The only standard Indian cotton with which it could be combined is Cambodia Co. 2. But there we are confronted with the difficulty that the full data is available only for the six seasons subsequent to 1929-30 which is not enough for the purpose of this investigation. We may, therefore, leave these cottons for the present in the hope of taking them up again when data extending over a sufficiently long period is available. Thus, the final division of the various standard Indian cottons into groups for the purpose of study of the effect of rain on the quality of cotton is as follows :

Cottons.	Cotton season.
(a) Verum 262, Nagpur & Akola, and C. A. 9	31 weeks.
(b) Wagad 8, and Surat 1027 A. L. F.	41 ..
(c) Jayawant, Nandyal 14,	41 ..
(d) Hagari 1 and Gadag 1.	41 ..

V. SECULAR CHANGE IN RAINFALL DISTRIBUTION VALUES.

The rainfall distribution values have been obtained by fitting polynomials of the fifth degree to the weekly totals of rain at each of the cotton growing districts. These are given in Tables II, III and IV in the Appendix. The values of a' indicate

the average rainfall per week, the values of b' indicate the average rate of increase or decrease of rain during this period, c' and d' specify the parabolic and cubic terms of the rainfall sequence, while e' and f' are higher terms involving more complex features of the distribution. In order to find out whether there are any progressive changes in the quantity and distribution of rain from season to season, the rainfall distribution values were treated in the same manner as the data for quality were analysed in Part III. Polynomials of the second degree were fitted to each series of rainfall constants, and the values of X'_2 , X'_3 , which are the proper criteria for secular change, were thus obtained. These are given in tables 7, 8 and 9. In order to judge the significance of these terms, values of standard deviations obtained from the sum of squares after eliminating the effect of X'_2 and X'_3 are also given for each cotton and each rainfall distribution constant.

TABLE 7.

Secular Change in Rainfall Distribution value.

(a) Verum 262—Nagpur & Akola, C. A. 9 cottons.

Cotton		a'	b'	c'	d'	e'	f'
Verum 262 Nagpur.	Mean	1.4980	-.2071	-.3714	.1349	.0264	-.0469
	X'_2	.1434	.0871	-.1133	-.0203	.0493	.0358
	X'_3	.2539	-.1946	-.0179	.0558	.0801	-.0463
	Standard deviation.	.4457	.1627	.1299	.1285	.0769	.0515
Verum 262 Akola.	Mean	.9769	-.1031	-.2427	.0649	.0070	-.01144
	X'_2	.3159	-.2067	-.1416*	.1526*	.1051	-.06106
	X'_3	-.0413	-.0975	.0033	.1135	-.0309	-.08310*
	Standard deviation.	.1821	.1385	.06726	.0682	.0419	.03132
C. A. 9.	Mean	.9577	.0674	-.2991	-.01011	.1060	-.01578
	X'_2	-.6578*	.0635	.2443*	-.06494	-.1052	.0347
	X'_3	.0830	-.0884	-.1362	.00476	.0609	-.0093
	Standard deviation.	.2091	.08934	.07822	.06065	.04155	.03290

Of the three cottons given in table 7, Verum 262 (Nagpur) does not show any progressive change. Some change is indicated for Verum 262 (Akola) for which X'_2 , for c' and d' and X'_3 for f' are significant. But the most remarkable secular change

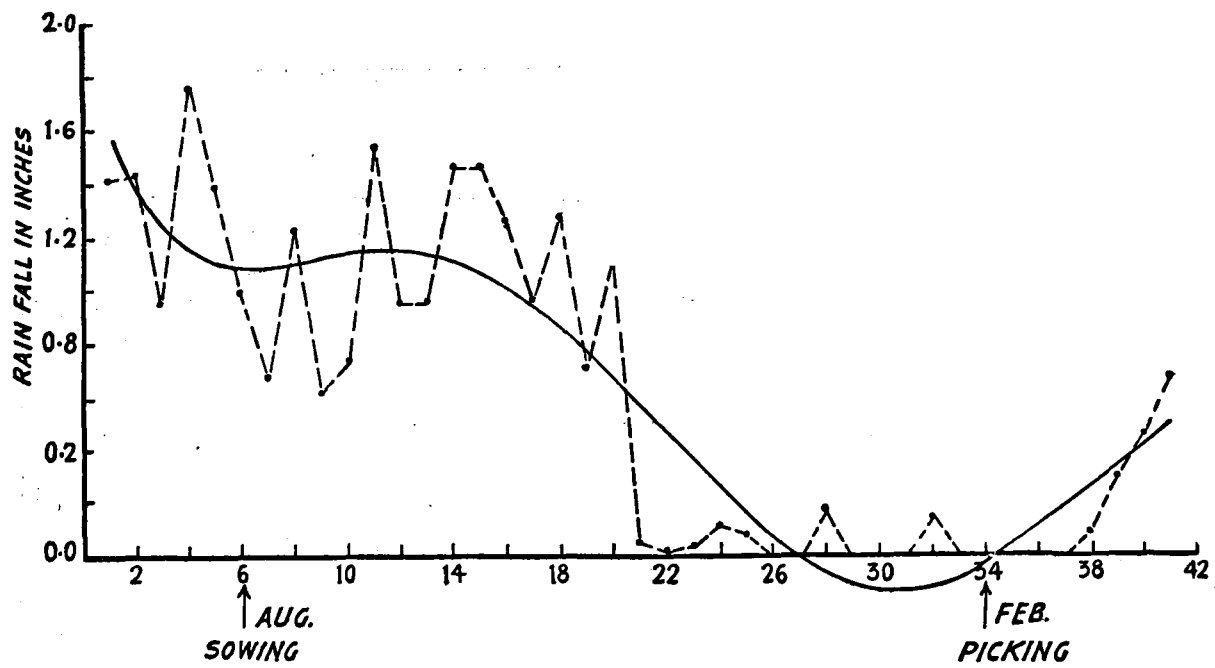


Fig. 7 —Distribution of Rainfall (Weekly totals) for the Government Farm, Dharwar.

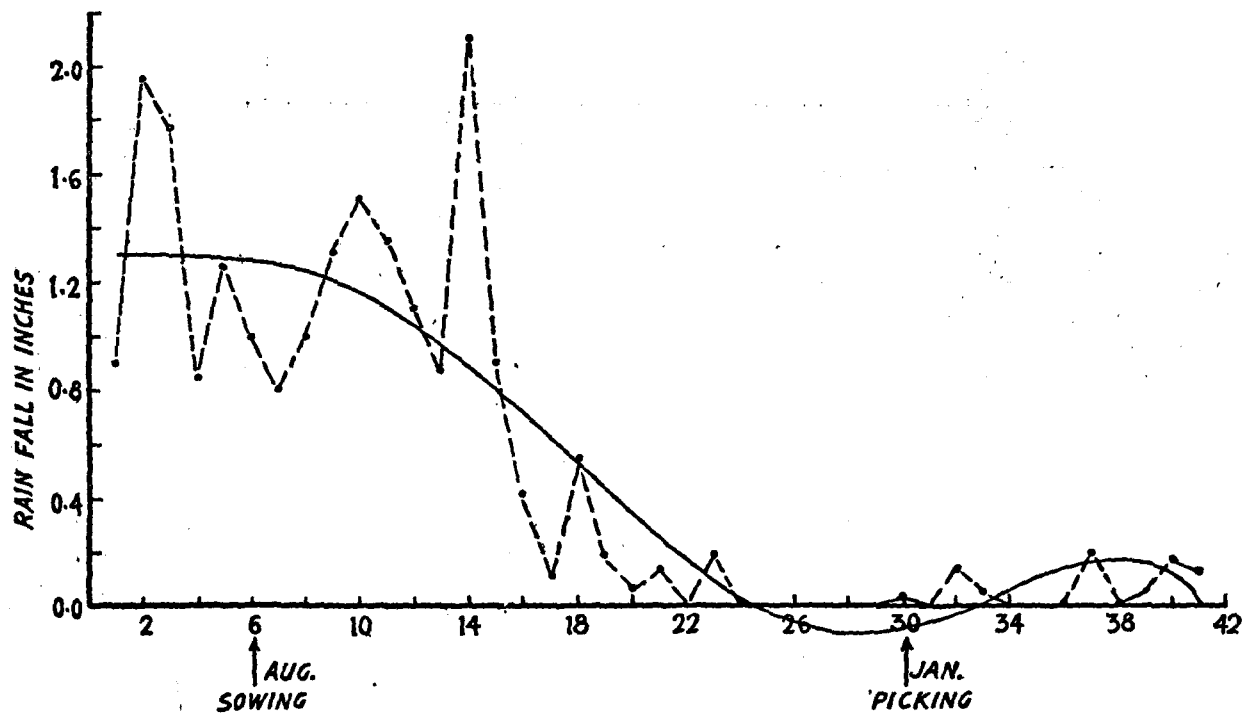


Fig. 8.—Distribution of Rainfall (Weekly totals) for the Government Farm, Nandyal.

especially for a' and c' is shown by C. A. 9, for which the values of X' , are highly significant. In an unchanging series the values of X'_2 and X'_3 vary about zero in an approximately normal distribution. Slow changes in the original series are indicated by the high positive or negative value of X'_2 and X'_3 . If such changes are suspected and occur it is necessary to eliminate them in order to obtain variance due to random causes. It may be noted, however, that definite conclusions with regard to the nature and extent of progressive changes cannot be obtained from the short-series of values at our disposal.

TABLE 8.

Secular changes in Rainfall Distribution Values.

(b) Wagad 8 and Surat 1027 A. L. F.

Cotton		a'	b'	c'	d'	e'	f'
Wagad 8	Mean	.6723	-.3450	-.0142	.1668	-.1197	.01618
	X'_2	-.2041	.0658	.0460	-.0392	-.0051	.01783
	X'_3	-.0884	.00001	.0929	-.0957	+.0297	.03897
	Standard deviation.	.3302	.1758	.0818	.12598	.09779	.05948
Surat 1027 A. L. F.	Mean	1.0245	-.4728	-.0703	.2465	-.1528	.02361
	X'_2	.4272	-.1517	-.1043	.1401	-.0636	-.01142
	X'_3	-.1613	.0704	-.0052	-.01726	.04619	-.04270
	Standard deviation.	.2799	.1478	.11985	.10277	.09757	.07378

In the case of Wagad 8 and Surat, none of the rainfall constants indicate any significant secular change although some of the values of X' , are rather large. The variance of the total rainfall measured by a' may be divided into two parts (a) that due to slow changes (b) that due to random causes. Thus for Surat 1027 A.L.F. the variance estimated from the residuals of the polynomials of the 2nd degree is 94.8 per cent of the variance of the original series, so that 5.2 per cent of the total variance in annual values of rain may be ascribed to slow changes and the remaining (94.8) to the chance fluctuation of each particular year. Thus there is some reason to suspect that the different years are not wholly independent, but some obscure cause is liable to change the mean by small amounts in either direction for a number of consecutive years. In order to get definite evidence on this point 13 years are not enough, and it is hoped that more definite information may be possible when data for a larger number of years becomes available.

TABLE 9.

Secular Change in Rainfall Distribution Values.

(c) Jayawant, Nandyal 14, Hagari I & Gadag I

Cotton.		a'	b'	c'	d'	e'	f'
Jayawant	Mean	.6101	-.2505	.0460	.0628	.0209	-.0201
	X' ₂	.3115	-.0784	-.0432	.0430	.0258	-.0094
	X' ₃	-.0980	-.0624	.0781	-.0744*	-.0247	+0175
	Standard deviation	.1636	.0884	.04486	.03390	.03343	.04090
Nandyal 14	Mean	.5147	-.2715	.0658	.0431	-.0212	-.01255
	X' ₂	-.2089	.13301	-.01840	.02136	-.02985	.03795*
	X' ₃	.0569	.01104	.04543	.00033	-.00251	.04882*
	Standard deviation.	.1438	.08927	.06211	.05010	.03399	.01835
Hagari I	Mean	.37036	-.14355	-.02355	.07973	-.01845	-.02909
	X' ₂	.00973	.01926	.04129	-.01773	.00629	.01478
	X' ₃	-.00381	-.00846	.05349	.00063	-.04047	.04522
	Standard deviation.	.1210	.06746	.04248	.05328	.03528	.02630
Gadag I	Mean	.38718	-.15018	.03864	.06827	-.03709	.00745
	X' ₂	.04109	-.00172	.01135	-.01030	.02403	.000384
	X' ₃	-.03747	-.05183	.03240	-.06191	.00498	.009011
	Standard deviation.	.1290	.0575	.02845	.1152.	.03042	.02197

In this group, X'₂ of d' for Jayawant, and X'₂, X'₃ of f' for Nandyal are significant. Thus, there is evidence of slow changes in each of the groups of cottons studied consequently in order to get a more homogeneous material subject to chance fluctuations only, we have eliminated the effect of these secular changes and the residuals thus obtained are used for correlation purposes.

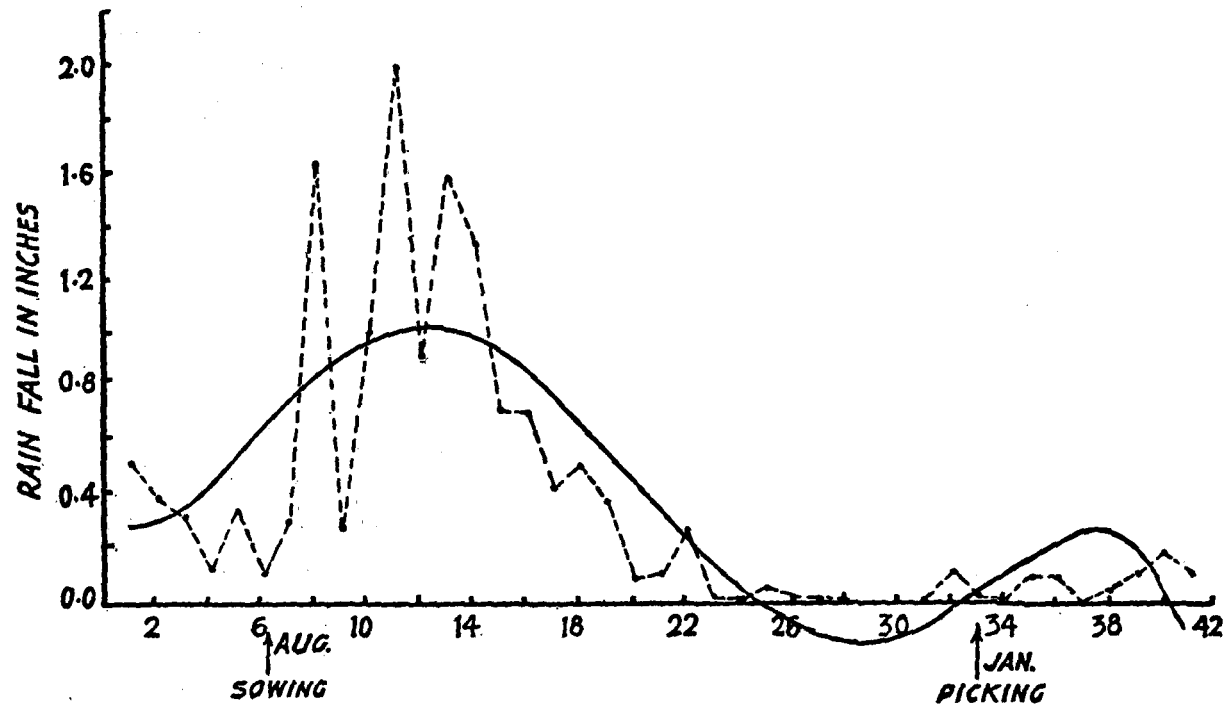


Fig. 9.—Distribution of Rainfall (Weekly totals) for the Government Farm, Hagair.

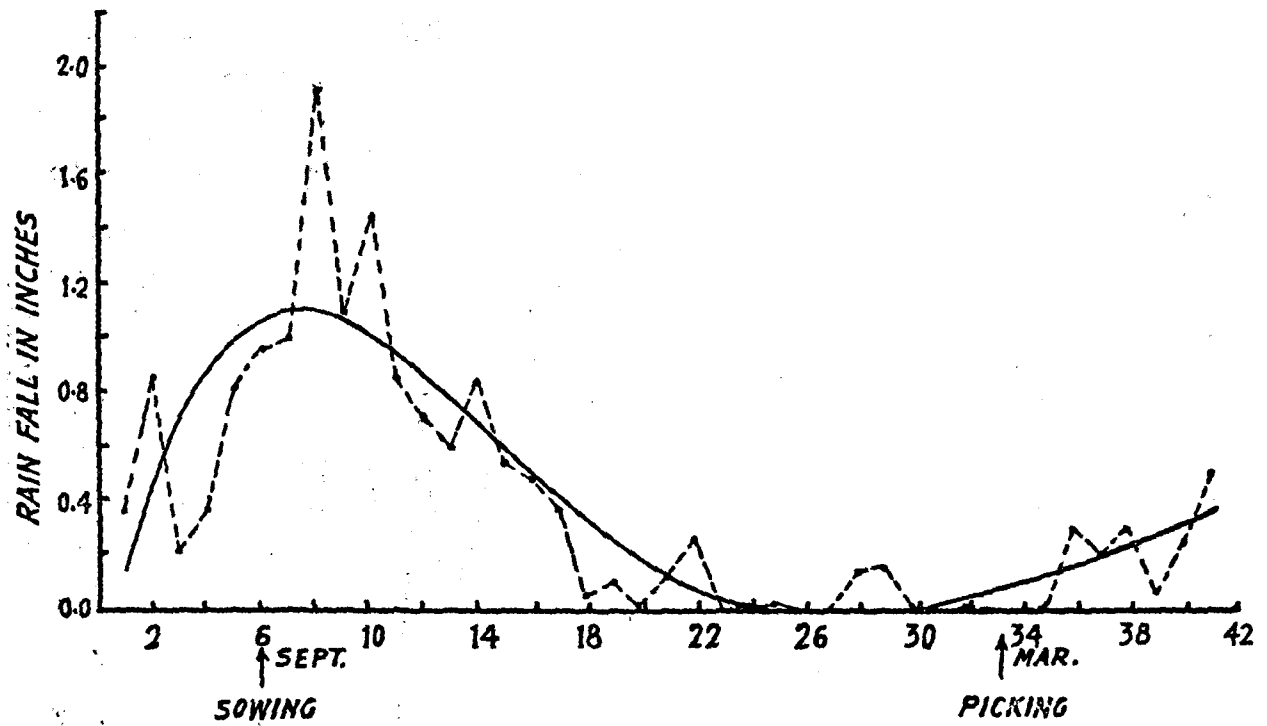


Fig. 10 — Distribution of Rainfall (Weekly totals) for the Government Farm, Gadag.

VI. RAINFALL AS AN IMPORTANT WEATHER-ELEMENT TO ACCOUNT FOR ANNUAL VARIATION IN QUALITY OF INDIAN COTTONS.

In order to assess the influence of rainfall in causing the annual variation in quality, it is necessary to correlate the quality residuals with the residuals of the six rainfall distribution values a' , b' , c' , d' , e' and f' . For this purpose, first the crude sum of squares and products is formed for each cotton from the figures of rainfall distribution values given in tables II, III & IV in the Appendix. These are separately tabulated (Appendix Tables V, VI, and VII) so that they may be utilised for further investigation when data for a few more years become available. To these, corrections for the mean are applied in the usual manner, while corrections, for the secular change are applied by subtracting from them the sum of squares and products of the values X' , and X' , given in Tables 7, 8 and 9. The sums of squares and products of the residuals of the independent variables thus obtained are given in tables 10, 11 and 12.

TABLE 10.

Sums of Squares and products of residuals of Rainfall constants.

(a) Verum 262, Nagpur and Akola, C. A. 9 cottons.

Cotton		a'	b'	c'	d'	e'	f'
Verum 262 Nagpur	a'	1.192120	-.145013	-.325303	+.048928	.148717	-.041045
	b'	-.145013	.158779	.001095	-.111636	-.003011	.042545
	c'	-.325303	.001095	.101267	.017103	-.046213	-.000624
	d'	.048928	-.111636	.107103	.099043	-.020944	-.033062
	e'	.148717	-.003011	-.046213	-.020944	.035514	-.000191
	f'	-.041045	.042545	-.000624	-.033062	-.000191	.015928
Verum 262 Akola	a'	.190039	.096055	-.043338	-.057217	-.008004	.000626
	b'	.096055	.115168	-.054786	-.051607	.019605	-.008294
	c'	-.043338	-.054786	+.027144	.024963	-.010607	.002667
	d'	-.057217	-.051607	.024963	.027925	-.008374	-.000125
	e'	-.008004	.019605	-.010607	-.008374	.010533	-.000620
	f'	.000626	-.008294	.002667	-.000125	-.000620	.005885
C. A. 9	a'	.262316	.058427	-.061826	-.031464	.014209	.019508
	b'	.058427	.047887	.002302	-.023468	-.002593	.009863
	c'	-.061826	.002302	.036713	.008730	-.013136	-.005265
	d'	-.031464	-.023468	.008730	.022071	.001244	-.009940
	e'	.014209	-.002593	-.013163	.001244	.010357	.000350
	f'	.019508	.009863	-.005265	-.009940	.000350	.006495

Since the data is available for a comparatively small number of years for each cotton, we combine the residual sum of squares and products for the cottons given in each of the tables 10, 11, and 12, to obtain the corresponding sum of squares and products for the groups (a), (b), (c) and (d) mentioned on page 219. It should be noted, however, that this method cannot give the same precise information about each cotton as a large number of years treated separately is capable of doing, but under the circumstances already explained it is the best that can be used.† Consequently, the results of the present investigation should be regarded a first approximation for the cottons within each specified group.

TABLE 11.

Sum of squares and products of residuals of rainfall Constants.

(b) Wagad 8 and Surat 1027, A. L. F.

Cotton.	a'	b'	c'	d'	e'	f'
Wagad 8	a' .872248	— .441099	— .082028	.325577	— .222331	.005426
	b' — .441099	.247349	.008547	— .156145	.133653	— .027033
	c' — .082028	.008547	.053538	— .043736	— .007743	.033695
	d' .325577	— .156145	— .043736	.126973	— .076017	— .008068
	e' — .222331	.133653	— .007743	— .076017	.076508	— .024087
	f' + .005426	— .027033	.033695	— .008068	— .024087	.028307
Surat 1027	a' + .783350	— .332818	— .132730	.244268	— .092459	— .045667
A. L. F.	b' — .332818	.288375	— .033415	— .106413	.114368	— .035410
	c' — .132730	— .033415	.143640	— .059800	— .063285	.077602
	d' .244268	— .106413	— .059800	+ .105609	— .044094	— .021112
	e' — .092459	+ .114368	— .063285	— .044094	.095208	— .050640
	f' — .045667	— .035410	.077602	— .021112	— .050640	.054429

† An allowance can be made for the difference in the mean-values of rain at different stations, by including the product of the station mean and individual mean each season, as an independent variate, but for want of long records this has not been done.

TABLE 12.

Sum of squares and products of residuals of rainfall constants.

(o) Jayawant, Nandyal 14, Hagari I & Gadag I.

Cotton.		a'	b'	c'	p'	e'	f'
Jayawant	a'	.160591	-.074811	-.016882	.020040	-.011581	.011450
	b'	-.074811	.046909	.010835	-.005658	.006038	-.003233
	c'	-.016882	.010835	.012072	-.005607	.006695	.001007
	d'	.020040	-.005658	-.005607	.006896	-.004774	.003897
	e'	-.011581	.006038	.006695	.004774	.006707	-.004464
	f'	.011450	-.003233	.001007	.003897	-.004464	.010036
Nandyal 14	a'	.165461	-.092335	.022041	-.010819	.013272	-.011871
	b'	-.092335	.063751	-.027205	.016142	-.009363	.005535
	c'	.022041	-.027205	.030861	-.021648	.008792	-.000607
	d'	-.010819	-.016142	-.021648	.020079	-.010870	.001989
	e'	.013292	-.009363	.008792	-.010870	.009241	-.003603
	f'	-.011871	.005535	-.000607	.001989	-.003603	.002693
Hagari I.	a'	.117050	-.059051	-.001102	.038172	-.030566	.018034
	b'	-.059051	.036408	-.005340	-.016026	.016517	-.009110
	c'	.001102	-.005340	.014439	-.011000	.002238	.002409
	d'	.038172	-.016026	-.011000	.022709	-.013216	.004772
	e'	-.030566	.016517	-.002238	-.013216	.009957	-.004679
	f'	.018034	-.009110	.002409	.004772	-.004679	.005532
Gadag I	a'	.133134	-.039435	.008463	.024062	-.008816	.003219
	b'	-.039435	.027451	-.000239	-.008429	.002493	-.001827
	c'	.008463	.000239	.006478	.001486	.001632	.002382
	d'	.024062	-.008429	.001486	.010611	-.004862	.003683
	e'	-.008816	.002493	.001632	-.004862	.007403	-.002373
	f'	.003219	-.001827	.002382	.003683	-.002373	.003862

In order to find out the regression of quality of cotton on the rainfall constants, Fisher's Matrix Method' is adopted, which is described in detail by one of us elsewhere (Koshal, 1934). The four matrices for the four groups of cottons are give in table 13.

TABLE 13.

Matrix of multipliers for evaluating regression co-efficients.

Cotton		a'	b'	c'	d'	e'	f'
(a) Verum 262 Nagpur and Akola, C. A. 9	a'	2.282291	.807648	7.357065	-.013359	2.65946	1.287645
	b'	.807648	15.714238	4.930024	24.819319	12.468868	14.684410
	c'	7.357065	4.930024	37.164913	1.760805	25.581299	5.081146
	d'	-.013359	24.819319	1.760805	54.794818	23.703668	45.378623
	e'	2.65946	12.468868	25.581299	23.703668	51.038171	22.388725
	f'	1.287645	14.684410	5.081146	45.378623	22.388725	83.470199
(b) Wagad 8 and Surat 1027 A. L. F.	a'	258.7522	730.2306	730.6028	714.1454	326.0074	240.4839
	b'	730.2306	2122.1109	2196.3064	2258.8892	1111.4283	802.8180
	c'	730.6028	2196.3064	2492.2073	2736.9119	1564.3019	1038.5761
	d'	714.1454	2258.8892	2736.9119	3257.4784	2056.1026	1376.4172
	e'	326.0074	1111.4283	1564.3019	2056.1026	1511.2669	983.2140
	f'	240.4839	802.8180	1038.5761	1376.4172	983.2140	711.3441
(c) Jayawant & Nandyal 14	a'	37.8849427	62.4290391	-5.1754349	-83.2377655	-78.2300321	-20.9627528
	b'	62.4290391	112.8255113	-2.0724661	-137.8721395	-137.3547223	-41.5694750
	c'	-5.1754349	-2.0724661	97.0710233	94.6510299	-36.6197999	-69.820079
	d'	-83.2377655	-137.8721395	94.6510299	348.6619414	233.0540367	5.6800126
	e'	-78.2300321	-137.3547223	-36.6197999	233.0540367	388.3555861	161.7575693
	f'	-20.9627528	-41.5694750	-69.820079	5.6800126	161.7575693	187.4665860
(d) Hagari 1 and Gadag 1	a'	16.3590502	15.0587489	-18.8376736	-27.5531268	3.1350362	17.2658873
	b'	15.0587489	43.7134194	6.2949132	-5.9458018	-19.5632370	4.2796418
	c'	-18.8076736	6.2949132	132.5557539	89.3879466	-37.2727430	-126.1582006
	d'	-27.5531268	-5.9458018	89.3879466	148.3859730	40.7745168	-93.1192029
	e'	3.1350362	-19.5632370	-37.2727430	40.7745168	169.1799772	79.4432961
	f'	17.2658873	4.2796418	-126.1582006	-93.1192029	79.4432961	280.1613225

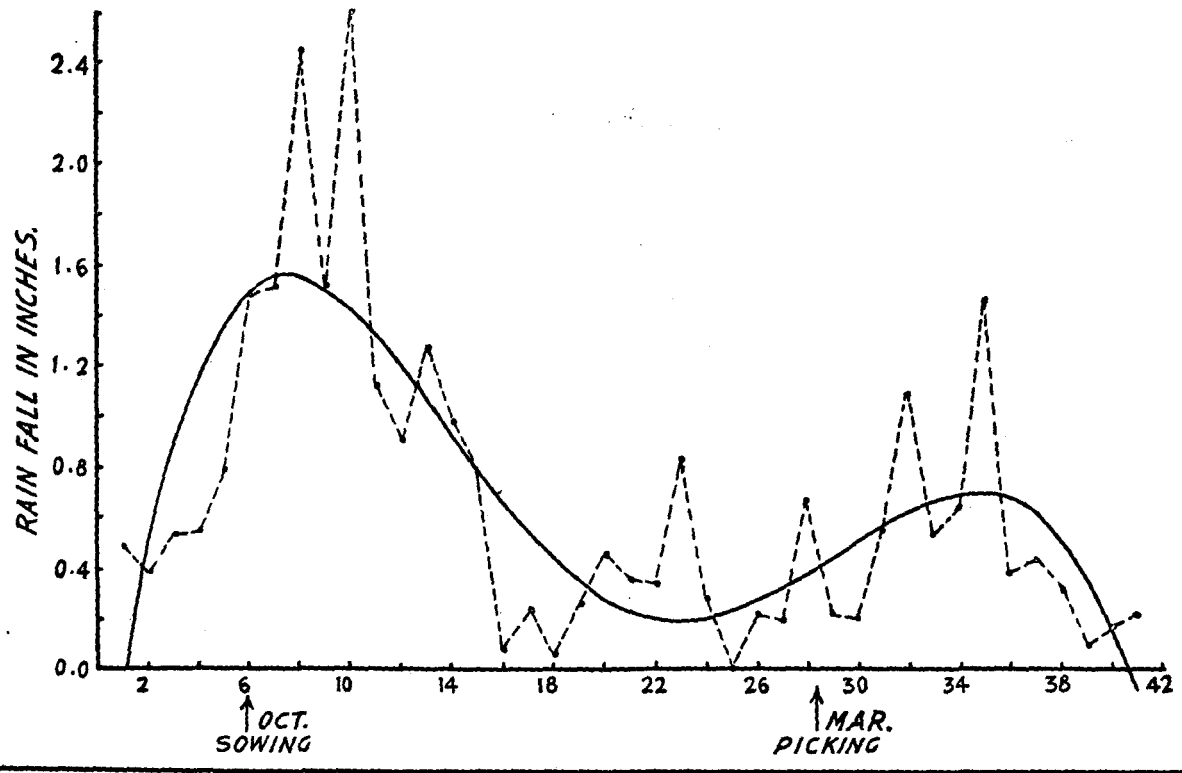


Fig. (11).—Distribution of Rainfall (Weekly totals) for the Government Farm, Kollpati.

TABLE 13.

(See page 226.)

Matrix of Multipliers for evaluating regression co-efficients.

The criteria used for specifying quality of cotton are (i) spinning value as indicated by the highest standard warp counts (c) (ii) fibre-length (l) (iii) fibre-weight (w). Of these the first is the most important and the latter two have been selected in virtue of their high correlation with the first. In order to find their regression on rainfall constants, we need the products of their residuals and residuals of rainfall distribution values. For this purpose, the crude products of quality data and a' b', c', d', e' and f' given in tables II, III and IV are obtained. These products are separately tabulated (Appendix—Table VIII) for use in further investigation of a similar kind. These crude products are corrected for the mean, and then corrections for the secular change are applied by subtracting the products of the corresponding values of X', and X', given in Tables 7, 8 and 9 and table I in the Appendix. The sums of products of residuals thus obtained are given in table 14.

TABLE 14.

Sum of squares of residuals of quality data and rainfall constants.

Cotton		a'	b'	c'	d'	e'	f'
Verum	c	-2.2491	.2937	.5831	.1310	-.5403	.0707
262	l	-.030775	.004628	.007584	.004838	-.009517	.000375
Nagpur	w	-.001189	.000130	.001057	.002437	-.002618	-.000701
Verum	c	-.5089	-.1205	.1789	.2880	-.1405	-.2808
262	l	-.014078	-.010602	.005404	.006178	-.001655	-.000339
Akola	w	.004484	-.001679	.000431	-.000399	-.001005	.001077
C. A. 9	c	-3.2293	-.5711	.6128	.1568	-.1518	-.2231
	l	-.012003	-.004508	.000590	.002400	.000760	-.001960
	w	.003673	.001436	-.003230	-.002029	.001506	.000721
Wagad 8	c	2.8574	-1.0648	-.07443	1.1322	-0.3492	-0.4084
	l	.016689	-.001762	.003220	.006361	-.003071	-.000875
	w	-.033400	.017658	.002450	-.012932	.010227	-.000962

TABLE 14.—*contd.**Sum of squares of residuals of quality data and rainfall constants.*

Cotton		a'	b'	c'	d'	e'	f'
Surat	c	2.9834	-.6880	-1.3991	1.2753	-.0592	-.6824
1027	l	.009704	-.005785	-.003901	.009143	-.005275	-.006230
A. L. F.	w	-.014923	.001023	.010328	-.006765	-.001762	.004600
Jayawant	c	-1.187323	.390041	.30729	-.29245	.14609	.01554
	l	-.015436	.009191	.004323	-.001323	.003040	-.000183
	w	.008024	-.004864	-.000463	.000332	.000600	-.000633
Nandyal	c	-1.29727	.71796	-.14767	-.11887	.09173	.06578
14	l	-.008115	.000431	.003866	-.004628	.002917	-.000973
	w	.001713	-.000697	-.000811	.002083	-.001569	.000212
Hagari I	c	-1.16665	.78089	-.18255	.08308	.13368	.05241
	l	-.015001	.006359	.000164	-.002683	.002386	-.001360
	w	.002879	-.003681	.001179	.000253	-.001194	-.000655
Gadag I	c	-2.163603	1.219117	-.433605	-.482411	-.327651	-.108196
	l	-.007609	.005508	-.002849	.001601	-.002333	.000787
	w	-.004110	.001816	.000568	-.000176	-.000780	.001225

These sums of products for the different cottons are then added to give the corresponding sum of products appropriate to its group. The six sums of products of each group are multiplied in order with the values in the first column of the corresponding matrix given in table 13. The sum of these products gives the regression on a'. In a similar manner if the same six sums of products are multiplied with the values in the second column of the matrix, the sum of the resulting products gives the regression on b'. In a similar manner the regression on c', d', e' and f' are obtained by multiplying with the values in 3rd, 4th, 5th and 6th columns respectively of the corresponding matrix. The partial regression co-efficients thus obtained are given in table 15.

These regression co-efficients can be used for two main objects:—

- (i) To study the influence of rainfall in accounting for the annual variation in quality.
- (ii) To study the regression of quality on rainfall at different periods of the season.

TABLE 15.

Partial Regression of quality of cotton on rainfall constants.

Group of cotton.	Property specifying quality.	Regression on					
		a'	b'	c'	d'	e'	f'
Verum 262 Nagpur & Akola C. A. 9	c	-6.651402	-6.762430	-17.402558	-15.217703	-24.259803	-35.238020
	l	-.0686805	.0312009	-.2178502	.1655279	-.1910392	.0569510
	w	-.0012219	-.0148005	-.0626001	-.0058722	-.1107145	.0430399
Wagad 8 and Surat 1027 A. L. F.	c	-10.7736321	-53.4653670	-106.8720902	-153.3194809	-136.5842919	-92.4463436
	l	-.3193140	-.9099310	-1.1625785	-1.367578	-1.1061258	-.801884
	w	.0414076	.2561760	.6809083	.9106834	.8683386	.4469485
Jayawant & Nandyal 14	c	-11.8557006	-9.7679762	-27.2617888	-18.3655269	45.9905991	46.2582280
	l	-0.2803531	-0.3513213	0.1961618	0.7156738	0.9604267	0.2350166
	w	-0.0880778	-0.1992745	0.1309252	0.4494334	0.1671664	-0.1059425
Hagari I and Gadag 1	c	-3.3423569	39.3295144	-27.8775909	-37.1783209	-80.1322403	34937.9501
	l	-0.1205645	0.1643172	0.1175371	0.2072271	-0.2836761	-0.0563343
	w	-0.0795569	-0.0485491	0.2514554	0.0791139	-0.3176703	-0.2537789

TABLE 15.

(See page 229.)

Now, if the annual variation in the value of highest standard warp counts is ascribable to a large extent to the influence of rainfall, the mean square due to the six regression co-efficients should be significantly greater than the residual which is due to the deviations from the regression formula. If the sum of the squares due to rainfall be denoted by R then $R = \Sigma p$.

where

$$p_1 = b_1 \Sigma q a'$$

$$p_2 = b_2 \Sigma q b'$$

where

b_1, \dots, b_6 are the partial regressions on a', \dots, f'
 q = quality residual,
 a', \dots, f' are the rainfall constants after removing the secular change.

The quantity R is subtracted from the total sum of squares due to annual causes to obtain the residual. The complete analysis of variance for the four groups of cottons is given in table 16, which also includes factors showing the relative importance of the various rainfall constants.

From this analysis it transpires that a' is an important constant, although it may be noted that it represents only about one half of the total annual variation due to rainfall and the other half is provided by the constants b', \dots, f' . If only the average values of rainfall for different seasons were at our disposal half the information provided by the rainfall sequence would be lost, which shows that in order to assess the proper significance of rainfall influencing the quality of cotton, further knowledge of its distribution is essential.

TABLE 16.

Analysis of variance—Importance of rainfall constants.(a).—*Verum 262, Nagpur & Akola, and C. A. 9. —*

Variance due to:	Degrees of freedom.	Sum of squares.	Mean square.
Regression on a' only.	1	21.6803	21.6803
„ b', \dots, f'	5	23.6108	4.7222
„ a', \dots, f'	6	45.2911	7.5485
„ a', \dots, d'	4	25.5456	6.3864
„ a', \dots, e'	5	30.4150	6.0880
Residual	12	68.4989	5.7082
Total	18	113.7900	

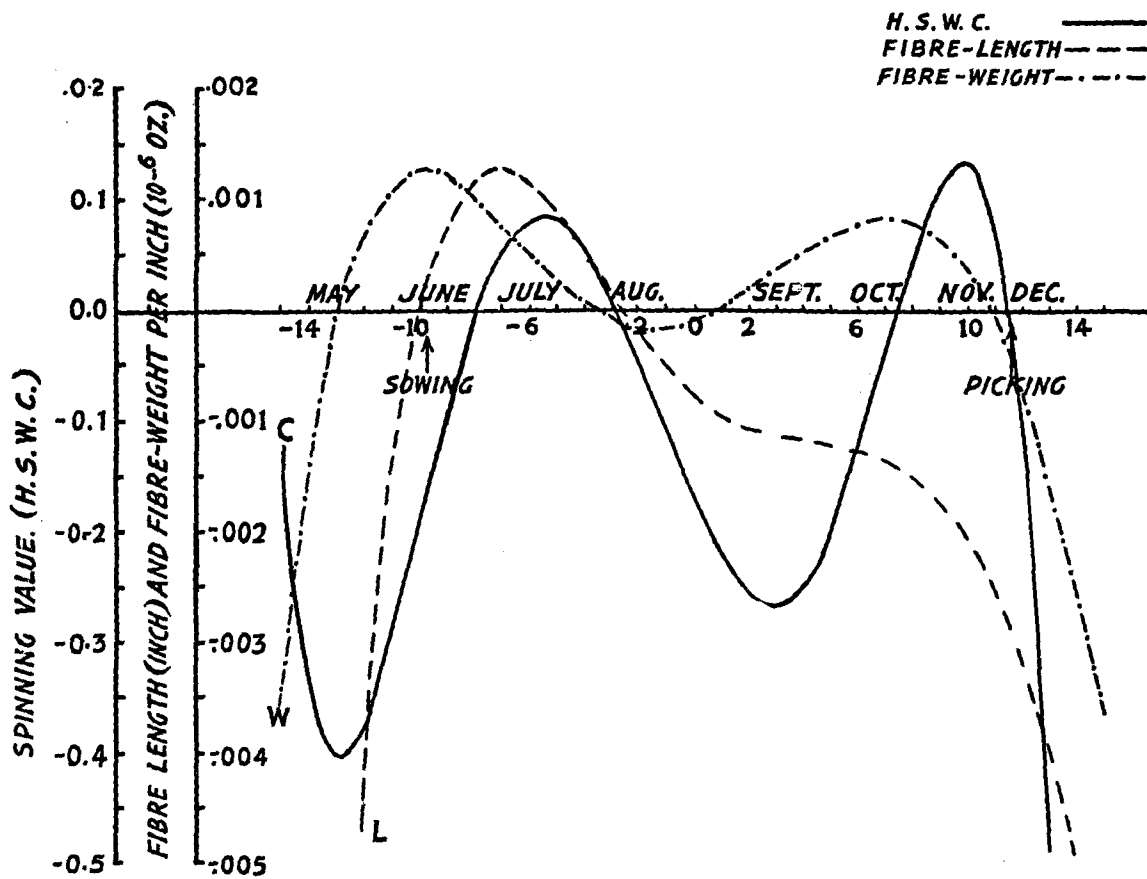


Fig. 12—Effect of an additional inch of rain on the quality of Cotton. Group (a) C. A. 9, Verum 262 (Nagpur, and Akola).

TABLE 16—*contd.**Analysis of variance—Importance of rainfall constants.*(b).—*Surat and Wagad 8.*—

Variance due to :	Degrees of freedom.	Sum of squares.	Mean square.
Regression on a' only	1	20.6061	20.6061
„ b' .....f'	5	26.7621	5.3524
„ a' .....f'	6	47.3682	7.8947
„ a' .....d'	4	34.8447	8.7112
„ a' .....e'	5	35.3539	7.0708
Residual	12	38.2868	3.1905
Total	18	85.6550	

(c).—*Jayawant and Nandyal 14.*—

Variance due to :	Degrees of freedom.	Sum of squares.	Mean square.
Regression on a' only	1	18.9332	18.9332
„ b' .....f'	5	17.6029	3.5206
„ a' .....f'	6	35.5361	6.0894
„ a' .....d'	4	24.9733	6.2433
„ a' .....e'	5	25.1217	5.0243
Residual	8	22.2707	2.7838
Total	14	58.8068	

(d).—*Hagari 1 and Gadag 1.*—

Variance due to :	Degrees of freedom.	Sum of squares.	Mean square.
Regression on a' only	1	44.3298	44.3298
„ b' .....f'	5	91.0782	18.2156
„ a' .....f'	6	135.4080	22.5680
„ a' .....d'	4	75.7702	18.9426
„ a' .....e'	5	131.0510	26.2802
Residual	10	93.0444	9.3044
Total	16	228.4524	

The mean square due to rain is in every case over $1\frac{1}{2}$ times that due to residual and in the case of groups (b), (c) and (d) it is over two times the residual. On the whole, about $\frac{1}{3}$ to $\frac{2}{3}$ of the total annual variation is accounted for by the single weather element, rain. This amount is fairly large, when we remember that quadratic terms of rainfall have been left out for want of long records. It should be noted, however, that the mean square due to six degrees of freedom provided by the rainfall sequence is not significantly greater than the residual. The residual is based upon a small number of degrees of freedom (8 to 12) and the effect is likely to become significant when larger number of years for each cotton become available. Furthermore, from the analysis of variance tables for the four groups of cottons, it is clear that, next to

a' , the important rainfall constants are e' and f' , so that the great arithmetical labour involved in retaining the six rainfall distribution values a' , b' , c' , d' , e' and f' is justified.

VII. INFLUENCE OF RAINFALL AT DIFFERENT PERIODS OF THE SEASON ON THE QUALITY OF COTTON.

As stated on p. 228 the second use of the regression co-efficients is to calculate the effect of an additional inch of rain at different times during the progress of the season. For this purpose the six regression co-efficients are divided by factors of the form.

and
$$\frac{(r!)^2}{(2r)!} 31.32 \dots \dots \dots (31+r) \text{ for 31 weeks.}$$

$$\frac{(r!)^2}{(2r)!} 41.42 \dots \dots \dots (41+r) \text{ for 41 weeks.}$$

in order to obtain the constants A, B, C, D, etc. From these, equation (3) on p. 209 is evaluated by substituting the values of the terms $n_s, \frac{n_t}{n_s}$ etc. appropriate to 31 and 41 weeks respectively. The course of the regression function a is plotted in figures 12-15 where t is the time in seven-day interval measured from—the central point of the season. Thus, t runs from -15 to $+15$ for 31 weeks and -20 to $+20$ for 41 weeks.

It is necessary to bear in mind that the curves in fig. 12—15 not only indicate the effect of rain as such, but of all the weather conditions associated with it. Thus, rain in the picking period would be associated with the diminished sunshine, which may interfere with the final ripening and drying of the fibres. Heavy rain near the sowing operations may either wash away the soil nutrients or may interlog the pore spaces, thus modifying the soil aeration and hindering the proper germination of the seed and the subsequent growth of the plant. All these factors are incorporated in the total effects of rain shown in the figures.

Let us first consider the curves for H. S. W. C. From the study of all the four graphs the following conclusions may be drawn :

- (i) Rain in the last stage of ripening *i.e.*, 'picking period' is harmful.
- (ii) In the maturation period, additional rain above the normal is beneficial. This positive effect is found in all the three graphs, and occurs in the winter months—November to January. Rain during this period is associated with higher temperature and it is probably the moist heat that is most beneficial to the proper thickening of the fibres.
- (iii) The growing period can be divided into two parts; the first period after sowing *i.e.*, the period of rapid vegetative growth, and the second period which includes the flowering stage. In the case of Verum 262, C. A. 9, Surat 1027 A. L. F. and Wagad 8, additional inch of rain is beneficial in

the first period, *i.e.*, in July and August, while it is harmful in the months of September and October. The case of Jayawant, Nandyal 14, Hagari I and Gadag 1 is somewhat different as additional rain is harmful throughout the growing season. This is probably due to the fact that in the case of these cottons most of the rain falls prior to sowing and during the sowing period; consequently the soil is saturated with moisture due to the residual effects of the previous rain. The case is similar to that of over-feeding; additional rain instead of doing any good leads to a definite harmful effect. In view of these results it would be instructive to carry out well designed field experiments at Dharwar and Nandyal Agricultural Stations with a view to finding out the optimum conditions of sowing the cotton. An outline of the field experiments for elucidating the effect of weather on crops which may be followed with advantage has been given by one of us (Koshal 1935)⁶. It would be desirable to determine both yield and quality so that the relative influence of rainfall upon each may be ascertained.

The slope of the length curves in all the three graphs is in the same direction as the curve for counts, but that of a weight curve is in the opposite direction. Thus the high positive correlation between spinning value and length, and the high negative correlation between counts and weight, and fibre-length and fibre-weight is clearly indicated.

These graphs are of great practical importance—especially for irrigation problems. The effective use of irrigation water is one of the vital problems which confronts the agriculturist in the irrigated areas. A knowledge of the best time of application of water to a crop materially assists him in making the most economical use of water supply. It sometimes happens that irrigation is given at a time when the plant does not need it, consequently the water supplied is not only wasted, but may actually decrease the yield and quality of the crop. The graphs 12, 13, 14 and 15 provide the necessary clue for the application of irrigation water on account of the partial failure of rain. In cottons which are partly rain-fed and partly irrigated, irrigation water should not be given in equal amounts or at equal intervals of time, but should be properly adjusted with the incidence and intensity of rainfall.

Let us now study the graphs in greater detail in order to bring about the peculiarities of the cottons within each group. Fig. 12 shows the effect of additional inch of rain at different times of the year on the quality of cotton for the three varieties, *viz.*, C. A. 9, Verum 262 (Nagpur) and Verum 262 (Akola). Reference to table II (in Appendix IV) will show that the mean values of spinning performance for these cottons are different. Thus, the mean spinning values for the Nagpur and Akola samples of Verum 262 are 24.8 and 21.1 respectively, while for C. A. 9 it is 34.0, a

value which is about 50% higher than the other two cottons. This difference is also reflected in the mean values of fibre-length and fibre-weight. In order to make allowance for this disparity in the mean spinning value of the various cottons, a percentage graph has been constructed and is shown in fig. 12a. It obviates the necessity of adopting different scales for the spinning value and the two fibre-properties studied in this paper.

The 'count' graph starts with an average loss of about 1% and rapidly reaches a maximum loss of about 1.7% in the middle of May, about a fortnight before the sowing operations. During the next few weeks the average loss rapidly decreases until in the middle of June, about a fortnight after sowing, the additional one inch of rain or irrigation water is beneficial. This beneficial effect of rain lasts for about six weeks, with the maximum advantage of about 0.4% in the middle of July. From the middle of August onwards, the harmful effects are again witnessed, and the curve rapidly falls until in mid-September it registers a maximum damage of about 1%, after which the loss diminishes rapidly, reaching again the positive region in mid-October, when the maturation period starts. During this period, which lasts for about a month, the curve rises rapidly registering a maximum benefit of about 0.6% in the first week of November, and then rapidly falls, crossing the neutral axis early in December.

Thus there are two regions when the additional rain or irrigation water is harmful to the growing plant, one a short time before sowing and the other a comparatively longer one, about a month after sowing, *i.e.*, during the later stages of growing; while there are two periods when excess of rain or additional irrigation is beneficial. These occur immediately after sowing, *i.e.*, during germination and the initial stages of growth, and during the maturation period when the lengthening and thickening processes of fibre take place. Let us now examine the fibre-length and fibre-weight curves in order to find out how far the changes in these characters are reflected in the spinning performance of the cotton. It should be noted that fibre-weight is negatively correlated with H. S. W. C., consequently positive effect (*i.e.*, increase in weight) would correspond to deterioration in quality. The fibre-length curve starts with a maximum damage of about 2% and slowly rises till about the sowing period it reaches the positive region; on the other hand the fibre-weight curve rises rapidly assuming +ive value within two weeks and records a maximum damage of about 0.7% about the middle of June, just when the beneficial effect on length becomes evident. It shows that extra rain before sowing leads to the extra thickening of the fibres at the expense of the lengthening process, with the final loss of quality of cotton. However, the slow improvement in length from May onwards is reflected in the rising curve of the H. S. W. C., which reaches its first maximum about three weeks after the length curve, when opportunely enough the trend in fibre-weight is also in a favourable direction. Following the course of the fibre-weight curve it will be noticed that the peaks and depressions do not correspond in position to the depres-

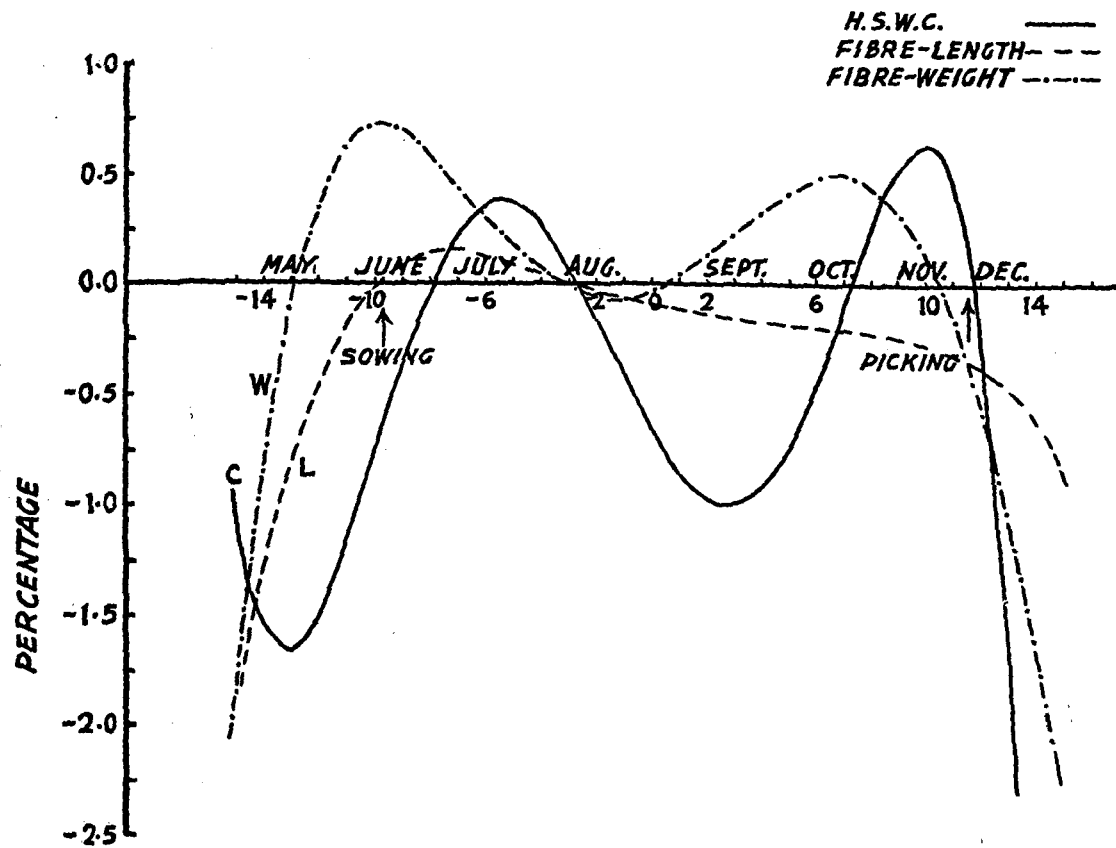


Fig. 12a.—Effect of an additional inch of rain on quality of Cotton. Percentage change in spinning value and fibre-properties. Group (a). C. A. 9, Verum 262 (Nagpur, and Akola).

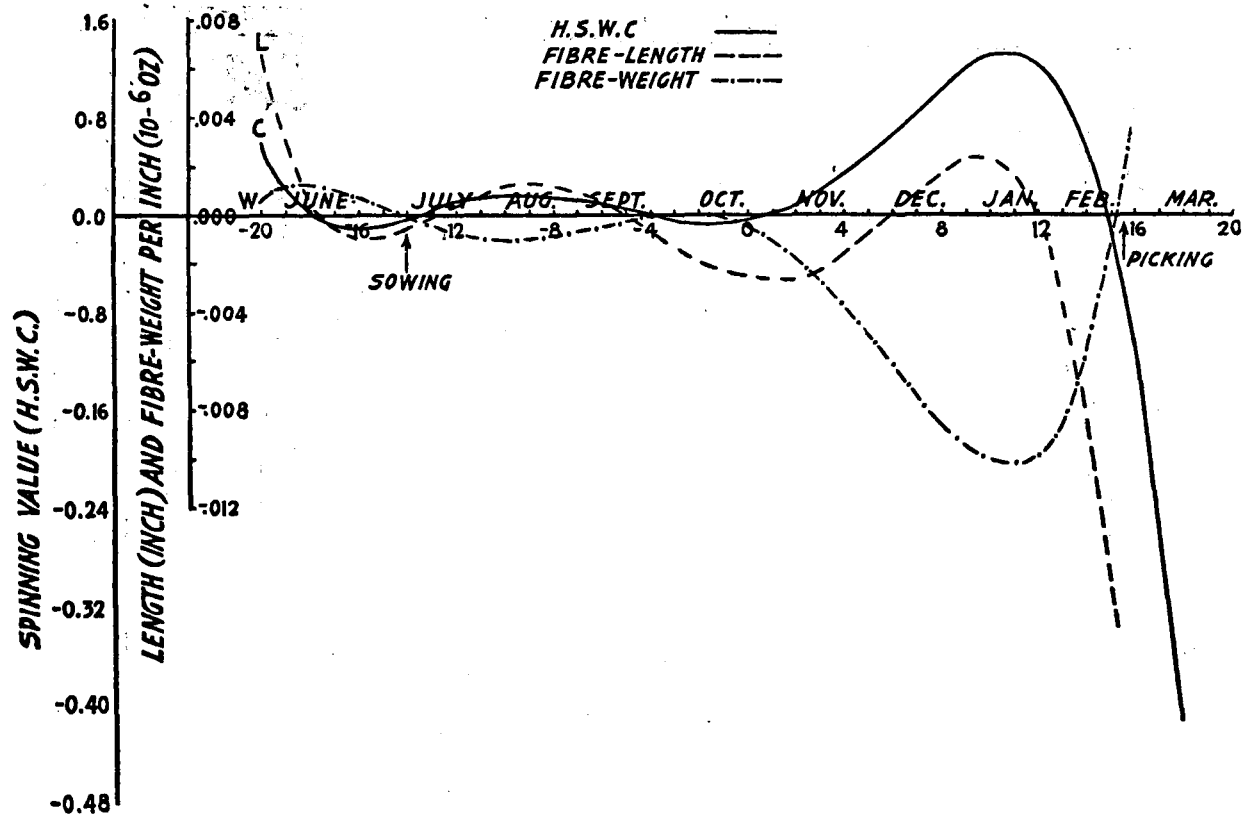


Fig. 13.—Effect of an additional inch of rain on the quality of Cotton. Group (b), Surat 1027 A. L. F. and Wagad 8.

sions and peak in the 'count' curve but occur about 3 or 4 weeks later. Thus, the first crest in fibre-weight curve occurs about the middle of June, followed by a trough about the middle of August, while the crest in the count curve occurs a month earlier about the middle of July. In the length curve the maximum benefit of about 0.15% occurs during the sowing period, after which it steadily diminishes till about the middle of August it enters the negative region, but the loss remains practically steady for the next two months, the average value being 0.15%. Thus, during the sowing period and for a few weeks after, extra rain tends towards the development of length and fineness of staple, both of these factors contributing towards better quality of cotton. In the months of September and October, however, extra rain retards the lengthening process and increases the fibre weight accompanied by an appreciable decline in the quality of cotton. It should be noticed, however, that in this region the change in the H. S. W. C. is rather greater than that which can be accounted for on the basis of variation in length and fibre-weight alone, showing the operation of some other factors as well.

Fig. 13a shows the percentage changes in the spinning value and the fibre-properties of Surat 1027 A.L.F. and Wagad 8, due to an additional inch of rain or irrigation water given at the different periods of the season. A characteristic feature of the tracts where these cottons are grown is that there is very scanty rain (about 5%) before sowing, followed by heavy rain (about 25%) in the next four weeks. These cottons are more susceptible to seasonal changes, and there are large and well defined periods in which the rain has a beneficial effect. There are two well defined depressions and two peaks in the 'count' curve, but unlike the previous case it is the positive region which occupies the greater length of time. The crests and troughs in the fibre-length curve occur in almost the same position as the 'count' curve; but in the fibreweight curve the crest occurs about a fortnight in advance of the corresponding depression in the 'count' curve. The count curve has a strongly marked depression in early June, when the loss is about 0.8%. It is followed by the first maximum in the middle of August when the rain is beneficial to the same extent. The second minimum occurs in early October with a loss of 0.2% only, followed by a maximum benefit of about 7.5%. The benefit in winter months as indicated by the graph is large for the co-efficient α indicating the effect of additional one inch of rain over the average is +ive and high. However, the practical outcome of this effect is small, for the average quantity of rain which falls during this period is very small. Thus, the average rain per week during the three winter months, November, December and January is .03" for Wagad 8 and .07" for Surat 1027 A. L. F., consequently the net benefit to the crop of the variations in the rain which occur in this period would be proportionately small. But the potential effect is there, and it would be instructive to give a large dose of water by irrigation in this period and study its influence on the spinning quality. Perhaps, the position will be clearer if we find the effect of an additional 10 per cent of rain in the months

of August and January (4 weeks each) where the regression function a may be regarded as fairly constant. Its value for the former period may be taken as $+0.8\%$ and for the latter about $+7\%$. Now the average weekly rain for these periods for Surat 1027 A. L. F. are $2.485''$ and $.062''$ respectively, consequently the benefit of additional 10% of rain would be about 0.2% and $.04\%$ for the respective periods. Thus in spite of the smaller value of the co-efficient a , the net benefit is greater for the month of August, where heavy rain falls and greater fluctuations occur from season to season. It should also be noticed that, as in the previous case, the improvement in the spinning value in the cold weather is greater than that warranted by the changes in length and fineness of the staple showing that in this region the extra rain or water acts beneficially through channels other than length and fibre-weight.

Fig. 14a gives the percentage change in the spinning value and the fibre-properties of Jayawant and Nandyal, and fig 15a for Gadag 1 and Hagari I cottons due to an additional inch of rain or irrigation water received by the crop at different parts of the season. The characteristic feature of the tracts in which these cottons, particularly Jayawant and Nandyal, are grown is that there is heavy rain prior to the sowing operations, so that the soil is already over-saturated with moisture. Consequently, it is to be expected that extra rain during growing season would be harmful. In fact the 'count' curve shows that throughout the growing period, additional rain is harmful. It is only in the flowering and first half of the maturation period that wet weather is found to be beneficial to quality. The fibre-weight curve resembles that of the previous graph for Surat and Wagad 8, but the troughs and crests in it occur a few weeks later than the corresponding crests and troughs in the count curve.

The count curve for Jayawant and Nandyal 14 shows a minimum of damage about the middle of July, when the loss is 0.6% only. It is followed by the maximum damage of about 1.6% in the growing period. This harmful effect is associated with the changes in the fibre-length and fibre-weight, for the minimum and maximum of their respective curves occur just in this period. Thus, heavy September rains or additional irrigation in this period will lead to the development of shorter and thicker fibres with consequent loss to quality of these cottons.

VIII. THE PREDICTION OF SPINNING VALUE FROM RAINFALL SEQUENCE

The regression co-efficients given in table 15 of Section VI, will now be used for the prediction of spinning value of a cotton from rainfall distribution data and it will be seen that some very interesting results are obtained. It may be mentioned that as the number of seasons for each cotton is small, it may not be possible always to attain very great accuracy. It is, however, hoped that

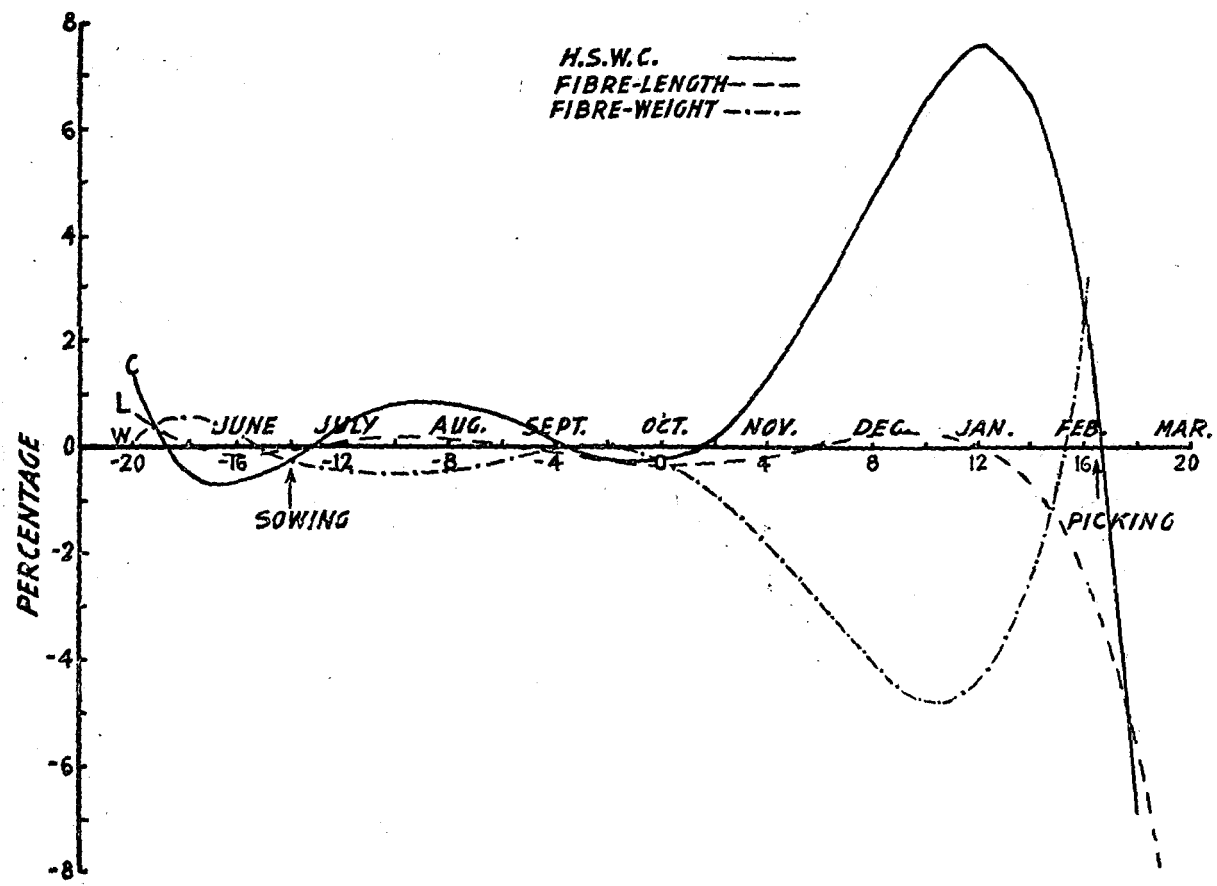


Fig. 13a.—Effect of an additional inch of rain on quality of Cotton.
 Percentage change in spinning value and fibre-properties
 Group (b). Surat 1027 A. L. F. and Wagad 8.

TABLE 16a.

Prediction of Spinning Values from Rainfall Distribution Values.

Surat 1027 A.L.F. and Wagad 8.

Cotton	Season.	Observed value	Theoretical Values		Differences	
			Rainfall without eliminating secular change	Rainfall and secular change	Rainfall without eliminating secular change	Rainfall and secular change
Surat 1027 A.L.F.	1923-24	30	30.705	30.900	-0.705	-0.900
	1924-25	32	30.922	30.531	1.078	1.496
	1925-26	26	27.702	27.275	-1.702	-1.275
	1926-27	32	33.284	32.158	-1.284	-0.158
	1927-28	30	31.487	30.805	-1.487	-0.805
	1928-29	32	30.321	29.260	1.679	2.740
	1929-30	34	32.436	31.682	1.564	2.318
	1930-31	29	30.184	29.530	-1.184	-0.530
	1931-32	30	33.065	32.804	-3.065	-2.804
	1932-33	31	33.044	33.152	-2.044	-2.152
	1933-34	37	35.123	36.100	1.877	0.900
	1934-35	34	31.523	33.258	2.477	0.742
	1935-36	34	31.231	33.553	2.769	0.447
Wagad 8	1925-26	12	12.442	12.218	-0.442	-0.218
	1926-27	14	14.415	13.713	-0.415	0.287
	1927-28	15	15.454	15.013	-0.454	-0.013
	1928-29	15	14.692	14.430	0.308	0.570
	1929-30	12	13.007	12.739	-1.007	-0.739
	1930-31	12	12.566	12.407	-0.566	-0.407
	1931-32	16	15.151	15.088	0.819	0.912
	1932-33	13	13.510	13.688	-0.510	-0.688
	1933-34	16	16.232	16.490	-0.232	-0.490
1934-35	14	11.714	12.433	2.286	1.567	
1935-36	12	11.827	12.787	0.173	-0.787	
Total deviation without regard to sign (d)					30.157	23.918
Residual sum of squares					54.274	38.269

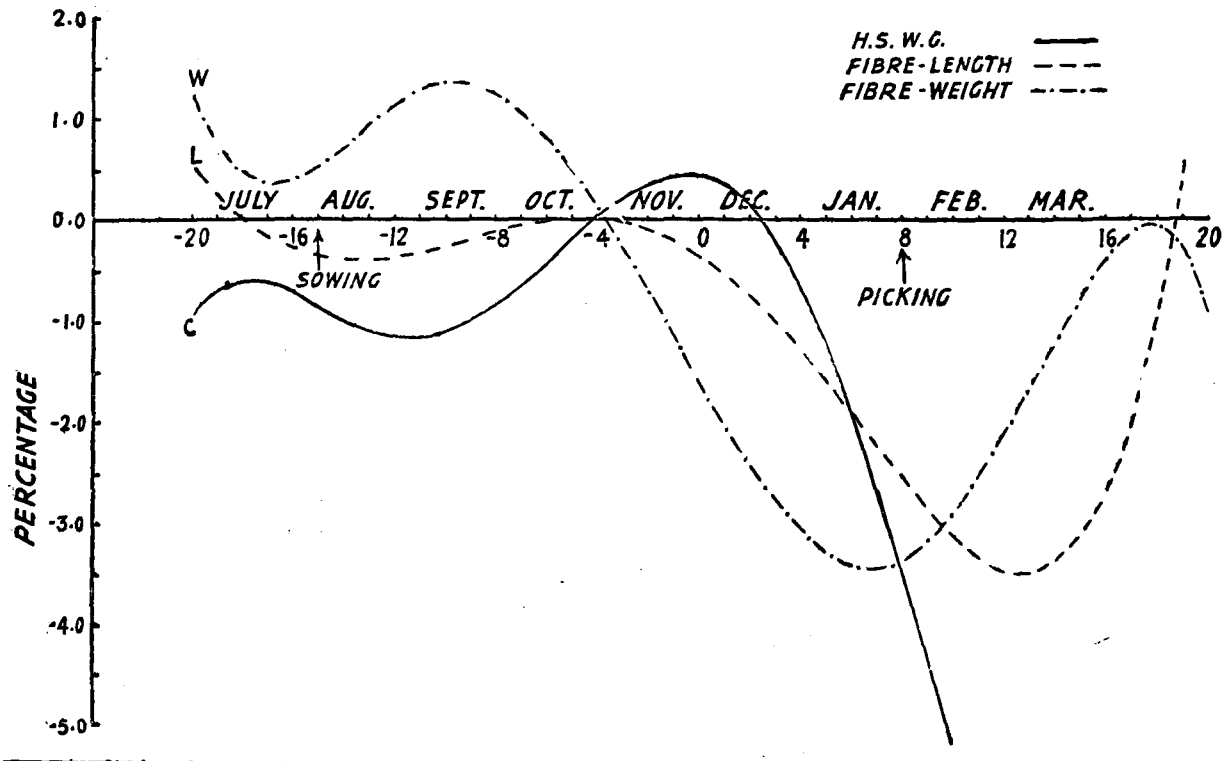


Fig. 14a.—Effect of an additional inch of rain on quality of cotton. Percentage change in spinning value and fibre-properties. Group (c).—Jayawant, and Nandyal 14.

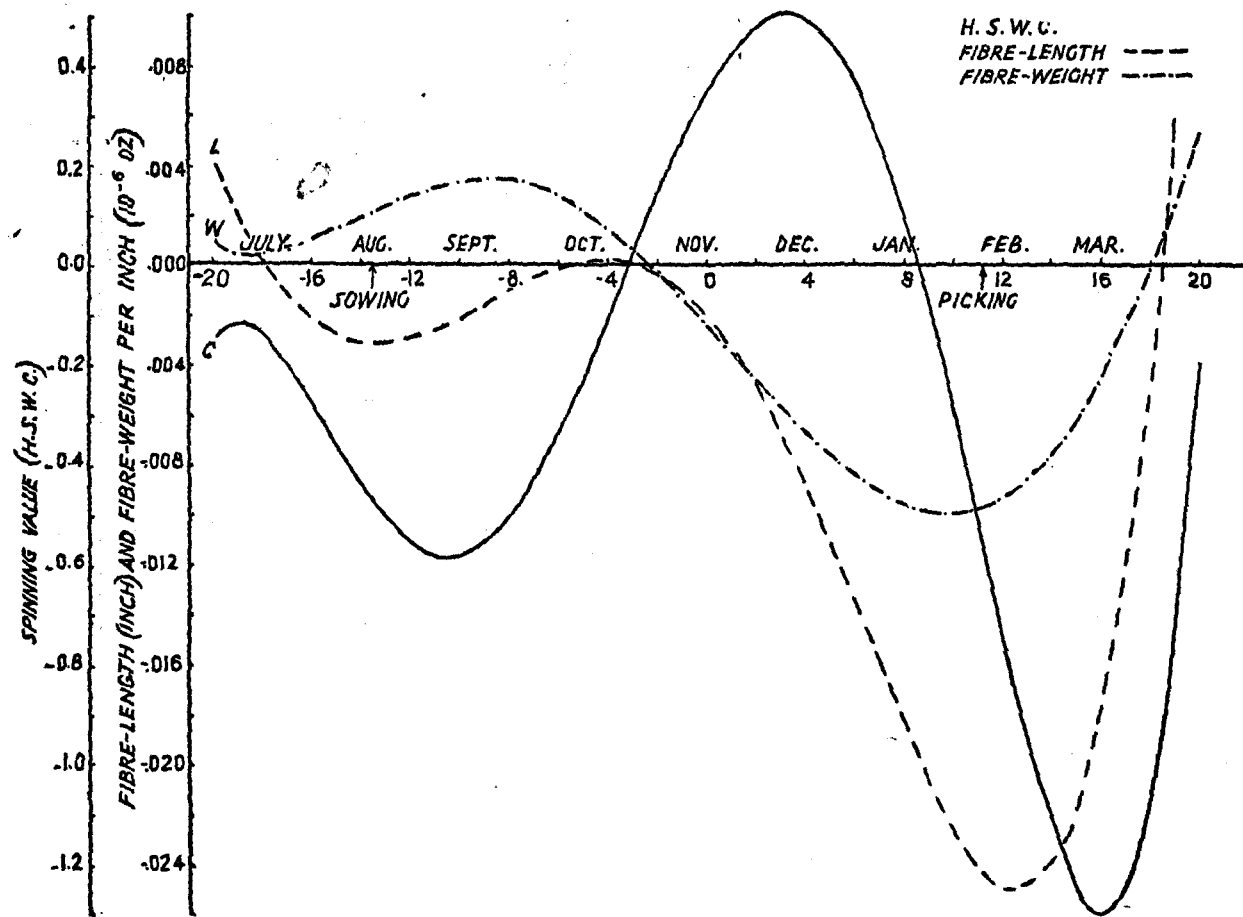


Fig. 14.—Effect of an additional inch of rain on the quality of Cotton. Group (c) Jayawant, and Nandyal 14.

when enough data for a sufficient number of years becomes available, the regression formula as a means of *future* prediction will be placed on a much sounder basis. This hope is strengthened by the fact that the agreement for the period under investigation between the observed and calculated values is fairly close with the exception of a few values as indicated by the figures in tables 16a, 16b and 16c. The theoretical values are also calculated from the regression equation obtained without eliminating the secular change. From a comparison of the two sets of theoretical values the influence of the secular change is at once apparent. Not only is the residual sum of squares (and also the total sum of deviations without regard to sign) smaller, but in most cases the theoretical value agrees more closely with the observed spinning value when allowance is made for the secular change.

Table 16a gives the results for the two Bombay cottons, Surat 1027 A.L.F. and Wagad 8. Reference to table 2 in Section III will show that in Surat about 30% of the total variability is due to the secular change, while in Wagad 8 only a negligible amount (about 8%) can be ascribed to it. This is reflected in the difference between the observed and calculated values given in the last two columns of the table. Thus the values of d (total deviation) differ by about 22% (that with secular change being less). Of the individual values, it is interesting to note that the *extreme variations* in the quality of cotton are *well accounted for* by the *extreme variations* in climate as indicated by the principal weather element—the rainfall sequence. Thus, corresponding to the highest and lowest values of Surat 1027 A.L.F., viz., 26 and 37, for the years 1925-26, and 1933-34, the theoretical values are 27.3, and 36.1 respectively. Similarly the theoretical values corresponding to 34, for the seasons 1934-35 and 35-36, are 33.3 and 33.6—a fair agreement—showing the importance of the removal of secular change in crop and weather data, prior to correlation.

Table 16b includes the results for the cottons Jayawant and Nandyal 14, and 16c for Hagari 1 and Gadag 1. Reference to tables 2 and 5 of Section III will show that for Jayawant about 20% and for Nandyal more than 60% of the total variation is due to secular change. Hagari 1 and Gadag 1, however, show no secular change, although the total variation is fairly high. The influence of secular change for Nandyal 14 and Jayawant is well reflected in the values of the residual sum of squares, which are reduced from 61,160, to 22,209, or about one third of that when the secular change is not eliminated.

TABLE 16a.

Prediction of Spinning Values from Rainfall Distribution Values.

Surat 1027 A.L.F. and Wagad 8.

Cotton	Season.	Observed value	Theoretical Values		Differences	
			Rainfall without eliminating secular change	Rainfall and secular change	Rainfall without eliminating secular change	Rainfall and secular change
	1923-24	30	30.705	30.900	-0.705	-0.900
	1924-25	32	30.922	30.531	1.078	1.496
	1925-26	26	27.702	27.275	-1.702	-1.275
	1926-27	32	33.284	32.158	-1.284	-0.158
Surat	1927-28	30	31.487	30.805	-1.487	-0.805
1027	1928-29	32	30.321	29.260	1.679	2.740
A.L.F	1929-30	34	32.436	31.682	1.564	2.318
	1930-31	29	30.184	29.530	-1.184	-0.530
	1931-32	30	33.065	32.804	-3.065	-2.804
	1932-33	31	33.044	33.152	-2.044	-2.152
	1933-34	37	35.123	36.100	1.877	0.900
	1934-35	34	31.523	33.258	2.477	0.742
	1935-36	34	31.231	33.553	2.769	0.447
	1925-26	12	12.442	12.218	-0.442	-0.218
	1926-27	14	14.415	13.713	-0.415	0.287
	1927-28	15	15.454	15.013	-0.454	-0.013
	1928-29	15	14.692	14.430	0.308	0.570
Wagad	1929-30	12	13.007	12.739	-1.007	-0.739
8	1930-31	12	12.566	12.407	-0.566	-0.407
	1931-32	16	15.151	15.088	0.849	0.912
	1932-33	13	13.510	13.688	-0.510	-0.688
	1933-34	16	16.232	16.490	-0.232	-0.490
	1934-35	14	11.714	12.433	2.286	1.567
	1935-36	12	11.827	12.737	0.173	-0.787
Total deviation without regard to sign (d)					30.157	23.918
Residual sum of squares					54.274	38.269

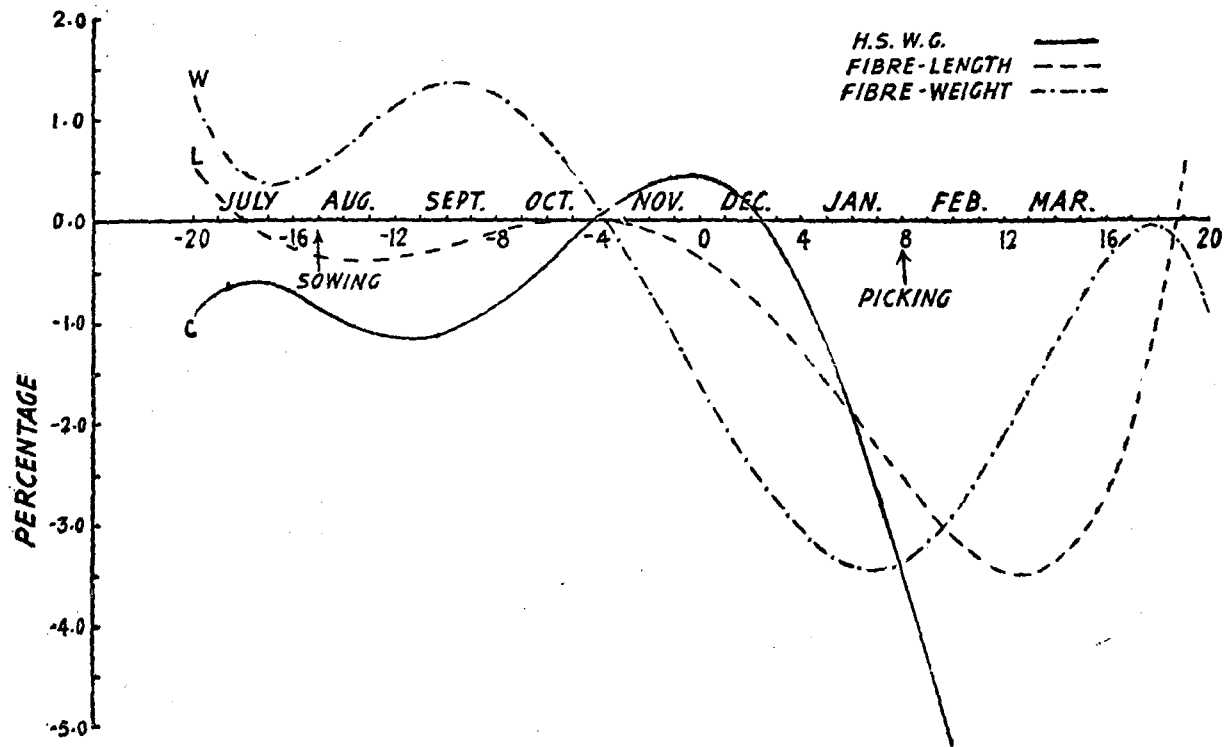


Fig. 14a.—Effect of an additional inch of rain on quality of cotton. Percentage change in spinning value and fibre-properties. Group (c).—Jayawant, and Nandyal 14.

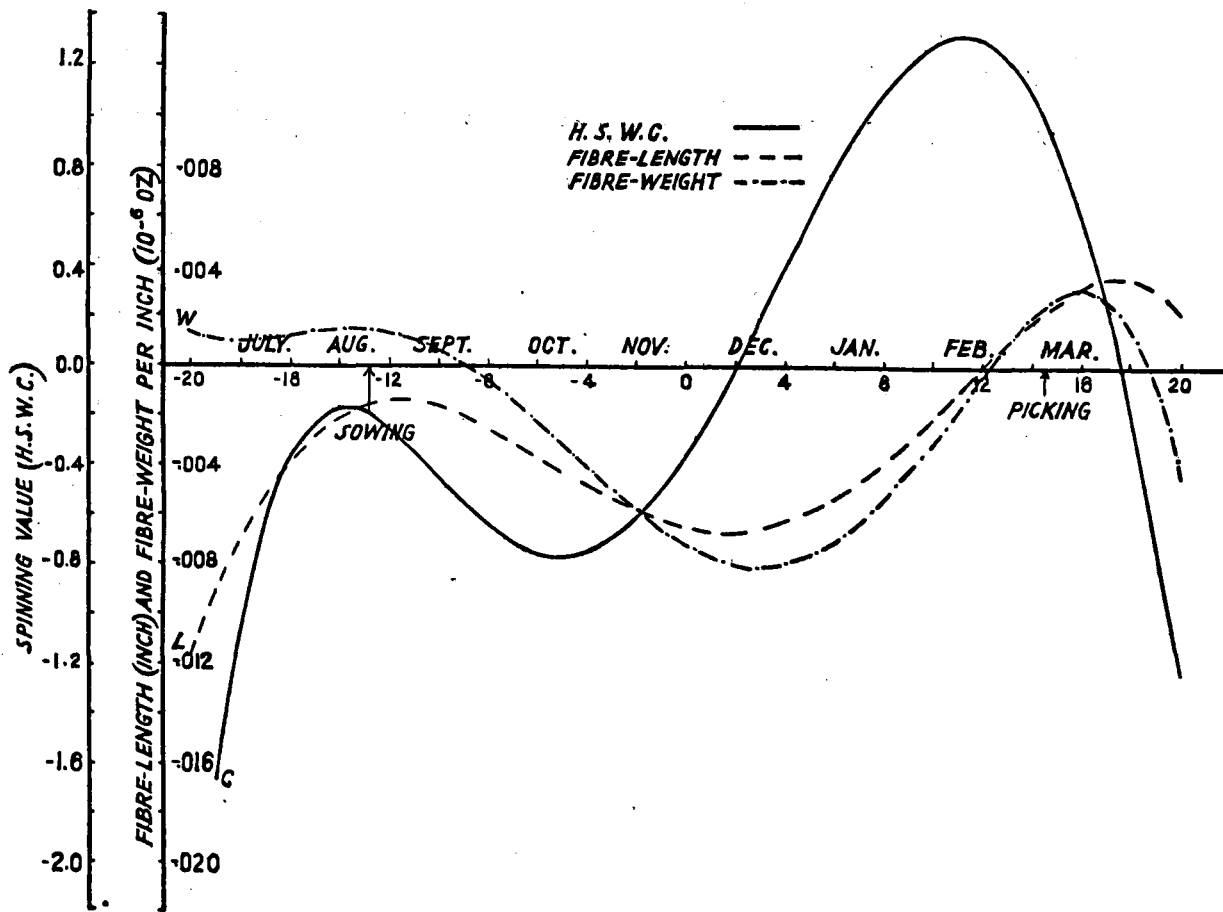


Fig. 15.—Effect of an additional inch of rain on the quality of Cotton. Group (d). Hagari 1 and Gadag 1.

TABLE 16b.

Prediction of Spinning Values from Rainfall Distribution Values.

Nandyal 14 and Jayawant (Dharwar).

Cotton	Season	Observed value.	Theoretical Values		Differences	
			Rainfall without eliminating secular change	Rainfall and secular change	Rainfall without eliminating secular change	Rainfall and secular change
Nandyal 14	1924-25	32	34.768	33.733	-2.766	-1.733
	1925-26	32	32.243	31.244	-0.243	0.756
	1926-27	34	33.283	32.193	0.717	1.807
	1927-28	31	32.445	31.056	-1.445	0.044
	1928-29	31	31.721	31.395	-0.721	-0.395
	1929-30	35	34.935	33.978	0.065	1.022
	1930-31	35	35.209	34.407	-0.209	0.593
	1931-32	30	30.800	31.754	-0.800	-1.754
	1932-33	37	37.895	38.812	-0.895	-1.812
	1933-34	37	35.441	36.835	1.559	0.165
	1934-35	40	35.036	38.584	4.964	1.416
Jayawant (Dharwar)	1926-27	38	38.202	38.016	-0.202	-0.016
	1927-28	38	38.952	37.351	-0.952	0.649
	1928-29	38	41.118	39.366	-3.118	-1.366
	1929-30	40	38.827	39.507	1.173	0.493
	1930-31	37	37.592	37.252	-0.592	-0.252
	1931-32	40	39.534	38.632	0.466	1.368
	1932-33	36	35.201	36.670	0.799	-0.670
	1933-34	33	38.454	38.608	-0.454	-0.608
	1934-35	42	39.119	41.627	2.881	0.373
Total deviation without regard to sign (d)					25.023	17.292
Residual sum of squares					61.160	22.209

TABLE 16c.

Prediction of Spinning Values from Rainfall Distribution Values.

Hagari 1 and Gadag 1.

Cotton	Season	Observed Value	Theoretical Values		Differences	
			Rainfall without eliminating secular change	Rainfall and secular change	Rainfall without eliminating secular change	Rainfall and secular change
Hagari 1	1924-25	30	29.155	28.364	0.845	1.636
	1925-26	30	31.140	31.050	-1.140	-1.050
	1926-27	27	27.875	27.904	-0.875	-0.904
	1927-28	29	28.121	28.647	0.879	0.353
	1928-29	24	25.807	26.439	-1.807	-2.439
	1929-30	27	28.288	28.698	-1.288	-1.698
	1930-31	36	28.668	29.336	7.332	6.664
	1931-32	30	30.398	30.744	-0.398	-0.744
	1932-33	25	27.697	27.413	-2.697	-2.413
	1933-34	28	26.829	26.687	1.171	1.313
	1934-35	29	30.976	29.721	-1.976	0.721
Gadag 1	1925-26	30	29.102	30.055	0.898	-0.055
	1926-27	38	55.285	36.277	2.715	1.723
	1927-28	38	37.141	38.017	0.859	-0.017
	1928-29	26	27.136	27.601	-1.136	-1.601
	1929-30	32	34.625	34.067	-2.625	-2.067
	1930-31	35	35.266	34.782	-0.266	0.218
	1931-32	29	30.289	30.113	-1.289	-1.113
	1932-33	30	27.970	27.181	2.030	2.819
	1933-34	30	29.420	28.615	0.580	1.385
	1934-35	33	32.823	32.147	0.177	0.853
	1935-36	30	31.927	32.155	-1.927	-2.155
Total Deviation without regard to sign (d)					34.910	33.947
Residual sum of squares					101.973	92.913

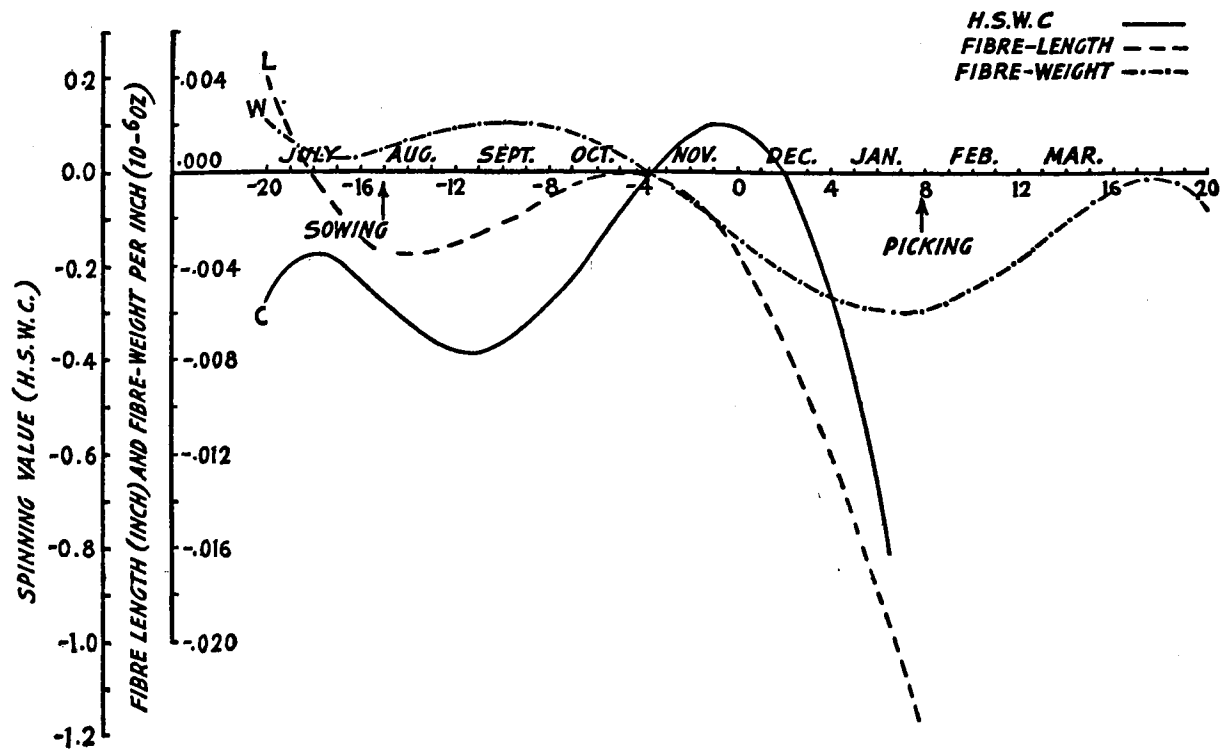


Fig 15a.—Effect of an additional inch of rain on quality of cotton. Percentage change in spinning value and fibre-properties. Group (d), Hagari 1 and Gadag 1.

ACKNOWLEDGMENTS.

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APPENDIX I.

		Thus.	
26	1	0.952195	1.354646
27	..	0.952195	1.550513
28	..	0.952195	1.645890
29	..	0.952195	1.694533
30	..	0.952195	1.721712
31	..	0.952195	1.721712
32	..	0.952195	1.721712
33	..	0.952195	1.721712
34	..	0.952195	1.721712
35	..	0.952195	1.721712
36	..	0.952195	1.721712
37	..	0.952195	1.721712
38	..	0.952195	1.721712
39	..	0.952195	1.721712
40	..	0.952195	1.721712
41	..	0.952195	1.721712
Total	39.04	1166.35	19134.88
	223431.27	207031.11	16126968.95

		0.69	0.37	0.08
S'_1	1	1	1	1
S'_2	19	4	2	1
S'_3	190	10	3	1
S'_4	1330	20	4	1
S'_5	7315	35	5	1
S'_6	33649	56	6	1

TABLE 17.

CALCULATION OF RAINFALL DISTRIBUTION VALUES.

Jayawant. (Government Agricultural Farm, Dharwar, 1932-33.)

Week No.	S_1	S_2	S_3	S_4	S_5	S_6
1	1.14	1.14	1.14	1.14	1.14	1.14
2	2.03	3.17	4.31	5.45	6.59	7.73
3	2.93	6.10	10.41	15.86	22.45	30.18
4	2.38	8.48	18.89	34.75	57.20	87.38
5	1.96	10.44	29.33	64.08	121.23	208.66
6	0.45	10.89	40.22	104.30	225.58	434.24
7	0.55	11.44	51.66	155.96	381.54	815.78
8	3.43	14.87	66.53	222.49	604.03	1419.81
9	1.22	16.09	82.62	305.11	909.14	2328.95
10	1.35	17.44	100.06	405.17	1314.31	3643.26
11	0.38	17.82	117.88	523.05	1837.36	5480.62
12	0.14	17.96	135.84	658.89	2496.25	7976.87
13	0.85	18.81	154.65	813.54	3309.79	11286.66
14	3.01	21.82	176.47	990.01	4299.80	15586.46
15	2.41	24.23	200.70	1190.71	5490.51	21076.97
16	4.09	28.32	229.02	1419.73	6910.24	27987.21
17	1.47	29.79	258.81	1678.54	8588.78	36575.99
18	3.89	33.68	292.49	1971.03	10559.81	47135.80
19	3.39	37.07	329.56	2300.59	12860.40	59996.20
20	0.40	37.47	367.03	2667.62	15528.02	75524.22
21	0.27	37.74	404.77	3072.39	18600.41	94124.63
22	0.16	37.90	442.67	3515.06	22115.47	116240.10
23	37.90	42.67	3515.06	22115.47	116240.10	527968.86
24	--					
25	--					

Now with the help of this table and the totals given at the end of the 22nd week, the values of S_1 , S_2 , S_3 , etc., can be easily obtained.

$$\begin{aligned}
 S_1 &= 37.90 + 0.69 + .37 + 0.08 && = 39.04 \\
 S_2 &= 442.67 + 19 \times 37.90 + 4 \times .69 + 2 \times 0.37 + .08 && = 1166.35 \\
 S_3 &= 3515.06 + 19 \times 442.67 + 190 \times 37.90 + 10 \times .69 \\
 &\qquad\qquad\qquad 3 \times .37 + .08 && = 19134.88 \\
 S_4 &= 22115.47 + 19 + 351506. + 190 \times 442.67 + 133 \times 37.90 \\
 &\qquad\qquad\qquad + 20 \times .69 + 4. \times 37 + 0.08 && = 223431.29 \\
 S_5 &= 116240.10 + 19 \times 22115.47 + 190 \times 3515.06 + \\
 &\qquad\qquad\qquad 133 \times 442.67 + 7315 \times 37.90 + 35 \times 69 \\
 &\qquad\qquad\qquad + 5 \times .37 + .08 && = 2070311.11 \\
 S_6 &= 527968.86 + 19 \times 116240.10 + 190 \times 22115.47 + \\
 &\qquad\qquad\qquad 1330 \times 3515.06 + 7315 \times 442.67 + 33649 \times 37.90 \\
 &\qquad\qquad\qquad + 56 \times .69 + 6 \times .37 + .08 && = 16126968.95
 \end{aligned}$$

On a calculating machine, the process of calculating each S is a continuous one and all the six values may be obtained in a few minutes

From the values of S_1 , S_2 , S_3 , S_6 , six series of quantities a , b , c , d , e and f may be obtained from the following equations:—

$$a = \frac{1}{n'} S_1$$

$$b = \frac{1.2}{n' (n' + 1)} S_2$$

$$c = \frac{1.2.3}{n' (n' + 1) (n' + 2)} S_3$$

$$d = \frac{1.2.3.4}{n' (n' + 1) (n' + 2) (n' + 3)} S_4$$

$$e = \frac{1.2.3.4.5}{n' (n' + 1) (n' + 2) (n' + 3) (n' + 4)} S_5$$

$$f = \frac{1.2.3.4.5.6}{n' (n' + 1) (n' + 2) (n' + 3) (n' + 4) (n' + 5)} S_6$$

The co-efficients of S_1, S_2, \dots, S_6 are readily obtained from table 18 thus of 41 weeks :

$$a = \frac{S_1}{41} = \frac{39.04}{41} = 0.952195$$

$$b = \frac{S_2}{861} = \frac{1166.35}{861} = 1.354646$$

$$c = \frac{S_3}{12341} = \frac{19134.88}{12341} = 1.550513$$

$$d = \frac{S_4}{135751} = \frac{223431.27}{135751} = 1.645890$$

$$e = \frac{S_5}{1221759} = \frac{2070311.11}{1221759} = 1.694533$$

$$f = \frac{S_6}{9366819} = \frac{16126968.95}{9366819} = 1.721712$$

From these the rainfall distribution values a', \dots, f' are evaluated in the usual manner from the following equations:—

$$a' = a$$

$$b' = a - b$$

$$c' = a - 3b + 2c$$

$$d' = a - 6b + 10c - 5d$$

$$e' = a - 10b + 30c - 35d + 14e$$

$$f' = a - 15b + 70c - 140d + 126e - 42f.$$

TABLE 18.

Table for checking polynomial calculations.

S'_1	S'_2	S'_3	S'_4	S'_5	S'_6
1	1	1	1	1	1
1	2	3	4	5	6
1	3	6	10	15	21
1	4	10	20	35	56
1	5	15	35	70	126
1	6	21	56	126	252
1	7	28	84	210	462
1	8	36	120	330	792
1	9	45	165	495	1287
1	10	55	220	715	2002
1	11	66	286	1001	3003
1	12	78	364	1365	4368
1	13	91	455	1820	6188
1	14	105	560	2380	8568
1	15	120	680	3060	11628
1	16	136	816	3876	15504
1	17	153	969	4845	20349
1	18	171	1140	5985	26334
1	19	190	1330	7315	33649
1	20	210	1540	8855	42504
1	21	231	1771	10626	53130
1	22	253	2024	12650	65780
1	23	276	2300	14950	80730
1	24	300	2600	17550	98280
1	25	325	2925	20475	118755
1	26	351	3276	23751	142506
1	27	378	3654	27405	169911
1	28	406	4060	31465	201376
1	29	435	4495	35960	237336
1	30	465	4960	40920	278256
1	31	496	5456	46376	324632
1	32	528	5984	52360	376992
1	33	561	6545	58905	435897
1	34	595	7140	66045	501942
1	35	630	7770	73815	575757
1	36	666	8433	82251	658008
1	37	703	9139	91390	749398
1	38	741	9880	101270	850668
1	39	780	10660	111930	962598
1	40	820	11480	123410	1086008
1	41	861	12341	135751	1221759
41	861	12341	135751	1221759	9366819

Table 18 can be used for other purposes as well. Thus, should it be necessary to modify the old record by the insertion of a new value or alteration or omission of any of the old values, the whole process of successive summation need not be gone through *ab initio*, but appropriate corrections can be applied (with the help of table 18) to the old values of a' , b' , c' , etc., in order to obtain the corresponding new values.

APPENDIX II.

USE OF CHECK-SUM IN POLYNOMIAL CALCULATIONS.

The rainfall distribution values obtained for the different years for any one cotton may be checked collectively by a single process involving check sum. For this purpose, weekly totals for all the years (check sum) are obtained, and from these the values of a', b' c', etc., are calculated in the same manner as for the record of each year separately. These values of a'.....f' should be equal to the sum of the corresponding values of a'.....f' for the different years comprising the check sum.

The accuracy of the values of X', X', for the different rainfall distribution values for each cotton can also be ascertained by a 'check sum.' The sum of a', b', c', d' e', f', for each year is calculated, and for the series of values thus obtained, X', and X', are evaluated. These should be equal to the sum of the corresponding values of X', and X', for the six rainfall constants.

The sums of squares and products of rainfall distribution values may be checked by the use of check sum in the usual manner, and the method was extended to check the sums of squares and products of residuals obtained after removal of secular change.

APPENDIX III.

THE CALCULATION OF POLYNOMIAL VALUES.

For the purpose of drawing graphs it is sometimes desirable to obtain the polynomial values corresponding to each weekly record. This can readily be done by the process of successive summation by forming columns of differences. For this purpose, first a series of terminal values are calculated from the rainfall constants by the help of the following equations :—.....

$$\begin{aligned}\Delta_Y^5 &= \frac{-6.7.8.9.10.11}{(n'-1)(n'-2)(n'-3)(n'-4)(n'-5)} f' \\ \Delta_Y^4 &= \frac{5.6.7.8.9}{(n'-1)(n'-2)(n'-3)(n'-4)} (e'+11f') \\ \Delta_Y^3 &= \frac{-4.5.6.7}{(n'-1)(n'-2)(n'-3)} (d'+9e'+44f') \\ \Delta_Y^2 &= \frac{3.4.5}{(n'-1)(n'-2)} (c'+7d'+27e'+77f') \\ \Delta Y &= \frac{-2.3}{n'-1} (b'+5c'+14d'+30e'+55f') \\ Y &= a'+3b'+5c'+7d'+9e'+11f'.\end{aligned}$$

The process of evaluation of terminal values is illustrated in table 19 where the terminal values for Jayawant cotton are given at the foot of the table. These were calculated from the mean values of $a' \dots \dots f'$ for the nine seasons 1926-27 -1934-35. Before building up the column of differences, it is desirable to insert the 11th, 21st, 31st and the last value of each column, directly by calculation. For this purpose table 18 may be used. The appropriate co-efficients with which to multiply the terminal values are indicated by figures in the ascending order, starting from the figure in S' , which corresponds to a figure one less than the position of the value to be inserted in the difference column. Starting from values 10, 20, 30 and 40 these co-efficients are shown by line-steps in order to obtain the 11th, 21st, 31st value of each difference column, and 41st (*i.e.*, last) polynomial value. Thus, the 11th, 21st and 31st values of the 3rd difference column are given by:—

$$\text{11th value} = \Delta_y^3 + 10 \Delta_y^4 + 45 \Delta_y^5$$

$$\text{21st value} = \Delta_y^3 + 20 \Delta_y^4 + 190 \Delta_y^5$$

$$\text{31st value} = \Delta_y^3 + 30 \Delta_y^4 + 435 \Delta_y^5$$

while the corresponding values for the 2nd difference column are given by:—

$$\text{11th value} = \Delta^2 y + 10 \Delta^3 y + 45 \Delta^4 y + 120 \Delta^5 y.$$

$$\text{21st value} = \Delta^2 y + 20 \Delta^3 y + 190 \Delta^4 y + 1140 \Delta^5 y.$$

$$\text{31st value} = \Delta^2 y + 30 \Delta^3 y + 435 \Delta^4 y + 4060 \Delta^5 y.$$

In a similar manner the 21st and the 31st polynomial values can be inserted while the last polynomial value which provides a final check on all the calculations is given by:— $-y + 40 \Delta y + 780 \Delta^2 y + 9880 \Delta^3 y + 91390 \Delta^4 y + 658008 \Delta^5 y$.

TABLE 19

Calculation of Polynomial Values.

Jayawant (Government Agricultural Farm, Dharwar)

Mean Weekly rainfall for years 1926-27—1934-35.

Week No.	Observed values.	Polynomial values.	First difference.	Second difference	Third difference	Fourth difference
1	1.426	1.5649				
	1.445	1.3632	.20170			
	0.953	1.2280	.13515	.066546		
	1.773	1.1450	.08300	.052155	.0143912	
5	1.393	1.1015	.04356	.039441	.0127135	.00167762
	0.994	1.0862	.01524	.028320	.0111211	.00159245
	0.684	1.0897	-.00347	.018706	.0096138	.00150729
	1.218	1.1037	-.01399	.010515	.0081917	.00142212
10	0.608	1.1213	-.01765	.003660	.0068547	.00133695
	0.739	1.1370	-.01570	-.001943	.0056030	.00125178
	1.541	1.1464	-.00932	-.006379	.0044363	.00116661
	0.945	1.1459	.00041	-.009734	.0033549	.00108145
15	0.948	1.1334	.01250	-.012093	.0023586	.00099628
	1.465	1.1074	.02604	-.013540	.0014475	.00091111
	1.471	1.0672	.04021	-.014162	.0006216	.00082594
	1.256	1.0129	.05425	-.014043	-.0001192	.00074077
20	0.948	0.9454	.06752	-.013268	-.0007748	.00065561
	1.279	0.8660	.07944	-.011923	-.0013453	.00057044
	0.699	0.7764	.08953	-.010092	-.0018305	.00048527
	1.098	0.6791	.09739	-.007862	-.0022306	.00040010
25	0.046	0.5764	.10271	-.005316	-.0025456	.00031493
	0.018	0.4711	.10525	-.002541	-.0027753	.00022977
	0.037	0.3662	.10487	.000379	-.0029199	.00014460
	0.113	0.2647	.10151	.003359	-.0029794	.00005943
30	0.079	0.1695	.09520	.006312	-.0029530	-.00002574
	..	0.0835	.08605	.009155	-.0028427	-.00011091
	..	0.0092	.07424	.011802	-.0026466	-.00019607
	0.180	-.0509	.06008	.014167	-.0023654	-.00028124
35	..	-.0948	.04391	.016166	-.0019990	-.00036641
	..	-.01210	.02620	.017713	-.0015474	-.00045158
	..	-.01284	.00747	.018724	-.0010107	-.00053675
	0.144	-.01168	-.01164	.019113	-.0003888	-.00062191
40	..	-.0864	-.03043	.018795	.0003183	-.00070708
	..	-.0383	-.04812	.017684	.0011106	-.00079225
	..	0.0256	-.06381	.015696	.0019880	-.00087742
	..	0.1021	-.07656	.012745	.0029506	-.00096259
41	..	0.1874	-.08531	.008747	.0039983	-.00104775
	0.093	0.2764	-.08892	.003616	.0051313	-.00113229
	0.301	0.3625	-.08619	-.002734	.0063494	-.00121809
40	0.446	0.4383	-.07580	-.010386	.0076526	-.00130326
41	0.673	0.49472	-.056375	-.1942272	.00904104	-.001388426

Total 25.013 25.0116 Fifth difference :— .000085168.

Having obtained a skeleton of the table by inserting a few values (indicated by bold type) in each difference column, the intervening figures may be filled up with great rapidity and confidence by successive summation. The special advantage of this procedure is that mistakes are avoided, for if a small mistake is made in one column its commulative effect is carried forward in the successive columns with the result that it becomes a laborious job to locate the mistake and correct the subsequent figures afterwards.

APPENDIX IV.

TABLE I—Values of X'_2 and X'_3 —Quality Data.

Cotton		H. S. W. C.		Fibre-length.		Fibre-weight.	
		X'_2	X'_3	X'_2	X'_3	X'_2	X'_3
Bombay	Jayawant	1.549202	1.519440	0.029692	0.043125	-0.028792	-0.028900
	Gadag I	-3.718531	0.785066	-0.018111	-0.017396	0.006677	0.002470
	Surat 1027 A. L. F.	5.337021	1.698559	0.012607	0.061919	-0.021349	-0.006884
	Wagad 8	+ .286044	-1.467737	0.007627	-0.007517	0.006003	0.003085
Punjab	289F	11.250950	-3.071989	-0.074369	0.027315	0.015827	-0.017894
	4F	-0.968252	5.270584	-0.005165	0.027349	-0.042862	-0.029559
	Mollisoni	1.906944	-1.023986	0.025744	0.034470	-0.011245	0.000420
U. P. and C. P.	C. A. 9	10.069798	-2.507096	-0.046476	-0.008367	0.001290	-0.021360
	Verum 262 (Nag-pur)	1.032801	2.127244	-0.055510	0.011216	0.003869	-0.000846
	Verum 262 (Akola)	1.032801	-1.519449	-0.038732	0.016331	0.003096	0.020166
Madras	Cambodia	-3.718525	-0.170643	-0.017161	0.010241	-0.027173	0.009586
	Hagari I	-0.476731	0.580275	-0.013347	-0.033435	0.016405	-0.023263
	Nandyal 14	6.769638	3.857104	0.007627	0.021145	0.003719	-0.010201
	Karunganni C. 7	0.286044	5.290654	-0.011447	0.002040	0.012875	-0.018177

TABLE II—RAINFALL CONSTANTS AND QUALITY DATA.

(a) *Verum 262 Nagpur & Akola; C. A. 9.*

Cotton	Season	Rainfall Distribution Values						Quality Data.		
		a'	b'	c'	d'	e'	f'	H.S.W.C.	Fibre-length.	Fibre-weight.
Verum 262 (Nagpur)	1926-27	1.649	-.450	-.334	.179	.110	-.113	24	.84	.167
	27-28	1.681	-.328	-.370	.277	-.058	-.074	26	.88	.194
	28-29	1.119	.011	-.287	.014	-.025	-.036	26	.86	.193
	29-30	1.294	.014	-.368	-.034	.020	.035	21	.81	.166
	30-31	0.993	-.252	-.207	.181	-.053	-.038	26	.82	.186
	31-32	1.858	-.141	-.539	.092	.078	-.021	25	.83	.176
	32-33	1.441	-.349	-.319	.309	-.016	-.115	23	.82	.180
	33-34	2.246	-.242	-.587	.110	.156	-.057	24	.77	.188
	34-35	1.201	-.127	-.332	.086	.026	-.003	28	.83	.183
	Mean		1.4980	-.2071	-.3714	.1349	.0264	-.0469	24.8	.829	.1814
Verum 262 (Akola)	1927-28	0.827	-.011	-.189	.026	-.050	-.041	19	.83	.189
	28-29	0.873	.012	-.197	-.000	-.037	.006	23	.84	.168
	29-30	0.762	-.268	-.095	.128	-.081	.029	21	.84	.176
	30-31	0.843	-.005	-.266	-.025	.069	.060	18	.80	.170
	31-32	1.348	.135	-.336	-.076	.005	.006	21	.78	.174
	32-33	0.861	-.113	-.256	.092	.043	-.032	25	.82	.163
	33-34	1.112	-.258	-.218	.092	.011	.012	21	.80	.184
	34-35	1.008	-.159	-.300	.147	.067	-.079	22	.80	.165
	35-36	1.158	-.261	-.327	.200	.036	-.064	20	.80	.195
	Mean		0.9769	-.1031	-.2427	.0649	.0070	-.0114	21.1	.812	.1760
Cawnpore American C. A. 9.	1924-25	1.307	-.026	-.517	.050	.222	-.066	28	.90	.147
	25-26	1.334	.006	-.394	.030	.107	-.023	28	.87	.132
	26-27	1.065	.099	-.388	-.087	.138	.027	34	.88	.164
	27-28	1.153	.205	-.240	-.012	.108	.001	30	.86	.158
	28-29	0.539	.028	-.121	.048	.037	-.060	40	.89	.149
	29-30	0.896	-.024	-.325	.031	.118	-.019	34	.87	.165
	30-31	0.968	.139	-.272	-.033	.102	-.016	37	.86	.154

CONSTANTS AND QUALITY DATA.

(b) *Surat 1027 A.L.F. and Wagad 8.*

Cotton.	Season.	Rainfall Distribution Values					Quality Data.			
		a'	b'	c'	d'	e'	f'	H.S.W. C.	Fibre-length.	Fibre-weight.
Surat 1027 A.L.F.	1923-24	0.590	-.303	-.027	.176	-.129	.019	30	1.00	.190
	24-25	1.003	-.406	-.156	.254	-.075	-.031	32	0.95	.184
	25-26	0.697	-.414	.161	.036	-.102	.075	26	0.92	.213
	26-27	1.535	-.736	-.129	.433	-.237	-.016	32	0.98	.180
	27-28	0.856	-.350	-.064	.140	-.099	.060	30	0.94	.186
	28-29	0.639	-.255	-.084	.137	-.051	.004	32	0.96	.184
	29-30	1.177	-.658	.048	.313	-.334	.123	34	0.97	.180
	30-31	1.007	-.525	.001	.234	-.212	.097	29	0.94	.201
	31-32	1.302	-.485	-.232	.322	-.106	-.025	30	0.90	.175
	32-33	0.910	-.440	-.083	.292	-.188	-.005	31	0.94	.190
	33-34	1.306	-.441	-.257	.295	-.028	-.116	37	0.99	.169
	34-35	1.279	-.669	.012	.296	-.281	.119	34	0.96	.183
	35-36	1.107	-.465	-.104	.277	-.145	.003	34	1.01	.168
	Mean	1.0245	-.4728	-.0703	.2465	-.1528	.0236	31.6	0.958	.1848
Wagad 8	1925-26	0.490	-.306	.102	.023	-.074	.063	12	0.79	.232
	26-27	0.870	-.353	-.151	.260	-.072	-.074	14	0.80	.238
	27-28	1.295	-.708	-.003	.373	-.320	.076	15	0.77	.170
	28-29	0.616	-.243	-.092	.145	-.060	-.010	15	0.80	.215
	29-30	0.348	-.177	-.003	.078	-.059	.009	12	0.76	.195
	30-31	0.473	-.261	.019	.096	-.087	.034	12	0.78	.257
	31-32	0.532	-.235	-.071	.154	-.050	-.062	16	0.80	.225
	32-33	0.833	-.482	.034	.233	-.233	.081	13	0.84	.240
	33-34	1.057	-.504	-.107	.335	-.186	-.036	16	0.80	.199
	34-35	0.520	-.302	.064	.084	-.104	.054	14	0.78	.232
	35-36	0.361	-.224	.052	.054	-.072	.043	12	0.78	.216
	Mean	0.6723	-.3450	-.0142	.1668	-.1197	.0162	13.7	0.791	.2199

TABLE IV—RAINFALL CONSTANTS AND QUALITY DATA.

(c) *Jayawant, Nandyal 14, Hagari I & Gadag I.*

Cotton	Season	Rainfall Distribution Values.						Quality Data.			
		a'	b'	c'	d'	e'	f'	H.S. W.C.	Fibre- length	Fibre- weight.	
Jayawant (Dharwar)	1926-27	.441	— .272	.075	.021	— .013	— .018	38	.88	.180	
	27-28	.542	— .233	.100	.022	.012	— .010	38	.88	.174	
	28-29	.508	— .200	.080	.070	.018	.029	38	.96	.186	
	29-30	.429	— .217	.009	.037	.024	— .059	40	.92	.181	
	30-31	.505	— .093	.017	.101	.047	— .063	37	.96	.175	
	31-32	.774	— .277	.047	.093	.040	.008	40	.93	.183	
	32-33	.952	— .402	— .011	.100	.038	— .057	36	.92	.194	
	33-34	.790	— .314	— .021	.117	— .040	.026	38	.90	.147	
	34-35	.550	— .247	.118	.004	.062	— .037	42	.94	.140	
	Mean		.6101	— .2506	.0460	.0628	.0209	— .0201	38.6	.921	.1733
Nandyal 14	1924-25	.500	— .249	.105	.031	— .010	.001	32	.89	.161	
	25-26	.819	— .410	.040	.051	.003	— .034	32	.88	.159	
	26-27	.432	— .273	.070	.050	— .055	.000	34	.94	.172	
	27-28	.636	— .325	.070	.032	— .007	— .037	31	.88	.176	
	28-29	.680	— .447	.186	— .052	.036	— .050	31	.92	.168	
	29-30	.381	— .152	— .030	.086	— .012	— .043	35	.92	.169	
	30-31	.381	— .214	.043	.058	— .047	.007	35	.86	.167	
	31-32	.520	— .265	— .000	.124	— .078	— .013	30	.85	.187	
	32-33	.331	— .183	.05	.004	.002	— .013	37	.91	.156	
	33-34	.491	— .232	.113	.023	— .028	.019	37	.89	.163	
	34-35	.491	— .237	.076	.067	— .037	.025	40	.94	.171	
Mean		.5147	— .2715	.0658	.0431	— .0212	.0125	34.0	.898	.1681	
Hagari I	1924-25	.409	— .205	— .014	.112	— .067	— .008	30	.86	.154	
	25-26	.321	— .071	— .050	.069	.005	— .019	30	.82	.132	
	26-27	.406	— .177	— .055	.119	— .040	— .050	27	.82	.188	
	27-28	.328	— .155	— .011	.055	— .007	— .028	29*	.85*	.167*	
	28-29	.336	— .153	.037	— .009	.026	— .052	24	.84	.186	
	29-30	.416	— .138	— .101	.134	— .022	— .065	27	.84	.175	
	30-31	.298	— .093	— .032	.070	.010	— .044	36	.91	.166	
	31-32	.309	— .104	— .053	.089	— .012	— .028	30	.86	.172	
	32-33	.463	— .181	— .043	.098	— .027	— .025	25	.82	.175	
	33-34	.604	— .253	.035	.134	— .083	.039	28	.80	.171	
	34-35	.184	— .049	.028	.006	.014	— .040	29	.83	.167	
	Mean		.3704	— .1435	— .0235	.0797	— .0185	— .0291	28.6	.841	.1685
Gadag I	1925-26	.403	— .230	.042	.040	— .029	— .006	30	.82	.135	
	26-27	.236	— .134	.047	.042	— .048	.027	38	.81	.161	
	27-28	.472	— .088	.027	.086	— .087	.003	38	.86	.150	
	28-29	.473	— .141	.073	.103	— .005	.019	26	.82	.146	
	29-30	.323	— .169	— .010	.095	— .070	.006	32	.84	.148	
	30-31	.203	— .060	.005	.058	— .015	— .003	35	.88	.153	
	31-32	.437	— .154	.076	.091	— .044	.020	29	.80	.154	
	32-33	.527	— .192	.017	.116	— .035	— .012	30	.81	.134	
	33-34	.539	— .224	.036	.062	— .038	.015	30	.81	.153	
	34-35	.263	— .091	.044	— .020	.013	— .029	33	.79	.147	
	35-36	.383	— .169	.068	.078	— .050	.402	30	.84	.162	
	Mean		.3872	— .1502	.0386	.0683	— .0371	.0075	31.9	.825	.1494

* Calculated values.

TABLE V—CRUDE SUMS OF SQUARES AND PRODUCTS; RAINFALL CONSTANTS.

(a) *Verum 262 Nagpur & Akola; C. A. 9.*

Cotton		a'	b'	c'	d'	e'	f'
Verum 262 (Nagpur)	a'	21.413170	-2.974175	-5.353907	1.878762	0.532638	-0.679817
	b'	-2.974175	0.590280	0.687063	-0.375695	-0.063583	0.142063
	c'	-5.353907	0.687063	1.356173	-0.432530	-0.141636	0.152899
	d'	1.878762	-0.375695	-0.432530	0.266324	0.014629	-0.093292
	e'	0.532638	-0.063583	-0.141636	0.014629	0.050650	-0.013292
	f'	-0.679817	0.142063	0.152899	-0.093292	-0.013292	0.039134
Verum 262 (Akola)	a'	8.889348	-0.871771	-2.221738	0.556807	0.088013	-0.115855
	b'	-0.871771	0.263074	0.199364	-0.154430	-0.005602	0.023046
	c'	-2.221738	0.199364	0.577196	-0.137996	-0.040878	0.036040
	d'	0.556807	-0.154430	-0.137996	0.101998	0.008244	-0.025563
	e'	0.088013	-0.005602	-0.040878	0.008244	0.022971	-0.005192
	f'	-0.115855	0.023046	0.036040	-0.025563	-0.005192	0.017699
Cawnpore American C. A. 9	a'	8.955989	0.590617	-2.811840	-0.075503	1.002087	-0.140100
	b'	0.590617	0.100669	-0.151705	-0.034150	0.049684	0.003318
	c'	-2.811840	-0.151705	0.920144	0.019439	-0.332487	0.046965
	d'	-0.075503	-0.034150	0.019439	0.027231	-0.001280	-0.010804
	e'	1.002087	0.049684	-0.332487	-0.001280	0.126262	-0.018925
	f'	-0.140100	0.003318	0.046965	-0.010804	-0.018925	0.010028

TABLE VI—CRUDE SUMS OF SQUARES AND PRODUCTS: RAINFALL CONSTANTS.

(b) Surat 1027 A. L. F. & Wagad 8.

Cotton		a'	b'	c'	d'	e'	f'
Surat 1027 A. L. F.	a'	14.635648	-6.706364	-1.112809	3.590298	-2.162683	0.270854
	b'	-6.706304	3.152943	0.414227	-1.644357	1.066816	-0.181849
	c'	-1.112809	0.414227	0.218806	-0.299658	0.082810	0.057430
	d'	3.590298	-1.644357	-0.299658	0.915689	-0.543673	0.053712
	e'	-2.162683	1.066816	0.082810	-0.543673	0.405091	-0.098810
	f'	0.270854	-0.181849	0.057430	0.053712	-0.098810	0.063633
Wagad 8.	a'	5.893197	-3.005805	-0.204501	1.575663	-1.109306	0.118004
	b'	-3.005805	1.560953	0.065392	-0.791799	0.587686	-0.087269
	c'	-0.204501	0.065392	0.066494	-0.080456	0.013458	0.035611
	d'	1.575663	-0.791799	-0.080456	0.443785	-0.298359	0.017196
	e'	-1.109306	0.587686	0.013458	-0.298359	0.235095	-0.044332
	f'	0.118004	-0.087269	0.035611	0.017196	-0.044332	0.033024

TABLE VII—CRUDE SUMS OF SQUARES AND PRODUCTS: RAINFALL CONSTANTS.

(c) *Jayawant, Nandyal 14, Hagari I and Gadag I.*

Cotton		a'	b'	c'	d'	e'	f'
Jayawant (Dharwar)	a'	3.617355	-1.468908	0.214577	0.385435	0.113582	-0.103634
	b'	-1.468908	0.621949	-0.094383	-0.145947	-0.041549	0.041761
	c'	0.214577	-0.094383	0.039090	0.012711	0.012298	-0.005541
	d'	0.385435	-0.145947	0.012711	0.049749	0.009974	-0.009176
	e'	0.113582	-0.041549	0.012298	0.009974	0.011910	-0.008921
	f'	-0.103634	0.041761	-0.005541	-0.009176	-0.008921	0.014073
Nandyal 14	a'	3.126726	-1.656984	0.401133	0.228719	-0.100567	-0.088053
	b'	-1.656984	0.892671	-0.225750	-0.109726	0.049909	0.048595
	c'	0.401133	-0.225750	0.080916	0.009172	-0.006109	-0.008170
	d'	0.228719	-0.109726	0.009172	0.040960	0.021548	-0.003131
	e'	-0.100567	0.049909	-0.006109	-0.021548	0.015073	-0.001935
	f'	-0.088053	-0.008170	-0.008170	-0.003131	-0.001935	0.008248
Hagari I.	a'	1.626020	-0.643635	-0.096828	0.362806	-0.105535	-0.100510
	b'	-0.643635	0.263509	0.032181	-0.142262	0.046121	0.036727
	c'	-0.096828	0.032181	0.025103	-0.032348	0.005113	0.012973
	d'	0.362806	-0.142262	-0.032348	0.092945	-0.029538	-0.020975
	e'	-0.105535	0.046121	0.005113	-0.029538	0.015381	-0.000511
	f'	-0.100510	0.036727	0.012973	-0.020975	-0.000511	0.017104
Gadag I.	a'	1.785233	-0.677188	0.172267	0.316733	-0.165985	0.034646
	b'	-0.677188	0.278240	-0.065765	-0.117990	0.063468	-0.014610
	c'	0.172267	-0.065765	0.024077	0.028379	-0.013698	0.005846
	d'	0.316733	-0.117990	0.028379	0.065823	-0.033273	0.008719
	e'	-0.165985	0.063468	-0.013698	-0.033273	0.023138	-0.005360
	f'	0.034646	-0.014610	0.005846	0.008719	-0.005360	0.004554

TABLE VIII—CRUDE SUMS OF PRODUCTS OF RAINFALL CONSTANTS AND QUALITY DATA.

Cotton		a'	b'	c'	d'	e'	f'
Verum	c	332.493	-46.216	-82.404	30.309	5.578	-10.447
262	l	11.13919	-1.54744	-2.75730	1.01286	0.18592	-0.35192
Nagpur	w	2.445385	-0.337580	-0.605935	0.222585	0.040689	-0.077094
Verum	c	185.489	-19.777	-46.079	12.602	1.345	-2.392
262	l	7.11407	-0.75793	-1.76295	0.47646	0.04494	-0.08299
Akola	w	1.552022	-0.167612	-0.384326	0.105147	0.009786	-0.018916
Cawnpore	c	282.985	20.928	-88.114	-3.603	31.072	-4.678
American	l	7.49725	0.52002	-2.34568	-0.07359	0.83300	-0.12672
C. A. 9	w	1.303478	0.095129	-0.406796	-0.015965	0.144229	-0.020493
Surat	c	426.043	-195.718	-30.861	103.321	-63.140	8.890
1027	l	12.76989	-5.89500	-0.88157	3.08171	-1.90768	0.28883
A. L. F.	w	2.438849	-1.132472	-0.156359	0.582795	-0.368011	0.061886
Wagad 8	c	104.442	-53.141	-3.009	26.451	-18.473	1.983
	l	5.86457	-3.00816	-0.12695	1.45810	-1.04496	0.13975
	w	1.591330	-0.816502	-0.031294	0.390070	-0.279332	0.038409
Jayawant (Dharwar)	c	210.855	-86.769	16.321	21.445	7.397	-6.951
	l	5.05586	-2.06755	0.38101	0.52359	0.17804	-0.16794
	w	0.953660	-0.391671	0.070284	0.099178	0.033157	-0.032242
Nandyal 14	c	190.016	-99.897	24.519	16.143	-8.042	-4.181
	l	5.07700	-2.68119	0.65497	0.42128	-0.20664	-0.12360
	w	0.952087	-0.502403	0.120355	0.081834	-0.040819	-0.023342
Hagari I	c	115.491	-44.450	-7.588	25.206	-5.706	-9.092
	l	3.41086	-1.32141	-0.21997	0.73501	-0.16705	-0.27216
	w	0.689411	-0.269158	-0.043018	0.147683	-0.034345	-0.055369
Gadag I	c	133.555	-51.529	13.111	23.471	-13.432	2.514
	l	3.50791	-1.35721	0.34720	0.62278	-0.33964	0.06831
					0.113774	-0.061547	0.113498

DISCUSSION.

Dr. Nazir Ahmad, summarising the analysis carried out on the results, available at the Laboratory, of tests made during the last ten years on about 10 standard Indian cottons, said that with one exception the cottons known as standard Indian cottons had been grown at Government agricultural farms. These were grown from the same seed stock under as nearly the same conditions as possible and the tests had been made on these cottons with greater thoroughness than on the ordinary agricultural samples. In each case the tests were made on duplicate lots while the number of tests were also greater than on ordinary agricultural samples. These tests were originally started with the main idea of correlating fibre properties with spinning value. Rainfall and temperature data were available for several of these cottons and therefore an effort was made to find out the effect of rainfall distribution and temperature on the fibre properties and the spinning quality of these cottons. Fisher's method of fitting Polynomials was adopted. In this method the relevant information was contained in a number of 'rainfall distribution constants' obtained by fitting orthogonal polynomials to the weekly totals of rainfall for each season, thus making full use of the meteorological data and yet reducing the constants to a small number. Although the rainfall data was available for a number of these farms over a large number of years the corresponding data for cotton was available for about ten years only. The data for a period for which both sets of values were available was taken into account for the purpose of this investigation. Fifth degree polynomials were fitted to the weekly totals of rainfall every year. This provided six constants which specified the average value and the distribution of rainfall throughout the season. The secular variation of rainfall from season to season as well as of the quality of cotton was eliminated by fitting orthogonal polynomials of the second degree. Since the data was available only for about ten years, certain important cottons were grouped together in order to have a sufficiently large number of values for correlating quality with rainfall. The cottons selected were Verum (Nagpur), Verum (Akola), C.A. 9, Jayawant, Nandyal 14, Gadag 1, Surat 1027, Hagari 1, and Wagad 8. The results of variation in the quality of cotton might be due to the effect of season, to a secular change brought about by gradual exhaustion of the soil, to the gradual infestation of the field or to the adaptability of the seed to the soil. The diagrams facing pages 210 and 211 of the paper show the result of elimination of secular change from the total variation. The shaded portions gave the deterioration or improvement, the black portion the slow changes that had taken place during the period and the white portion the annual variation. This white portion was correlated to the rainfall distribution after eliminating from it the effect of secular change. In order that the results obtained in different tracts or in different years for the same tract might be comparable, the time of incidence of rain was reckoned from a definite stage in the life history of the plant. The commencement of rainfall in the cotton season (for the purpose of this investigation) was taken to be about 5 weeks before the sowing of the

seed. The data relating to the regression formulae are given on pages 230 and 231. There were six constants of which Ia' connoted the mean rainfall. Although it represented only one half of the total annual variation due to rainfall it was the most important one among the six. Next in importance were the constants e' and f.' The mean square due to rain was in every case over $1\frac{1}{2}$ times that due to residual, and in the case of Surat and Wagad 8 it was more than twice the residual. On the whole, about $\frac{1}{3}$ to $\frac{2}{3}$ of the total annual variation was accounted for by the single weather element, rain. However, the mean square due to six degrees of freedom provided by the rainfall sequence was not significantly greater than the residual. The residual was based upon a small number of degrees of freedom (8 to 12) and the effect is likely to become significant when results for a larger number of years for each cotton become available. The following conclusions were deduced from a study of the curves showing the influence of additional inch of rain at different times between the sowing and the picking periods :—

- (1) Rain in the last stage of ripening, i.e., picking period is harmful.
- (2) In the maturation period, additional rain above the normal is beneficial. This positive effect is found in all the four graphs, and occurs in the winter months—November to January. Rain during this period is associated with higher temperature and it is probably the moist heat that is most beneficial to the proper thickening of the fibres.
- (3) The growing period can be divided into two parts : the first period after sowing, i.e., the period of rapid vegetative growth, and the second period which includes the flowering stage. Additional inch of rain in the case of Verum 262, C.A.9, Surat 1027 A.L.F. and Wagad 8 is beneficial in the first period, i.e., in July and August, while it is harmful in the months of September and October. The case of Jayawant, Nandyal 14, Hagari I and Gadag I is somewhat different as additional rain is harmful throughout the growing period. This is probably due to the fact that in the case of these cottons most of the rain falls during the sowing period ; consequently the soil is saturated with moisture due to the residual effects of the previous rain. The case is similar to that of over-feeding ; additional rain instead of doing any good leads to definite harmful effects.

Each curve was also discussed in greater detail which gave the percentage increase or decrease in the highest standard warp counts due to the effect of an additional inch of rainfall. It was found that the change in the spinning value of the cotton was not completely explained by the change in the fibre length and fibre weight, showing that the total change in the spinning value was due to the operation of other factors as well. These results gave information as to the best course to be adopted where water for irrigation was available, or for a study of the failure of the

crop due to early rain or late rain or due to its untimely occurrence. The second important consequence of this work is to calculate the effect on the spinning quality of cotton merely from the weather data. This aspect of the work was very recently done and it had not yet been concluded. In some cases where abnormal results were obtained, which could not be explained in terms of variation in fibre properties, they could be explained if the rainfall distribution was taken into account. For example, 1925-26 was a very bad year for Surat 1027 A.L.F. which spun only up to 26's standard warp counts whereas in 1933-34 it spun up to 37's. The variation in the fibre properties did not account for this difference of 11 counts, but if rainfall was taken into consideration, in 1925-26 the calculated value was 27's and in 1933-34 it was 36's. Similarly Gadag I in 1927-28 gave the highest count of 38's, but fell to 26's in 1928-29 and this could not be accounted for by fibre properties, but was accounted for by the rainfall distribution.

The President remarked that it was an exceedingly important paper. The conclusions related very closely to agricultural practice. He suggested that this paper might be discussed along with Rai Sahib Kalidas Sawhney's paper.

Mr. Ramanatha Ayyar commending the paper as a very valuable one giving useful information for both breeders and agronomists expressed the desire that Dr. Ahmad might produce more papers on similar lines. Dr. Ahmad, he observed, had combined some cottons owing to paucity of data under each individual type. In the third group* he had combined Jayawant, Nandyal 14, Hagari I and Gadag I. Botanically Jayawant and Hagari I belong to herbaceum group, Nandyal 14 to arboreum, and Gadag I to hirsutum group. When the relative response of the two species, arboreum and herbaceum to rainfall was considered he had his own doubts whether they could be combined. For instance, arboreums were very good on mixed soils whereas herbaceums thrived well on black cotton soils as in the Nandyal tract. Herbaceums did not like heavy rainfall, in the initial stage whereas heavy rainfall did not affect arboreums when grown under the same conditions. Agriculturally too, in years of very heavy rainfall arboreums gave better yield than herbaceums. It was therefore doubtful whether it would be desirable to combine different species of cotton when it was known definitely that they did not form random samples of the same population. Even with regard to duration they were different; for instance when they were sown simultaneously, herbaceums flowered later and their pickings were over earlier than in the case of arboreums. Referring to the remark on Karunganni cottons, he observed that Karunganni C 7 was sown only after the 15th October and the pickings were over by May. The samples that were sent to the

*In the paper as now incorporated, this group has been split up into two, viz., (c) Jayawant and Nandyal 14 and (d) Hagari I and Gadag I.

Technological Laboratory represent practically the main pickings. The few pounds got after May might represent about 5% to 10% of the total produce and in certain years no kapas were got at all after May. The statement that "Consequently we can regard the cotton season for it as extending over 31 weeks, thus eliminating the pseudo-effect of high rainfall in the picking period" required revision. He thought it would be better to consult local officers with regard to that point as they would be able to furnish the necessary information. The statement on page 236 that "Fig. 14a gives the percentage change in the spinning value and the fibre-properties of Jayawant, Nandyal and Hagari I cottons due to an additional inch of rain or irrigation water received by the crop at different parts of the season" seemed to indicate that the authors believed that an inch of irrigation water was equal to an inch of rain water. But it was well known that their effects were different. Referring to the conclusion on page 233 viz., "The case of Jayawant, Nandyal 14 and Hagari I is somewhat different as additional rain is harmful throughout the growing season. This is probably due to the fact that in the case of these cottons most of the rain falls prior to sowing and during the sowing period; consequently the soil is saturated with moisture due to the residual effects of the previous rain," he stated that his experience of the Nandyal tract was different. There was, no doubt, a rainfall of a few inches before sowing but the major portion of it was received only during the sowing period. It was only after the onset of heavy rainfall that sowings of any cotton were thought of in that tract. In regard to the conclusion that "In view of these results it would be instructive to carry out well-designed field experiments at Dharwar and Nandyal Agricultural Stations with a view to finding out the optimum conditions of sowing the cotton," he said, speaking about the Nandyal Agricultural Station, that the first crop to be sown at Nandyal was cotton. If cotton sowing was postponed to a later date, he was afraid no crop would be got. As an agriculturist he would not risk his name by sowing that crop late because it was known that even a difference of two days or even a day in sowing had a great effect on yield, and especially so in localities where the crop definitely depended upon rainfall, e.g., the Hagari and Nandyal tracts where the first opportunity should be taken to sow the seed at the earliest moment. In fact in years when rainfall was low sowing in dry land was preferred in order not to miss the season. This practice was common in Bellary and Tinnevely districts. The sowing period was based upon years of experience and if some experiment in regard to sowing was to be tried one might be sure of courting failure which would affect the worker's reputation in the tract.

Rao Sahab Kottur said that he was growing Jayawant and Gadag cottons continuously for a number of years in the Dharwar Farm and that his observations on the crop were that climatic conditions and rainfall affected the two cottons equally. His doubts about the experiments arose from the fact that the samples for experiments were taken merely from Government farms where the cultivation was such that all the rainfall was utilised on account of good cultivation, and that was not the

case for the countryside where conditions were different, and only a small portion of the rain was utilised for the crop due to defective cultivation. He could not say how far the results would be applicable to the countryside.

Mr. Hutchinson drew attention to rainfall figures for the four cottons included in the southern group and observed that there was a lot in what Mr. Ramanatha Ayyar had said. Gadag and Hagari had a distinct type of rainfall distribution from Jayawant and Nandyal. From the curves on pages 220 and 222 it would be seen that the incidence of rain at the beginning was quite different in the two curves and he suggested that it might be worth while separating Hagari and Gadag from Jayawant and Nandyal.*

Mr. Koshal stated that they had already been separated and would be included subsequently in the paper.

The President enquired whether any of the figures represented the rainfall a month previous to sowing.

Dr. Nazir Ahmad replying to the first point raised by Mr. Ramanatha Ayyar said that the combination of certain cottons was inevitable owing to the paucity of the data for each cotton. That was one reason why he had raised this point in the Committee also that even where the cultivation of a standard cotton is discarded for economic reasons it should be continued to be grown so that in another ten years' time there would be enough data to apply this method to each cotton by itself without combining it with others. So far as division of four cottons into two sub-groups was concerned, subsequent to the writing of the paper the four cottons had been separated into two sub-groups and owing to lack of time the results could not be included in the paper. He was thankful to Mr. Ramanatha Ayyar for his offer to send Karunganni samples. As regards rainfall and irrigation, he entirely agreed with Mr. Ramanatha Ayyar that one inch of rainfall should not be regarded as equal to one inch of irrigation water. On page 232 that point had been stressed by saying that "It is necessary to bear in mind that the curves in figs. 12-15 not only indicate the effect of rain as such, but of all the weather conditions associated with it." Therefore, that distinction was present in the authors' minds and would be clarified when sufficient data were available in 5 or 10 years' time. As regards the suggestion that the experiment was not based on agricultural practice he observed that unless one deviated from that practice no experiments could be carried on. In reply to the point raised by the President, he said that the effect of rainfall occurring 5 to 6 weeks prior to sowing had been worked out. Referring to the point raised by Rao Saheb Kottur, he stated that experiments had been carried out on samples from Government farms because they were selected cottons for which data were available and also because one could be certain of the purity of seed. In samples from the cultivators' fields the purity of the seed was often doubtful. If rain was not utilised

* In the paper as now incorporated, this suggestion has been given effect to.

to the same extent in cultivators' fields as in Government farms, perhaps the application of the formula would not be 100% true in the case of the farmers' fields. He could not see how the difficulty could be overcome as the introduction of the factor of impure seed would lead to greater uncertainty in the results.

The President observed that on account of the possible bearing on the question of forecasts, any help got from the results would be regarded as valuable, and considering the present state of forecasts he wondered how far results could be applied to particular conditions that might arise in future seasons. He thought that the information was very valuable and that the general trend of the indications was very helpful.

Dr. Nazir Ahmad stated that in addition to making tests on samples from Government farms tests on trade samples also were made. So far only the results of four to five years were available but in the course of another five years it might be possible to apply this method to trade cottons if relevant rainfall data is available.

GENERAL

Paper No. 1.

COTTON PROBLEMS OF HYDERABAD STATE

BY

K. SAWHNEY,

COTTON RESEARCH BOTANIST.

The average annual area of cotton in Hyderabad State is about 3,500,000 acres and the annual production about 480,000 bales of lint. Among all the crops grown in the State, cotton ranks second in acreage, *jowar* (*Sorghum vulgare*, Pers.) being the only crop with a large area. At the current prices, the State's annual production of cotton is equal in value to about $4\frac{1}{2}$ crores of rupees, and since the vast bulk of the crop is grown for export, its importance to the State as a source of fresh wealth cannot be too greatly emphasized. Problems relating to the cultivation of cotton in Hyderabad are many and of varying importance. It is proposed to mention in this note the most urgent of them. The advice of the members of the Conference regarding their solution will be greatly appreciated.

Cotton is grown in the State partly in the south-west monsoon and partly in the mildly cold, dry weather following it. In the Marhatwadda districts of Aurangabad, Parbhani, Nanded, Bhir, Osmanabad, Bidar and northern part of Gulbarga, cotton is sown with the setting in of the south-west monsoon in June and the crop is harvested from October to December or January. In Raichur district and southern part of Gulbarga, which form part of Karnatak, from eighty to ninety per cent of the crop is sown in August and September and harvested in February and March, whereas the remainder is grown as a *kharif* or autumn harvested crop. In Telingana cotton is raised chiefly as a *kharif* crop, but in practically every district about ten per cent of the area is planted with late-sown varieties. The seed for the late sowings is planted in September and the crop is picked in March and April. In districts growing cotton in both the seasons, the early and late sown crops are often found growing in the same village, and sometimes even in neighbouring fields. In such places it

is not uncommon to find a cultivator putting down a part of his land to one crop and a part to the other, specially if his holding happens to include heavy black as well as light sandy soil.

The practice of growing cotton as both *kharif* and *rabi* (spring harvested) crops is responsible for the multiplicity of varieties in cultivation. It also enhances the difficulty of maintaining them pure either in the field or in the ginning factories. Furthermore, the long period in which crops remain standing in a locality and the absence of a universally observed 'close season' between the successive crops enable the insect pests such as the spotted and pink bollworms, specially the former, to continue their activities unchecked. Here we have a statement of three major problems arising out of a single cause. They along with others are dealt with in the subjoined paragraphs.

A.—There are at present four distinct varieties, or, correctly speaking, mixtures of varieties in cultivation :—

(1) *Gossypium neglectum*, Tod. var. *rosea* predominates in the crop of Aurangabad and Parbhani and of large parts of Bhir, Osmanabad and Adilabad, which are not included in the Gaorani Protected Area. The annual area under this short-stapled mixture is about 2,000,000 acres and represents about sixty per cent of the total cotton area of the State. The produce of this tract is marketed as Hyderabad Omras and is fit for spinning 8-10's counts. Although *rosea* is a late maturing variety, yet owing to the absence of frost it suffers no check in the maturation of its produce. It gives a high yield and possesses a fairly good ginning outturn. Another important point about it is that its flowering period is of a short duration and it matures practically the whole of its produce before the date on which the Government revenue falls due for payment. In consequence of these characteristics, this variety has successfully ousted Bani cotton which was formerly grown extensively in these districts. However, Bani or *indicum* plant has not completely disappeared from these areas; even now it forms from ten to twenty per cent of the crop. The American variety is the third important component of the mixture and forms from five to ten per cent of the plant-population. Efforts for the improvement of this short-stapled mixture have been subsidiary to the improvement of Hyderabad-Gaorani (mentioned below), for which the Hyderabad Cotton Research Botanical Scheme has been primarily sanctioned. Banilla and Verum 262 have been imported from Khandesh and Berar respectively, and tested in Aurangabad and Parbhani districts for three successive years, but they have not been found successful in either of them. Their yields, specially in years of heavy rainfall, have been markedly lower than those of the local mixture. Banilla has also shown a deterioration in spinning properties. Improvement of the local variety by straight selection has been limited by the shortage of staff available. The little work that it has been possible to do during the past few years has produced two likely strains, one of *rosea* (Havri 3)

and one of *indicum* (Gaorani 12). Like the local variety, both the new strains are relatively late maturing, but whereas Havri 3 is equal to or a little better than the local in yield and ginning outturn, Gaorani 12 is better in spinning properties and market value (5-10 per cent 'on') but about ten per cent lower in yield than the local. The average staple length, the ginning outturn and the highest standard warp counts for these new strains as compared with the local mixture are as follows:—

Variety or Strain.	Ginning percentage.	Staple length.	Highest standard warp counts.
Local	32—34	.76 inch	9's
Havri 3	35—37	.78 ..	11's
Gaorani 12	31—32	.79-.82 ..	20's

As yet no seed of Havri 3 has been issued to the cultivators, but Gaorani 12 occupied in 1936-37 a compact block of 800 acres in a village near Parbhani. The yield has been fairly satisfactory, and seed sufficient for 8-10 thousand acres will be available for the next season. It is for consideration whether the distribution of the seed of Gaorani 12 should be continued, or in consequence of its lower yield than the local, the extension of its cultivation should be stopped. It may be mentioned that the distribution of the seed of Gaorani 12 for the increased area will not be difficult because the Government seed is issued as a *tagavi* loan. Opinion is also invited regarding the advisability of recommending Havri 3 as a substitute for the local variety.

(2) Hyderabad-Gaorani, the finest of the Hyderabad cottons, was formerly the principal variety of the whole of the Marhatwada division, but at present it is grown in Nanded (excluding Hadgaon taluka) and Bidar districts, eastern half of Osmanabad, and Mominabad and Nirmal talukas of Bhir and Adilabad districts respectively. The crop of Hadgaon taluka of Nanded district contains about forty per cent of *rosea*, but is marketed in Nanded, where since 1932 Government arrangements exist for its separate ginning and pressing.

The annual area under Hyderabad-Gaorani is about 900,000 acres and the annual production about 100,000 bales of lint, the vast bulk of which is used by the Indian mills. Its chief stations of export are Nanded, Umri, Bhainsa and Latur. In 1927 the Gaorani tract was notified a Protected Area.

The principal botanical components of Gaorani are *indicum* and *hirsutum* species occurring in the proportion of 4:1 or 70:30 in the different talukas. It is fit for spinning 24-30's standard warp counts. However, this variety has three prominent defects: its normal yield of seed cotton is poor (about 200 pounds per acre), ginning outturn is low (25-27 per cent only), and because of the small size of bolls, the

picking of its produce in a clean state is difficult. The production of strains free from these defects is the principal purpose of the Committee's Botanical Research Scheme in Hyderabad.

Selection of desirable plants from cultivators' crops of reputed Gaorani localities was started in 1929. Since then a number of strains possessing the desired characters have been produced and tested against Umri Bani, the best known and standard trade type. As the result of comparative tests for three years at Parbhani and two years at three places in the Gaorani Protected Area, two strains, namely Gaorani 4 and Gaorani 6 were selected in 1934 for trial on a larger scale. Gaorani 4 is a heavy yielding type, has a ginning outturn of 29 per cent. and is equal in spinning properties to the best Umri Bani grown at or around Umri in Nanded district, but is about ten days later than the local mixture in the maturation of its crop. Gaorani 6, though a heavier yielder than Umri Bani, is somewhat less prolific than Gaorani 4, but on the other hand it has a ginning outturn of 30-31 per cent and has been judged suitable for 30-40's counts as compared with 24-30's of Umri Bani. Also, it is earlier maturing than the local by about ten days and seems to do well in areas of heavy rainfall. Accordingly, in 1935-36 Gaorani 4 was planted on about 900 acres in a village ten miles north of Nanded, and Gaorani 6 on 500 acres at a place sixty miles east of Nanded, in Madhol taluka where rainfall is usually heavy. Unfortunately, the attack of Spotted Bollworm in 1935-36 was unusually severe at and around Nanded. Gaorani 4 suffered very badly from it and did not fulfil the hopes that it had raised early in the season. This was a clear setback. On the other hand, Gaorani 6 did well and gained admirers amongst the growers as well as the traders. In the current season (1936-37) Gaorani 4 occupies 3,000 acres in villages south of Nanded. The crop promises good yield but it remains yet to be seen how much of it actually materialises. Similarly, Gaorani 6 covers 6,000 acres in a group of villages in Madhol taluka and about 100 acres near the town of Nanded. So far the variety has behaved satisfactorily in both these places. However, it is not yet known what effect the abnormally heavy rains (seven to eight inches in one week) in the present month (November) have had on this strain or on Gaorani 4.

Besides the places mentioned above, these strains along with a few others were tested against the local variety at the Committee's Variety Testing Station at Latur, which is ninety miles south-west of Nanded. In only one season the seed could be sown at the normal time, and in that year (1935-36) none of the new strains gave a significantly higher yield than the local variety, which at this place consists of a mixture of seventy per cent *indicum* and thirty per cent *hirsutum*.

Furthermore, in 1934-35 lint samples of Gaorani 4, Gaorani 6 and the local variety from five different localities were tested by the Committee's Technological Laboratory, Matunga. Gaorani 6 was adjudged suitable for 30's to 40's warp counts, the

sample from Latur being fit for only 30's. On the other hand, Gaorani 4 from four localities was found fit for 30-35's counts, but its sample from Latur was found definitely coarse-stapled and was deemed suitable for only 25's counts as against 24's of the local variety of the same place.

Thus it will be seen that although the evidence collected so far inside the Protected Area does not prove the definite superiority of any one strain to the exclusion of all others, yet it points fairly clearly to the following broad facts, which may prove helpful in making the final choice :—

- (a) A number of the new strains of Gaorani produced and tested at Parbhani, (which is outside the Protected Area) have repeatedly given significantly higher yields than Umri Bani grown alongside them, but when tested within the Protected Area, at places which are from thirty to one hundred miles away from Parbhani, they have not shown the same high performance everywhere. It does not seem likely that it will be possible to obtain one pure-line strain which will give equally good results in the whole of the Gaorani area.
- (b) It seems probable that Gaorani 6 will suit the northern, central and eastern portions of the Protected Area.
- (c) For the southern and the south-western portions a strain better adapted to a relatively low and uncertain rainfall is required. It should also be able to give a fair crop even when sown two to three weeks after the normal sowing period. Such a strain is more likely to be produced from the local crop itself than from that of the more favourably situated northern and central parts of the Gaorani area.

It is of interest to note that in August last the Indian Central Cotton Committee recommended to the Government of Hyderabad that a Cotton Research Station should be established at a central place (preferably Nanded) in the Protected Area itself, and that the Gaorani improvement work should be shifted to it. The Committee also approved the proposal to start breeding work at its two Variety Testing Stations to supplement the trial of strains produced at Parbhani.

(3) The *kharif* crop of Karimnagar and the northern half of Warangal district is included in Hyderabad Oomras, but its major component is *indicum* instead of *rosea*. The area under Gaorani in these two districts will be a little over 100,000 acres. As yet it has not been possible to undertake any pure line breeding work for the improvement of the local variety, but during the past three years the new strains, Gaorani 4, Gaorani 6 and Gaorani 12 produced at the Cotton Research Station, Parbhani, have been tested against the local variety, in replicated plots at the Government Experimental Farm at Warangal. The experiments though not conclusive point strongly to the superiority of Gaorani 12 over the local in more than one

respect. In yield, if not better, it is at least equal to the local ; in ginning outturn it is better than the latter by 3-4 per cent ; in spinning properties it is equal to the local. It is proposed to have a larger area of this variety next season at the Government Farm and also to sow a few demonstration plots in the cultivators' fields of the two districts.

The *rabi* crop of Karimnagar and northern half of Warangal is composed largely of *herbaceum* or of a late maturing *indicum* type. No selection work has yet been possible to undertake for the improvement of these *rabi* varieties and as the area under them is small, it does not seem worth while to take up this work. However, it does appear advisable that, firstly, the *rabi* sowings should be discouraged in this tract, and, secondly, if *rabi* sowings cannot be avoided, they should be confined to one variety (preferably a strain of *indicum*), which should be similar to the *khariif* strain in staple length and ginning outturn.

(4) Cocanadas (*Gossypium obtusifolium*, Roxb. var. *Cocanada*) is grown on about 30,000 acres in Nalgonda district and the southern half of Warangal. This variety is grown largely as a *rabi* crop, though a small area is sown in the south-west monsoon also. The average annual production is about 3,500 bales of lint. No improvement work has been done with this cotton so far, but it is proposed to test Gaorani 12, which is a somewhat late maturing strain, as a possible substitute.

(5) Kumpta (*Gossypium herbaceum*, Linn.) is grown on about 400,000 acres annually in Raichur district and southern part of Gulbarga. In 1929 the south-western portion of Raichur with nearly 100,000 acres under cotton every year was notified as a protected area, and with a subvention from the Indian Central Cotton Committee the distribution of the seed of Jayawant and Gadag No. 1, two improved strains produced by the Bombay Department of Agriculture, was started. This extension work has now gone on for six years and the area under the improved varieties has gradually increased to about 30,000 acres scattered all over the protected area. Jayawant matures its crop a fortnight later than the local Kumpta, and needs late rains in order to give the best results. It has been tried in the eastern part of Raichur but has not been found better yielding than local Kumpta. Therefore, Jayawant has not found much favour with the cultivators of the eastern part of the district. On the other hand, during the past few years seed from Hagari in Madras Presidency has been gradually invading this tract. The exact area under this seed is not known, but it is understood to be increasing every year.

For want of trained assistants and funds, not much work has been done to improve local Kumpta. From the numerous plants selected from the cultivators' fields during the botanical survey of the cottons grown in the district, two high-yielding single-plant strains have been developed. In 1935-36 both these strains yielded better than Hagari, Jayawant and local Kumpta and gave higher ginning outturn than the latter two. These new strains along with a few others are again

being tried in the current year at the Government Experimental Farm, Raichur. The Indian Central Cotton Committee at its meeting in August 1936 sanctioned funds for the pursuit of this work at Raichur during the next five years. It is proposed to conduct comparative tests with a number of strains from Bombay and Madras Presidencies against local Kumpta and the single-plant strains isolated from it. The distribution of Jayawant seed in the protected area will continue until a more suitable strain becomes available to replace it.

B.—The next important problem is the rapid multiplication of pure seed of improved strains and its extensive distribution to the cultivators. The demand for improved seed is created by sowing demonstration plots in the cultivators' fields and alongside their own crops. The seed for the demonstration plots is supplied free, and the crops are sown, tended and harvested by the cultivators themselves.

Adequate facilities exist for the rapid multiplication of 'selfed' and first generation seed. In addition to an area of forty to fifty acres sown each year to cotton at the Government Experimental Farm, Parbhani, eight to ten acres are available annually at each of the two Variety Testing Stations financed by the Cotton Committee. The propagation plots at the Variety Testing Stations are planted exclusively with 'selfed' seed and at the Government Farm, Parbhani, with partly 'selfed' and partly first generation seed. These plots are usually manured with well rotten cattle dung or farm compost at the rate of five to ten cartloads per acre. The seed is dibbled by hand, the holes are spaced one foot in the row and two feet between rows, and only two seeds are sown in each dibble. By the use of a wide spacing* and low seed rate a large area is covered with a limited quantity of seed, and the manuring of plots ensures a fairly good yield. The technique runs smoothly up to this stage but the subsequent multiplication of the Farm seed presents great difficulties. No large seed farms have been established as yet by the Government and the *jagirs* and other private estates do not possess large compact blocks of cotton under unified control. Recourse has to be made to the small grower. The Agriculture Department selects one or more villages at convenient centres and with the help of Revenue Officials distributes on *taqavi* the second and subsequent generations' seed in separate blocks to all the cultivators therein. No other seed is permitted to be grown in such villages. The distribution of seed is done by the *taqavi* staff of the Agriculture Department working under a Deputy Director. Financial aid on *taqavi* loan for the interculture of the crop is given to growers in the villages taking improved seed for the first time. The crops grown from this seed are 'rogued' by the *taqavi* and propaganda staff, the produce is marketed and ginned under departmental supervision, and the required quantity of pure seed is purchased for the Government. This scheme is yet in its early stages and the difficulties met with relate chiefly to the marketing

* The normal spacing for cotton varieties grown in the State is about 18 inches between the rows. Plants in the drill-rows are not spaced regularly. In the absence of thinning, the 'stand' is usually thick.

of the crop. The cultivators are generally indebted to brokers who finance the crop not only in the villages selected for the multiplication of improved seed but also in many others besides them and which are not growing improved seed at present. The grower usually takes the produce to his own broker (who is also the money-lender). It is often difficult to persuade the broker to store, market and gin small lots of pure crop separately. Attempts are being made to overcome this difficulty, but suggestions from members who have had to do this type of work in similar circumstances will certainly be helpful. The location of the seed-multiplication centre at a place having only one large ginning factory that purchases cotton on its own account, the establishment of the Co-operative Sale Society for the financing of the crop, and the holding of one or more auctions at a convenient place, where the cultivators could dispose of their produce to one large buyer without disturbing relations with their brokers—are some of the measures under trial, but the final choice of means still remains to be made.

C.—The third major problem is the control of the activities of the pink and spotted bollworms. In the course of the investigation financed by the Indian Central Cotton Committee during the past four years it has been found that these two insects are responsible for the destruction of about twenty per cent of the potential annual crop. This is a serious loss to the grower and it is urgent that measures be adopted for the control of the pests as early as possible. It is now definitely known that the spotted bollworm continues its activities from one season to the next by spending the hot weather on the stray stand-over plants in the cotton fields and alternative host plants (both cultivated and wild), whereas the pink bollworm passes the same period as a long cycle resting larva either in the soil, or in *kapas* that may be stored from the end of one picking season to the beginning of the next. The existence of *rabi* and *kharif* crops in neighbouring fields in the southern and eastern districts of the State, and the practice of letting the plant stalks remain standing in the field for long after the final picking is taken, are responsible for the continued activity of the pests over a much longer period than would be possible if only the *kharif* or the *rabi* crop was grown in a locality or if the cotton plants were removed immediately after the final picking. The study of the effects of the likely control measures is now in progress.

D.—The extension of area under true breeding of improved strains of Gaorani has brought to light yet another problem which is likely to assume importance in the near future. *Fusarium* wilt as a major pest does not exist in a large part of the State. It is only in some of the villages adjoining Berar, Khandesh and Dharwar that wilt of cotton occurs as a major affliction. Even in these border villages the disease is serious in only such of them as have repeatedly imported and planted sowing-seed from the wilt infected tracts. The villages in the interior of the main cotton growing districts of the State are as yet practically free from the malady; only rarely does one come across a field in which the cotton crop shows signs of the exis-

tence of *fusarium* wilt. Pests and diseases have so often in the past been the undoing of true breeding of improved strains of cotton that even the rare occurrence of wilt in this State has to be taken as an indication of the way in which the wind may be expected to blow. Accordingly, since 1934 an effort has been made to test all the new strains for their resistance to wilt in a heavily infected plot at the Cotton Research Station. Although a large majority of the strains succumbed readily to the disease, yet we have now on hand a few resistant types belonging to different varieties. Their resistance under optimum conditions for wilt-infection has not been tested as yet, but it is proposed to get them submitted to such a test in the Cotton Committee's glasshouse erected for the purpose at Poona.

E.—Another problem awaiting solution is the production of a suitable quality cotton for an area of 300,000 acres, that has been brought under perennial irrigation by the construction of the Nizam Sagar Dam on the river Manjera in Nizamabad district. At present rice and sugarcane are the principal irrigated crops and the introduction of another lightly irrigated field crop in the rotation is an urgent necessity. A little *herbaceum* cotton is already grown in the district as an unirrigated crop on black soils. It is sown in September or October and harvested in March and April. The yield as well as the ginning outturn are low. It has been found by experience that in the conditions obtaining in Nizamabad district this variety does not respond adequately to irrigation. Consequently, during the past few years preliminary experiments have been conducted at the Government Farm, Rudroor (Nizamabad district), to determine the suitability of a number of long-stapled varieties, both indigenous and exotic, as irrigated types in this tract. It has been found that American cottons sown in September, or immediately after the end of the south-west monsoon in October, suffer heavily from jassids and do not grow successfully. When sown in the beginning of June, they are adversely affected by the temporary water-logging that results from the heavy rains in that month and the one next after it. Crops sown from six to eight weeks before the onset of rains seem to get well-established in the soil and do not suffer from the heavy rains so much as the crops planted in June after the arrival of the south-west monsoon. The pre-monsoon sowings appear to do specially well on *chalka* (red coloured, granitic) soil, which forms about three-fourths of the commanded area. However, a good deal of further work remains to be done before a large area can be brought under this crop. The frequency of irrigation, the quantity of water to be applied at each watering, the optimum date of ceasing irrigation, and the most suitable rotation for the crop are some of the chief problems that await study. They will be tackled when preoccupation in other directions permits their being taken up, or when the required additional technical assistance is forthcoming.

F.—Another problem that has been under investigation during the past four years is the possibility of growing unirrigated cotton on *chalka* soil in Telingana Division. At present very little cotton is grown on the *chalka* soils of this tract, *Jowar*

bajri (*Pennisetum typhoideum*, Pers.) and castor are the principal crops in cultivation. The introduction of a cash crop like cotton would add materially to the cultivators' income. Experiments conducted at the Government Farm, Sangareddi (Medak district) and the trial crops grown in some of the cultivators' fields have shown that it is possible to grow remunerative crops of rain-fed cotton on deep *chalka* soils. Here again a new strain of Gaorani, namely Gaorani 12, has given the best yields. Gaorani 12 is a deep-rooted, sturdy plant. Its ginning outturn is thirty-two per cent and its fibre is fit for spinning 20's standard warp counts. It is now proposed to plant next year a large number of demonstration plots in the cultivators' fields in order to initiate the farmers into the growing of this crop. If the effort to grow cotton on a large scale on *chalka* soils of Telingana proves successful, it will improve a great deal the economic condition of the Telingana farmer who is in sore need of a money-making crop.

G.—Lastly, a botanical survey of the cotton crop of the State was started in 1931 and completed in June last. Much useful information regarding the types grown, their proportionate occurrence in the different districts and cultivation practices relative to cotton growing has been collected. This will help the Department of Agriculture in formulating a well-considered and co-ordinated policy of cotton research in the State.

From the foregoing paragraphs it will be evident that the most important problems facing cotton work in Hyderabad State are those relating to, firstly, the production of improved strains to replace the existing mixed varieties, all of which suffer from one or more defects; secondly, the maintenance of a supply of the pure seed of each improved type, and the increase of its cultivation by the growers; thirdly, the control of bollworms that do extensive damage under existing conditions; fourthly, the cultivation of irrigated cotton in areas commanded by the Nizam Sagar Dam; and fifthly, the extension of cotton growing to *chalka* soils in Telingana. All of the problems are engaging attention in varying degrees and something has already been done regarding each. However, a good deal more has still to be achieved before the average farmer can receive the full benefit of the cotton research in progress or planned.

DISCUSSION.

Rai Sahib Kalidas Sawhney, in introducing the paper, said that the Hyderabad State occupied the centre of the peninsula and as such it presented a mixture of the agricultural problems of the north as well as of the south. Explaining his paper with magic lantern slides he said that the Hyderabad State grew over $3\frac{1}{2}$ million acres of cotton and that 90 per cent of the cotton crop was sown in the kharif season and the remaining 10 per cent in the rabi season. Normally cotton was grown in the State in both kharif and rabi, i. e., practically for ten months in the year, but there were differences in varieties grown. Exhibiting a map of Hyderabad State, showing the distribution of commercial varieties he said that the north-eastern and north-western parts of the State formed the tract where short staple cottons (Hyderabad Oomras) were grown. The central portion was the Gaorani area, the cotton of which had a staple of $7\frac{1}{8}$ " to $15\frac{1}{16}$ ". The area on the left hand bottom corner of the map represented the southern part of Gulbarga and Raichur districts where Kumpta and the short staple Mungari cottons were grown. In the south-eastern corner Cocandas was in cultivation. Thus Hyderabad shared her problems with Berar and the Central Provinces in the north, Khandesh and Karnatak in the west, and Madras Presidency in the south. Her cotton problems were not therefore easy. There were four different varieties grown in separate areas and in different seasons. In the third map exhibited, there were two areas marked 1 and 2. One represented the Gaorani protected area, where medium staple cotton was grown, and the other a small area comprising about 100,000 acres declared as Raichur-Kumpta protected area where the seed of Jayawant cotton was being distributed. The practice of growing cottons both as kharif and rabi crop was responsible for the multiplicity of the varieties in cultivation. There was at the same time the difficulty of maintaining them pure, because, for example, Mungari cotton in the Raichur area was grown alongside the Kumpta cotton although the two cottons were sown at different times of the year. When they were brought into the market, there was nothing to prevent their being mixed. Similarly, in the north-eastern areas a number of varieties were grown and it was difficult to keep them pure. Another difficulty was that cotton crops remained standing in the field during a greater part of the year and this enhanced the difficulty of controlling the Pink Boll-worm and the Spotted Boll-worm. Dealing first with the short staple area which annually covered about 2 million acres he stated that the cotton grown in this area was a bad mixture of the various forms of *Gossypium arboreum* var. *neglectum* and *Gossypium hirsutum*: Of the neglectum types, *forma bengalensis* formed about 70 per cent of the mixture, *forma indica* about 15 per cent, and the remainder consisted of *Gossypium hirsutum* and the other forms of *arboreum*. The work on the improvement of these short staple cottons was started as subsidiary to the improvement of Gaorani variety and as a result two pure strains, namely, Havri 3 and Gaorani 12 (as mentioned on page 3 of the printed paper) were produced. As regards the three main characteristics of cotton, viz.,

ginning percentage, highest standard warp counts and staple length, the local variety had a ginning percentage of 32-34, a staple length of .76" and was fit for spinning a warp yarn of 9's count. Havri 3 had a ginning percentage of 35-37, with a staple length of .78" and could be spun into 11's count. Gaorani 12 had a ginning percentage of 31-32 and a staple of .79"-.82" with the highest standard warp count of 20's. Gaorani 12 gave a slightly lower yield than the local mixture but was distinctly superior in spinning performance. It was for consideration whether the distribution of Gaorani 12 should be continued. It had already been taken to a stage of 300 acres. The other question for consideration was the growing of short staple roseum cotton which would give the cultivator immediate benefit but it was very doubtful whether in the long run it would be profitable. In the Gaorani area, as a result of 4 or 5 years' work, two new strains Gaorani 4 and Gaorani 6 had been evolved. In 1936-37 Gaorani 6 occupied 6,000 acres and there was seed sufficient for 50,000 acres in the next season but before beginning its distribution he wanted to take the opinion of the Conference on the subject. His next point was that if a multiplicity of varieties was allowed to continue as at present it would be very difficult to maintain the varieties pure. He wanted to try the new Gaorani strains in areas in which other varieties were being grown at present and if any one of them gave satisfactory yield and spinning performance, the Committee should try to replace the local mixtures by this strain. As regards the problem of multiplication and distribution of improved pure strains to cultivators, he said that adequate facilities existed for the rapid multiplication of selfed and first generation seed but the subsequent large scale multiplication was difficult as there were not many Government seed farms or large private estates under unified control. Summarizing the steps at present taken to distribute seed of improved strains, he said that a few villages were selected in 1936 for one strain which was grown to the exclusion of other varieties. Thus the area under this strain formed a compact block which facilitated roguing of the crop and the marketing of the produce. Referring to the problem of the control of the Pink and Spotted Bollworms he stated that in the course of the investigation financed by the Committee during the past four years it had been found that the two insects were responsible for the destruction of about twenty per cent of the potential annual crop. The investigation had indicated certain measures which should be tried on a large scale before it could be definitely said that they were sufficient to control the pests. Such large scale trial of the likely control measures would be made shortly. With the extension of the area under improved strains several other problems had arisen, which were not thought of before. Generally speaking, there was not much of fusarium in the Hyderabad State but in the areas adjoining the wilt areas of Berar, East Khandesh and Dharwar there were some tracts which were wilt infected. There were also indications that wilt would probably become one of the major problems in Hyderabad. In view of this danger work was started on breeding wilt resistant types and a few strains had been evolved which under field conditions gave indications of their wilt-resistance. One of them was tested under rigorous conditions in Poona.

but had succumbed to wilt. It was intended to try the other strains as well under similar controlled conditions. Another problem awaiting solution was the production of a suitable quality cotton for the area of 300,000 acres that had been brought under perennial irrigation in Nizamabad district. In this area rice and sugarcane were at the moment the only principal crops besides jowar. The experiments conducted there with some American varieties of cotton had produced one or two strains which if sown in March, before the monsoon, gave a good crop, with a yield of 800 to 1,000 lbs. of seed cotton per acre. Another problem under investigation was the possibility of growing cotton in areas having chalka soils, in which the main crops grown were castor and jowar, neither of which was really a cash crop. Experiments had been carried out to find out whether any existing strains of cotton or any new strains from outside could be introduced in those areas. The last four years' experiments had shown that Gaorani 12 gave fairly good yield on chalka soils. Yields of 600 to 800 lbs. per acre had been obtained on this soil under rainfed conditions. Lastly, the botanical survey of the crop of the State had been completed only recently and the recommendations were before the Indian Central Cotton Committee and the Government of Hyderabad for their consideration. Data were available which would enable the Hyderabad State and the Indian Central Cotton Committee to lay down the future lines of work.

Mr. Afzal Husain wished to know what happened to the pink boll-worm in cases where there were two crops and whether it went from one crop to the other immediately.

Rai Sahib Kalidas Sawhney replied that the indications were that from the kharif crop it immediately transferred itself to the rabi crop in areas where rabi and kharif were grown side by side. The pink boll-worm spent the hot weather in a restive state in the cracks in the soil and later on with the onset of the south-west monsoon the long cycle moths emerged and started breeding on the stand-over crops which to a greater or smaller extent were present everywhere up to the end of July. The kharif crop was sown at the end of June, and the attack on this was started by the insects present in the 'stand over cotton.'

The President enquired what was meant by the stand-over crop.

Rai Sahib Kalidas Sawhney replied that in Hyderabad State leases of lands were renewed annually about the middle of April and after the tenant had harvested his crop he did not feel any responsibility to clear the land of the standing plants. He left the cotton land uncleared and the next tenant did not care to plough it for jowar till the middle of July. First at the beginning of May the tenant cleared only the land just required for cotton and the land for jowar was neglected so that there was practically up to the end of July a good deal of area under standing cotton stalks from the previous season.

Dr. Nazir Ahmad said that the differences in the spinning performance of the three cottons mentioned on page 3 of the paper might be ignored for all practical purposes. Gaorani 12 had a lower ginning percentage and from the mill point of view there was not sufficient improvement in quality. If it could be raised by further selection to a 20's class of cotton, as spun under mill conditions, then the disadvantage in ginning percentage might be counterbalanced; but as it stood, its utility was doubtful. As regards Gaorani 6, Gaorani 4 and Local he thought it would be worth while conducting well-designed experiments on those three cottons in addition to the tests that have already been made. If Rai Sahib Sawhney wished, the speaker could help him in laying down the outlines of a well-designed experiment to solve the problem regarding yield, ginning percentage and spinning quality. Referring to the point whether the practice of growing the two cottons side by side should be continued or whether only one variety should be established in the Gaorani area, he said that if the effect of growing the two varieties side by side was to reduce their resultant variability, then there was something to be said for it, but if the cottons were such that one of them was very susceptible to wilt and the other was not, then it was not wise to adopt this practice. If growing one variety was going to give better results, he advised going in for it by all means. All the consumers of Indian cottons, both here and abroad, looked forward to uniformity as one of the desirable characters, i. e., uniformity from season to season. When he discussed this problem with the representatives of the Lancashire millowners in 1935, they informed him among other things that the supply they got should be as uniform as possible; so that if one year they spun the cotton up to a certain count, they should be able to do so in the subsequent years. In their various representations to the Committee also they had stressed this point. So far as consumers were concerned they would pay a better premium for a cotton which showed uniformity in quality with time and the cotton breeders should take this factor into consideration.

Mr. Hutchinson thought that the problem of growing two cottons side by side was a little difficult as it did not mean on the same land, but side by side in the same villages and in different seasons. It meant that rabi Kumpta could not be grown in kharif nor kharif Mungari in rabi with the result that there were two varieties in two seasons. They had to be ginned in the same ginnery in the season and the trouble was that as they were very different in quality there was every inducement to mix them. The difficulty could be got over by growing two varieties of the same quality.

Mr. Venkataraman said it would be interesting to know the grader's valuation of the cottons in view of the difference in their spinning performance.

Mr. B. P. Deshpande referred to Rai Sahib Kalidas Sawhney's remarks on the effect of the spotted boll-worm on the cotton crop and enquired if any work was being done to ascertain the extent of the carry-over of the pest through the standing crop.

Rao Bahadur Kottur referring to the Committee's recommendation, as mentioned on page 5 of the paper, that a cotton breeding station should be established with a central place in the Gaorani protected area, said that his own experience was that such a necessity could be avoided by sub-dividing the tract into two or three divisions. At one time it was supposed and Dr. Howard himself was of opinion that one station for the whole of India would suffice but that opinion did not hold good now. No doubt there should be as many new stations as necessary but to multiply breeding stations in the same tract would be very expensive and he wanted to know the opinion of the Conference on that point. It was necessary to have testing stations in every sub-tract but he thought that the varieties should be supplied from the central breeding station.

Mr. Koshal drew attention to the difference in the spinning performance of Gaorani 4 and Gaorani 6 and Gaorani Local grown in different places and said that if similar experiments were carried out for a number of seasons in two or three districts more it would be possible to find out the interaction between varieties and places, and varieties and seasons. It would then be possible to recommend a suitable variety for a given area under general cultivation.

Rai Sahib Kalidas Sawhney, in reply to the first point of Dr. Ahmad and the point mentioned by Mr. Koshal, stated that replicated trials with a number of varieties added to the local cotton crop of each place had been carried out for the last three or four years in six or seven places. The total number of experiments carried out was 17 in three years and he had sent in for discussion at the Agricultural Research Sub-Committee a short note describing them but unfortunately it reached too late for inclusion in the agenda. Of the two new strains, Gaorani 4 gave significantly higher yield than the local variety in as many as 13 out of 17 trials, and Gaorani 6 outyielded the local in 11 trials. In only one place the local variety gave a significantly higher yield than Gaorani 6. Thus the trials suggested had already been carried out during the last three years and the odds were heavily in favour of the improved varieties. Samples of lint had been tested for quality. Every time both the improved strains had given higher performance than the local variety. Answering Mr. Venkataraman's query regarding grader's valuation he said that the local cotton was valued a few rupees 'off' Oomras, Havri 3 Rs. 10/- 'on' Broach, and Gaorani 12 about Rs. 25 'on' Broach. As regards the point raised by Mr. B. P. Deshpande regarding the carry-over of Spotted boll-worms he said that they bred continuously on the stand-over crops throughout the year. Referring to the division of the tract into different areas he said that the Gaorani protected area was divided into two distinct areas, one in the north-east which had a heavy rainfall and the other in the south-west with a distinctly lower rainfall. In both the areas there were testing stations. Experiments were carried out at these testing stations and a number of other sites and it was found that under the conditions obtaining in the south-west none of the new strains fulfilled expectations. He did

not think that one strain would be suitable for both the areas. As quite a large number of strains had been tried in the areas and as they were found to behave very differently, he thought it necessary to start local breeding work at least in the south-west where, as mentioned already, the rainfall was low as compared with the rest of the area. Finally, regarding the testing of strains for the Raichur area, he mentioned that such tests had been carried out with Jayawant and Hagari 1. The test of two years showed that whereas Jayawant was suitable for the western portion of the district, i. e., the area adjoining immediately the Dharwar district, it was not suitable for the eastern portion of the district where the rainfall was distinctly less. Jayawant was a late variety requiring more rainfall. So far as Hagari 1 was concerned it had been tried for two years. In one season the difference between Hagari and the local cotton was not significant and in the other season Hagari was slightly better. The experiments were still being carried out and a large number of types have recently been collected from the Bombay and Madras Presidencies for being tested at the Government Farm, Raichur.

COTTON MYCOLOGY

Paper No. 1.

BREEDING FOR WILT RESISTANCE IN COTTON*

BY

B. N. UPPAL,

PLANT PATHOLOGIST TO THE BOMBAY GOVERNMENT.

INTRODUCTION.

Wilt in cotton is caused by *Fusarium vasinfectum*, which, though a facultative saprophyte, is highly specialised in its parasitic relations. Whilst cotton wilt has been shown to be due primarily to the parasitism of this fungus, the fact that severely diseased zones in a field shift in location from one year to another clearly indicates a relationship between the disease and environmental conditions, and the paramount importance of these factors in determining its severity. Indeed, this relationship of environment, especially soil temperature, is so sharply limited that little or no wilt will be caused in a susceptible variety regardless of the prevalence of the parasite in the soil if the soil temperature is unfavourable. Although this is a basic conception in the parasitism of soil-borne facultative saprophytes, yet it is generally so vaguely understood as to preclude a correct evaluation of its relationship to breeding for wilt resistance. Most of the work on the breeding of wilt-resistant strains of cotton and other crops in this country has been done without adequate consideration of the paramount importance of the limiting environmental conditions, with the result that there has been much confused thinking about the meaning of wilt resistance.

Wilt resistance in cotton is mainly affected in its expression by two important factors: degree of soil infestation by the pathogene and soil temperature. Assum-

*The work herein reported is financed by the Indian Central Cotton Committee and is being done in collaboration with the Cotton Breeders at Broach and Jalgaon.

ing uniformly severe soil infestation, adverse soil temperatures can induce temporary resistance in plants of the susceptible variety resembling the "inherited" resistance shown by the immune variety at all temperatures. If, on the other hand, susceptible types of cotton are grown in infested soil in a range of optimum soil temperature (about 25° to 27°C.), all plants *must* wilt. This, however, does not happen under field conditions "where variations in soil infestation by the parasite and in the seasonal climatic conditions preclude uniformly severe testing for resistance."

It is sometimes argued that, although complete immunity is the ideal, selection for wilt resistance under field conditions is a sufficiently satisfactory basis for the isolation and fixation of resistant strains. This view-point is unconsciously based on the wrong assumption that field selection provides as uniform a basis of testing as pot culture. It is therefore essential to define resistance or immunity with respect to the optimum environment, and all degrees and standards of resistance must be measured in terms of the standard "environment" and not the variable environment as is obtained under field conditions. For we must recognise the basic conception in plant pathology that "disease" in plants is "the resultant of the interaction of a plastic host and a plastic parasite" modified by the potent influence of the environment. The relation of environment to the development of *Fusarium* wilt diseases is fundamental to the whole question of disease resistance, since the term "resistance" here assumes different meanings when used with respect to varying environment. If this be so, then it follows that the field-selected strains must vary in their wilt reaction according to seasonal conditions and the amount of infestation of the soil by the pathogene. For example, the highly wilt-resistant strain of *Cajanus indicus*, Type 80, developed at Pusa, when tested in wilt sick soil at Arbhavi Farm, suffered 40 to 60 per cent mortality from wilt. Selection for wilt resistance in cotton, as has been done in the Central Provinces and elsewhere, has therefore no permanent value, as field selection does not provide any real basis of distinction between "disease resistance" and "disease escape," and the selection and fixation of the so-called resistant strains under such conditions leads to the perpetuation of "mixture" of strains varying in genetic constitution and consequently in degrees of resistance. It is obvious therefore that the great need in the study of wilt resistance is the development of a technique whereby comparable results may be obtained at different times.

In cotton wilt air temperature plays an important part in the expression of wilt symptoms. Whilst the fungus may invade and establish itself in the root tissues at lower temperatures (about 20°C.), its further invasion of the root system and upward ascent into the stem leading to wilting and death of the aerial parts is largely dependent on favourable air temperatures (26° to 30°C.). Under adverse conditions susceptible plants may pass off as resistant to wilt, but may succumb to the disease in seasons more favourable to wilt or under more rigorously controlled conditions of

infection. This situation may be further complicated by variation in soil infestation, as it is evidently not possible to provide such uniform conditions of infection in the field as in pot culture. It is thus obvious that selection for wilt resistance under field conditions is hardly an adequate basis for distinguishing a truly resistant from an apparently resistant plant.

It is also a common observation that field-selected wilt resistant strains of cotton fail to maintain their resistance when grown in another locality where environmental conditions are quite different. For example, B. D. 8, which shows a high degree of resistance in field culture at Broach, suffered a heavy degree of wilt attack when grown in severely wilt sick soil near Ankleswar. The wilt-resistant strains developed in the Central Provinces, N. V. strains in Khandesh, etc., have shown similar reactions. This behaviour is easy to explain if it is realised that the so-called "strains" are merely "mixtures" varying in genetic constitution and consequently in degrees of resistance. Under favourable conditions of infection they behave like susceptible strains, but in the absence of these conditions they may show apparent resistance.

In the development of wilt-resistant varieties of cotton, it is also essential to study the genetic variability of the pathogene. In the vascular *Fusaria* this variation is expressed in culture characters and to a large extent in parasitism. Isolations of *Fusarium vasinfectum* from the cotton-growing areas in the Bombay Presidency have failed to reveal any differences in respect to pathogenicity, and this absence of selective parasitism in the cotton wilt fungus greatly simplifies the problem of producing resistant varieties. There are indications, however, that the Khandesh strain of *Fusarium vasinfectum* has slightly higher temperature relations for the development of wilt than the Broach or Dharwar strain. The variations in cultural characters, on the other hand, fluctuate within type limits, and are not a vital factor in the problem of selection and breeding for resistance to cotton wilt.

METHOD OF TESTING.

It is evident from the above discussion that the isolation and fixation of strains resistant to *Fusarium* wilt diseases should be done under the optimum conditions of infection. Such a technique was developed in connexion with our work on the isolation of wilt-immune types of sann hemp, and this method has shown promise of equally good success in breeding for wilt immunity in cotton. Before describing the results on the production of wilt-immune types in B. D. 8 and other cottons, the method used in their isolation will be briefly discussed.

The technique involved in the production of wilt-immune strains of cotton provides for the testing of promising strains in three stages.

- Stage I The Cotton Breeders produce promising wilt resistant strains suitable for their respective areas in a thoroughly and uniformly infested field.
- Stage II At Poona under optimum conditions of infection immune types are being re-selected from the highly resistant materials furnished by the Breeders.
- Stage III The Cotton Breeders will finally test the strains selected at Poona in their respective areas for wilt immunity and other agronomic characters.

Stages I and II will now be described in some detail.

Stage I. In order to make reliable comparative tests, it is necessary to use a plot which has been thoroughly and uniformly infected with the wilt organism and is relatively free from other soil-borne diseases affecting cotton. A highly susceptible variety of cotton is grown year after year to intensify the existing infection. In addition, wilt compost, prepared by mixing young cotton stalks with chopped naturally infected cotton plants and to which large quantities of the wilt organism grown on cotton meal in "giant" Erlenmeyer flasks have been added, is spread evenly over the surface and then harrowed into the soil. A plot receiving this treatment for a few years will be found to be very suitable for the preliminary field selection. The plot should be located in a region where the climate and soil are such as to favour the rapid development of wilt. As has been pointed out above, these conditions are absolutely essential in order to secure the development of wilt in most or all of the susceptible individuals with sufficient rapidity to ensure their elimination.

Cotton strains possessing desirable agronomic characters are tested under these conditions for a number of years until a strain showing a high degree of resistance *under field conditions* is secured. These field tests are intended to provide for resistant strains from which to re-select immune types in the second stage of more rigorous testing under controlled conditions of infection.

Stage II. The highly wilt-resistant material secured under field conditions is then put to a more rigorous test in a glasshouse in which a uniform temperature of 25 to 27°C. (the optimum range of infection) is maintained. The wilt organism is multiplied in large quantities on cotton meal in Erlenmeyer flasks, and appropriate quantities of this inoculum are mixed uniformly with sterilised black soil; the inoculated soil is allowed to lie in large iron trays for about a fortnight and is occasionally watered and turned over in order to permit of the maximum growth of the organism.

The progeny of each resistant plant is then tested separately in infested soil in small tubular pots, each pot containing not more than two to three seeds. The index of soil infectivity of each pot is so adjusted that the progeny of a single selection is never tested in a soil of lower infectivity than that of the previous year. Individual pots are examined every day, and all plants showing wilting or clearing of leaf veins or mottling are pulled out; the presence or absence of the fungus in such plants is finally determined by isolation in the laboratory. This process of drastic elimination is continued for six weeks or more, and at the end of this period only such plants as appear perfectly normal are transplanted to a thoroughly and uniformly wilt-infected bed. In actual practice a small-sized plot measuring 50 ft. × 50 ft. has been found to serve the purpose well. At the end of the season all plants are split open and examined for the vascular discoloration of the root and stem, and plants showing such discoloration are classed as diseased and rejected. The selfed seed of healthy plants is again tested in the glasshouse under conditions of optimum infection, and this process is repeated until a wilt-immune type is fixed. It is evident that this procedure is precisely the same as a plant breeder employs in breeding for certain morphological characters, with this difference, however, that when the objective is a physiological character such as wilt immunity, it is imperative that selection should be done under optimum conditions for the development of wilt.

SELECTION OF WILT IMMUNE TYPES.

B. D. 8. Broach Desi 8 (B. D. 8) is a strain produced by the Cotton Breeder at Broach. Since it has been grown for many years in a wilt-infected bed at Broach, it has developed a high degree of field resistance. This strain was therefore selected as a possible source for the isolation of a wilt-immune type.

SEASONS 1932-33 AND 1933-34.

In 1932 and 1933 the selfed seed of the single plant selections was sown in infested soil in pots; but no attempt was made to regulate fluctuations in soil temperature. Of 932 plants grown from the selfed seed, only 159 plants survived the disease but showed mottling or clearing of leaf veins indicating the presence of the fungus in the vascular tissue. The survivals were transplanted rather late in the season and were therefore ratooned. Of these, only 39 plants produced seed.

SEASON 1934-35.

The selfed seed of the 39 plants was further tested in pot culture at Broach. All cultures developed leaf mottling and, with the exception of cultures B. D. 8-6 and

B. D. 8-26, suffered varying percentage of mortality from wilt. The number of survivals in each case were transplanted in the infected field at Broach, The results are recorded in Table I.

TABLE I.

Results of tests in pot culture of *B. D. 8* at Broach, 1934-35.

Culture.	No. of effective plants.	Per cent. of deaths.	No. of plants transplanted.
B.D. 8-3	23	25.8	3
B.D. 8-4	16	37.8	1
B.D. 8-5	12	8.3	6
B.D. 8-6	14	0.0	14
B.D. 8-7	41	43.2	5
B.D. 8-8	49	10.0	16
B.D. 8-9	23	73.1	1
B.D. 8-13	20	75.0	1
B.D. 8-14	14	14.3	7
B.D. 8-15	13	23.1	7
B.D. 8-16	9	11.1	8
B.D. 8-17	18	61.6	1
B.D. 8-19	14	35.3	3
B.D. 8-20	8	50.0	2
B.D. 8-21	17	23.6	2
B.D. 8-23	22	13.5	5
B.D. 8-24	79	11.4	34
B.D. 8-25	26	3.8	16
B.D. 8-26	15	0.0	14
B.D. 8-27	19	79.5	1
B.D. 8-29	14	21.6	6
B.D. 8-31	6	33.4	3
B.D. 8-32B	12	58.1	1
B.D. 8-38A	9	55.6	1
B.D. 8-39A	5	0.0	4

TABLE I.—*contd.*Results of tests in pot culture of *B. D. 8* at Broach, 1934-35.

Culture.	No. of effective plants.	Per cent. of deaths.	No. of plants transplanted.
B.D. 8-39B	2	0.0	2
B.D. 8-40	4	75.0	1
B.D. 8-42B	8	20.0	3
B.D. 8-43	16	37.2	3
B.D. 8-44A	2	50.0	1
B.D. 8-44B	17	35.4	3
B.D. 8-46A	7	28.6	3
B.D. 8-46B	4	0.0	4
B.D. 8-74	3	66.6	1
B.D. 8-76B	8	87.5	1
B.D. 8-79A	6	16.7	4
B.D. 8-81B	2	50.0	0
B.D. 8-82B	4	0.0	3
B.D. 8-83	4	0.0	3

Season 1935-36

In the season 1935-36 the progenies of the wilt-free cultures, B. D. 8-6 and B.D. 8-26 and a few other promising cultures were tested in pots. The selfed seed from the single plants was sown in small tubular pots (a seed in each pot) containing sterilised soil to which a definite quantity of the inoculum had been added. The pots were kept in a glasshouse in which the air temperature fluctuated from 20 to 27°C. Daily observations were made for a period of 45 days, and the plants that wilted were incubated to make sure that death was due to *Fusarium vasinfectum*. Of a total population of 711 plants thus tested, 38 plants survived the disease at the end of 45 days (Table II). An outstanding feature of the survivals was that 26 plants were absolutely free from leaf mottle, whilst the rest developed this symptom only a few days before the conclusion of the test. All the 38 plants were transplanted in the heavily infected bed, and a small quantity of the fungus growth was also placed near the roots of each seedling to intensify the existing infection in the soil.

TABLE II.

Results of tests in pot culture of *B. D. 3* at Poona, 1935-36.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
B.D. 8-6-27	10	50.0	3
B.D. 8-6-28	47	46.8	19
B.D. 8-6-35	17	23.5	10
B.D. 8-6-38	29	62.1	2
B.D. 8-26-81	72	95.8	0
B.D. 8-26-82	138	99.2	1
B.D. 8-26-83	6	100.0	0
B.D. 8-26-84	20	95.0	0
B.D. 8-26-85	8	75.0	2
B.D. 8-26-86	3	100.0	0
B.D. 8-26-89	42	97.6	0
B.D. 8-26-90	4	75.0	0
B.D. 8-26-92	43	97.7	0
B.D. 8-5-23	5	60.0	0
B.D. 8-5-26	18	83.3	0
B.D. 8-14-66	15	73.3	0
B.D. 8-14-67	5	60.0	0
B.D. 8-14-68	3	100.0	0
B.D. 8-31-42	29	82.7	0
B.D. 8-39-116	20	85.0	0
B.D. 8-43-131	16	100.0	0
B.D. 8-43-132	25	96.0	0

N. B.—"Infection" includes deaths and such plants as show leaf mottle but do not invariably ill.

TABLE II.—*contd.*Results of tests in pot culture of *B. D. 8* at Poona, 1935-36.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
B.D. 8-44A-133	30	100.0	0
B.D. 8-44B-134	16	75.0	0
B.D. 8-44B-135	8	100.0	0
B.D. 8-44B-136	57	98.2	0
B.D. 8-46B-4	2	100.0	0
B.D. 8-83-9	23	82.6	1
Total	711		38

N.B.—"Infection" includes deaths and such plants as show leaf mottle but do not invariably wilt.

At the end of the season all plants were examined for root discoloration. The 12 plants which had developed leaf mottle rather late during the period of the glasshouse test showed the browning of the vascular bundles and were consequently rejected. Of the 26 plants that had shown no mottling during the 45-day test in the glasshouse, 12 plants were found to show slight discoloration of the roots, and were also rejected. Selfed seed was collected separately from the remaining 14 healthy plants. These plants were :—

Culture	Healthy plants
B.D. 8-6-27	2, 13
B.D. 8-6-28	17, 18, 21, 37, 41, 45, 60
B.D. 8-6-35	3, 4, 9, 13, 26

Season 1936-37.

Seed from these single plants was tested in infected soil as in the previous season, with this difference, however, that the temperature of the soil in pots in the glasshouse was maintained at 25 to 26°C.; the temperature sometimes falling to

23°C. in the early hours of the morning. Under these optimum conditions of infection the percentage of death was extremely low, but leaf mottle was still in evidence. This suggests the development of a very high degree of resistance in the plants since most of the plants with mottle did not suffer from wilt.

Table III shows the percentage of infection, expressed partly as wilting but mostly as mottling, which occurred in the progeny of each plant. At the conclusion of the 50-day test in the glasshouse, out of total population of 12,338 effective plants, only 17 plants remained free from leaf mottle and were looking perfectly healthy. These plants have been transplanted in the infected bed in the current season.

TABLE III.

Results of tests in pot culture of *B. D. 8* at Poona, 1936-37.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
B.D. 8-6-27-2	972	100.0	0
B.D. 8-6-27-13	1024	100.0	0
B.D. 8-6-28-17	886	100.0	0
B.D. 8-6-28-18	574	100.0	0
B.D. 8-6-28-21	1135	100.0	0
B.D. 8-6-28-37	896	100.0	0
B.D. 8-6-28-41	606	100.0	0
B.D. 8-6-28-45	529	99.8	1
B.D. 8-6-28-60	864	100.0	0
B.D. 8-6-35-3	520	99.8	1
B.D. 8-6-35-4	741	100.0	0
B.D. 8-6-35-9	609	97.5	15
B.D. 8-6-35-13	1413	100.0	0
B.D. 8-6-35-26	1570	100.0	0

N.B. "Infection" includes deaths and such plants as show leaf mottle but do not invariably wilt.

Crosses with B. D. 8. Several crosses of *B. D. 8* with other cotton strains have been tested for wilt resistance under the optimum conditions of infection in the glasshouse, and promising selections have been made. It is not proposed to discuss these results in this paper.

N. S. 12. New selection 12 (N. S. 12) is a district selection and highly resistant to wilt under field conditions.

Season 1934-35.

Five strains of N. S. 12 were tested in pot culture at Broach. Many plants survived the disease and remained free from any leaf symptoms (Table IV). The survivals were transplanted in the infected field and selfed. The peculiarity of this selection is that susceptible plants show clearing of leaf veins only under optimum conditions of infection, but under other conditions a small portion of the cotyledon may show yellowing.

TABLE IV.

Results of tests in pot culture of *N. S. 12* at Broach, 1934-35.

Culture.	No. of effective plants.	Per cent. of deaths.	No. of plants transplanted.
N.S. 12-1	91	14.3	43
N.S. 12-2	40	15.0	10
N.S. 12-3	38	20.8	10
N.S. 12-4	40	22.5	10
N.S. 12-5	54	0.0	45

Season 1935-36.

The progenies of the wilt-free culture, N.S. 12-5, and two other cultures, N. S. 12-2 and N.S. 12-3, were further tested at Poona in pot culture in a glasshouse in which air temperature fluctuated from 20 to 27°C. Daily observations were made for a period of 45 days, and at the conclusion of this test, only 51 plants were free from leaf yellowing and looking normal (Table V). These plants were transplanted in the infected bed very late in the season. Of these, 16 plants were rejected at the end of the season, as they showed slight root discoloration. Three plants did not produce flowers and were ratooned.

TABLE V.

Results of tests in pot culture of *N. S. 12* at Poona, 1935-36.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
N.S. 12-2-71	156	83.3	21
N.S. 12-2-73	39	84.6	0
N.S. 12-2-74	9	77.7	0
N.S. 12-2-75	9	66.6	0
N.S. 12-2-78	7	59.1	0
N.S. 12-2-80	9	100.0	0
N.S. 12-2-153	13	92.3	0
N.S. 12-3-81	138	91.3	0
N.S. 12-3-82	67	86.6	0
N.S. 12-3-83	23	52.1	0
N.S. 12-3-84	23	100.0	0
N.S. 12-3-86	78	97.4	0
N.S. 12-3-87	16	93.7	0
N.S. 12-5-101	163	75.4	21
N.S. 12-5-106	33	93.9	1
N.S. 12-5-107	14	85.7	1
N.S. 12-5-108	12	75.0	0
N.S. 12-5-109	11	90.9	1
N.S. 12-5-238	34	91.2	1
N.S. 12-5-239	14	100.0	0
N.S. 12-5-240	17	76.5	0
N.S. 12-5-245	92	68.5	5
N.S. 12-5-246	19	94.7	0

N.B.—"Infection" includes deaths and such plants as show leaf yellowing but do not invariably wilt.

Season 1936-37.

Selfed seed from the 32 healthy plants was tested in pot culture in a glasshouse under conditions of optimum soil temperature (about 25° to 26°C.). As in B.D. 8, wilting was not much in evidence, but most of the plants showed leaf mottle. At the end of the 50-day test, only 27 plants were free from leaf mottle and were transplanted in the infected bed (Table VI). These results suggest that selection under controlled conditions has resulted in the accumulation of a high degree of resistance in *N. S. 12*.

TABLE VI.

Results of tests in pot culture of *N.S. 12* at Poona, 1936-37.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
N.S. 12-2-71-12	14	100.0	0
N.S. 12-2-71-19	124	97.6	3
N.S. 12-2-71-21	84	100.0	0
N.S. 12-2-71-25	285	100.0	0
N.S. 12-2-71-45	7	100.0	0
N.S. 12-2-71-58	390	100.0	0
N.S. 12-2-71-61	455	100.0	0
N.S. 12-2-71-92	294	100.0	0
N.S. 12-2-71-103	101	100.0	0
N.S. 12-2-71-115	406	100.0	0
N.S. 12-2-71-118	525	100.0	0
N.S. 12-2-71-121	195	100.0	0
N.S. 12-2-71-147	57	98.3	1
N.S. 12-5-101-26	741	100.0	0
N.S. 12-5-101-31	169	96.6	6
N.S. 12-5-101-51	142	100.0	0
N.S. 12-5-101-76	571	100.0	0
N.S. 12-5-101-90	413	100.0	0
N.S. 12-5-101-98	361	100.0	0
N.S. 12-5-101-100	280	99.3	2
N.S. 12-5-101-105	272	100.0	0
N.S. 12-5-101-118	361	100.0	0
N.S. 12-5-101-120	284	100.0	0
N.S. 12-5-101-135	344	100.0	0
N.S. 12-5-101-144	473	100.0	0
N.S. 12-5-101-146	287	100.0	0
N.S. 12-5-101-165	630	99.8	1
N.S. 12-5-106-25	687	99.8	1
N.S. 12-5-107-10	1125	99.9	2
N.S. 12-5-238-34	469	99.4	3
N.S. 12-5-245-13	868	100.0	0
N.S. 12-5-245-21	641	99.8	1
N.S. 12-5-245-41	925	99.3	6
N.S. 12-5-245-62	441	99.8	1

N. B.—"Infection" includes deaths and such plants as show leaf mottle but do not invariably wilt.

Work in the Southern Maratha Country.—Work on the above lines is proceeding at Dharwar with a view to the selection of an immune type in Kumpta cottons. The work at Dharwar, though sufficiently well advanced, suffers from the disadvantage that there are no facilities at Dharwar for testing promising selections under optimum conditions of infection in a glasshouse. With the provision of a glasshouse this work can be brought to a speedy conclusion since the Cotton Breeder has excellent material from which immune types may be selected in the course of a few years.

Work in Khandesh.—The wilt-resistant strains developed by the Cotton Breeder at Jalgaon have not proved a promising material from which to re-select immune types under controlled conditions of infection. There are indications, however, that selection in N. V. strains in a highly wilt-infected bed at Jalgaon is resulting in the accumulation of a high degree of field resistance in these strains, which are likely to provide a source for the isolation of a wilt-immune type.

In the meantime selections for wilt-resistance are being made in strains of *Gossypium arboreum* var. *neglectum* (*Gossypium neglectum*) collected from all over the country including Burma, with the ultimate view to crossing a wilt immune type with one of the best N. V. selections of the Cotton Breeder at Jalgaon.

Season 1935-36.

Million Dollar.—This strain was tested in pot culture at Poona in a glasshouse, the air temperature of which fluctuated from 20 to 27°C. Daily observations were made for a period of 45 days, and 72 plants survived the disease at the end of this period. The survivals were transplanted in the infected bed, where 17 plants died and in 8 cases death was due to *Fusarium vasinfectum*. Of the remaining 55 plants, 38 produced flowers and were self-pollinated; the rest were ratooned.

Season 1936-37.

The selfed seed of the 38 plants was further tested in pot culture in a glasshouse where the air temperature fluctuated from 20 to 26°C. Daily observations were made for a period of 50 days, and at the conclusion of this test, 129 plants were free from leaf mottle and have been transplanted in the infected bed in the current season (Table VII).

TABLE VII.

Results of tests in pot culture of *Million Dollar* at Poona, 1936-37.

Culture.	No. of effective plants.	Per cent. of infection.	No. of plants transplanted.
M.D. 2	61	93.4	4
M.D. 3	46	60.9	18
M.D. 4	20	100.0	0
M.D. 5	48	79.2	10
M.D. 6	0	0.0	0
M.D. 7	12	100.0	0
M.D. 8	0	0.0	0
M.D. 9	94	96.8	3
M.D. 10	6	100.0	0
M.D. 11	42	95.2	2
M.D. 12	28	100.0	0
M.D. 13	50	90.0	5
M.D. 14	21	100.0	0
M.D. 15	28	100.0	0
M.D. 16	81	82.7	14
M.D. 17	61	100.0	0
M.D. 19	108	98.1	2
M.D. 21	42	90.5	4
M.D. 22	79	60.7	31
M.D. 25	24	100.0	0
M.D. 28	31	100.0	0
M.D. 30	27	100.0	0
M.D. 33	34	91.2	3
M.D. 34	21	100.0	0
M.D. 40	79	92.4	3
M.D. 44	14	42.8	8
M.D. 45	0	0.0	0
M.D. 46	0	0.0	0
M.D. 49	28	42.9	16
M.D. 52	15	53.3	5
M.D. 53	16	93.7	1
M.D. 55	26	100.0	0
M.D. 56	34	94.1	2
M.D. 58	9	100.0	0
M.D. 65	0	0.0	0
M.D. 67	33	100.0	0
M.D. 69	0	0.0	0
M.D. 72	6	100.0	0

N. B.—"Infection" includes deaths and such plants as show leaf mottle but do not invariably wilt.

GENETIC BASIS OF RESISTANCE.

It has been shown that resistance to *Fusarium* wilt diseases may be inherited, and that the factorial basis of this inheritance may differ in different plants. At least two distinct types of inheritance have so far been recognised in this group of plant diseases. The first type is represented by pea wilt, caused by *Fusarium solani* var. *martii* f. 2 (*Fusarium martii* var. *psi*), in which immune and susceptible plants fall in two discontinuous classes, and immunity is due to a single dominant gene. In the other type more commonly represented by flax wilt, caused by *Fusarium lini*, resistance is complex genetically, pointing to transgressive segregation. The first type can be readily fixed in a homozygous condition by selection, whilst the second type is not so fixed by repeated selection and is influenced apparently by environmental conditions.

Recently, however, it has been shown that resistance in cabbage to *Fusarium conglutinans* is of both the types. Type A resembles the resistance in peas to wilt and is controlled by a single dominant gene; whilst Type B like the resistance to flax or tomato wilt shows a more complicated relation. "In field trials, progenies containing type B vary in the amount of resistance displayed, ranging up to complete freedom from disease symptoms." "In greenhouse trials over a range of soil temperatures, type A remains stable, while type B resistance varies in degree in different progenies and breaks down with rise in soil temperature until it is usually completely suppressed at 24°C." Thus, in a cabbage like Wisconsin Hollander resistance is of type B and is controlled by modifying factors. These factors for resistance are different in type and reaction from the single dominant factor controlling resistance in the homozygous resistant (immune) lines (Type A). It has been suggested that the factors for resistance in Wisconsin Hollander are not dominant but are cumulative in effect.

In the case of cotton the position is somewhat similar to that in cabbage. Fahmy in Egypt has shown that in certain varieties of Egyptian cottons such as Giza 7 and Giza 2 (or the fixed immune strain Myco 4), wilt immunity is a unit character which, in crosses of immune with susceptible individuals, behaves as a dominant Mendelian character. There is, however, another type of resistance, resembling the resistance of Wisconsin Hollander cabbage to *Fusarium conglutinans*, which is of an intermediate type. The study of the progenies of crosses between immune and heterozygous (containing type B resistance) individuals shows that resistance is controlled by cumulative genes. The resistance of heterozygous individuals can be increased by selection in self-pollinated lines; but whether a resistance equal to that of immune lines can be developed as a result of the accumulation of modifying genes has not been determined.

As regards the genetics of resistance in Indian cottons, it is still early to offer a definite explanation. There are, however, clear indications from our work that wilt resistance in Indian cottons is not due to a single immunity gene but may be controlled by cumulative genes, as is the case in Egyptian cottons or type B resistance of Wisconsin Hollander cabbage. It still remains to be determined whether repeated selection of individuals free from leaf mottle in self-pollinated lines under optimum conditions of infection in the glasshouse will ultimately result in the production of lines possessing resistance of the order of type A. Nevertheless, it is true, as has recently been suggested by Mr. J. B. Hutchinson, that if a single immunity gene had existed in cotton stocks grown in wilt sick areas in this country, it would have been readily fixed, and undoubtedly "the absence of naturally selected immune strains in wilt sick areas provides a very strong evidence against the single immunity gene theory." However, whatever be the mode of inheritance of wilt resistance in Indian cottons, it is evident from the above discussion that better results will follow in the isolation and fixation of strains homozygous for complete resistance if selection is made under optimum conditions of infection.

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PLANT BREEDING

Paper No. 8.

THE GENETICS OF GOSSYPIUM AND ITS APPLICATION TO COTTON BREEDING

BY

J. B. HUTCHINSON, P. D. GADKARI
AND M. A. A. ANSARI.

- I. INTRODUCTION.
- II. INHERITANCE OF QUALITATIVE CHARACTERS.
- III. INHERITANCE OF QUANTITATIVE CHARACTERS.
 - (a) *Linkage and correlation.*
 - (b) *Inheritance of disease resistance.*
 - (c) *Back-crossing.*
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 - (e) *Acclimatisation and residual variance.*
- IV. INTERSPECIFIC HYBRIDISATION.
 - (a) *The genetic concept of the species.*
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I. INTRODUCTION.

There has always been some misunderstanding of the spheres of work of geneticists and plant breeders. The former are regarded as concerned only with the theoretical side of the subject while the latter are regarded as practical men with no time for pure science. In actual fact most of the recent progress in knowledge of the genetics of *Gossypium* has been made by workers closely concerned with the breeding of better cottons and we hope to show that further progress depends largely on the

extent of co-operation between cotton geneticists and cotton breeders. Harland (1932a) and Kearney (1930) have given excellent accounts of the state of knowledge of the genetics and botany of *Gossypium* and it is not proposed to deal with the work summarised by them.

II. INHERITANCE OF QUALITATIVE CHARACTERS.

Examination of recent literature shows that the following characters are inherited in a simple Mendelian manner:—

1. Asiatic Cottons.

CHARACTER.	FACTOR.	EFFECT OF FACTOR PAIR.	AUTHOR.
Anthocyanin	R R ^L R ^C R ^S R ^O R ^G	Red Red leaf Red calyx Spot Spotless Ghost spot	} Multiple allelomorph series. Hutchinson (1932b)
Crumpled	A } B }	Complementary for crumpling.	Hutchinson (1932a).
Corolla colour	Y Y ^F Y	Yellow } Pale } White }	} Multiple allelomorph series. Hutchinson (1931)
Sterility		Fertile-Sterile	Hutchinson & Gadkari (1935.)
Female Sterility	stg.	Normal-sterile	C. Vijayaraghavan, N. Keshava Iyengar & M. Venkoba Rao (1936.)
Petaloidy.	F ^{PD} .	Normal-petaloid	Ramanathan & Sankaran (1934.)
Pollen colour.		Yellow-white	Ramanathan & B. S. Iyer (1933.)

CHARACTER.	FACTOR.	EFFECT OF FACTOR PAIR.	AUTHOR.
Leaf shape.	L ^B	Mutant Broad.	Multiple allelo-morph series. Hutchinson (1934c)
	L ^L	Mutant Intermediate	
	L ^L	Laciniated	
	L	Narrow.	
	L	Broad.	
Leaf nectaries	N ^B	Present-absent	Leake (1914)
Lint colour	K	Khaki-white	Duplicate Hutchinson (1934c)
	D ¹	Light brown-white.	
	D ²	Light brown-white.	
Glabrous lintless	H ^G	Hairy linted-glabrous lintless.	Afzal & Hutchinson (1933)
Hairy lintless.	H ^L	Hairy lintless Hairy linted. H ^L H ^L lethal	
Seed fuzz.	T	Tufted-fuzzy.	Hutchinson (1935).

2. *New World cottons.*

Chlorophyll deficiency	C ^{HA} } C ^{HB} }	Green-chlorophyll deficient, duplicate genes.	Stroman & Mahoney (1935), Harland (1929c), (1932c).
	V	Green-virescent yellow.	Harlascher & Killough (1931).

CHARACTER.	FACTOR.	EFFECT OF FACTOR PAIR.	AUTHOR.
Red plant body	R ¹ R ² }	Red-Green. Duplicate genes.	McLendon (1912), Thadani (1923), Ware (1927) Harland (1929c)
Cluster habit. Short fruiting branches.	C ^h S ^h	Normal-cluster. Long sympodia-short sympodia.	Thadani (1923). Kearney (1930)
Crinkled dwarf.	Cr.	Normal—crinkled	Harland (1916) (1918)
Hairiness	H ^t	Hairy-glabrous	Harland (1929 c)
Leaf shape	O ⁿ O ^o O ^s	Normal Okra Super okra } Multiple } allelomorph } series.	Shoemaker (1909) Harland (1929b)
Corolla colour	Y ^b Y ^d }	Yellow-cream Duplicate genes.	Harland (1936b)
Petal spot	S ^r S ⁱ S ^w S ^b S ^o	Full spot Intermediate diate spot. } Weak spot Extinguished spot. } Spotless }	Multiple allelomorph series. Kearney (1924) Harland (1929c)
Pollen colour	P Q	Yellow-cream Dark yellow-pale yellow.	Harland (1929 c)
Lintless.		Linted fuzzy—lintless	Griffe & Ligon (1929)

CHARACTER.	FACTOR.	EFFECT OF FACTOR PAIR.	AUTHOR.
Lint colour	K ^H K ^B }	Khaki—white; duplicate genes.	Harland (1935).
	G ^L	Green—cream or white	{ Harland (1929c) Ware (1932b).
Seed fuzz.	N	Naked-fuzzy (Upland)	{ Thadani (1923) Kearney (1927) Carver (1923)
	T	Tufted-Naked (Peruvian)	Harland (1929c)
	S ^M	Less fuzzy-more fuzzy (Peruvian)	Kearney (1927)
	F ^T	Tufted-fuzzy (upland)	{ Carver (1929) Harland (1931a)
Seed fuzz. colour	G	Green-white	Carver (1929)
	B ^B	Brown-white.	

III. INHERITANCE OF QUANTITATIVE CHARACTERS.

The elucidation of the inheritance of quantitative characters has always been a difficult task for the geneticists. A considerable mass of data exists on the genetic analysis of such characters as earliness (node number) (Ludwig 1931, Ramanathan 1930, Harland 1929a), annual-perennial habit (monopodial and sympodial habits) (Leake 1914a), lint length (Kottur 1923, Kearney 1926), lint looseness (Fletcher 1907), ginning percentage (Leake 1914b), seed fuzz (Harland 1932a, Hutchinson 1935b), seed weight (Balls 1919, Hutchinson 1934c), size of the bolls (Kokuev 1935). Their studies uniformly reveal multiple factor inheritance with monomodal frequency distribution in F₂. Such characters as lint index, seed weight and lint length are probably affected by large numbers of genes and in an ordinary population exposed to natural crossing many such factors may be present in a heterozygous condition. Wherever characters of agricultural value have been subjected to genetic analysis, "blending" or quantitative inheritance has been demonstrated.

Fisher (1930) has shown that this type of inheritance, depending on the segregation of many factors of small individual effect, might have been predicted from a consideration of the action of selection. It is therefore clear that the elucidation of the problems involved in "quantitative" inheritance is the most important task of the geneticist who hopes to assist the practical breeder.

a) *Linkage and correlation.*

The genetic analysis of character correlations is of great importance to the plant breeder. Firstly, where linkages occur, it will be of value to know in which types desirable characters are present in the coupling phase, as in hybrids involving such types the desired character combinations will occur in greater number than in hybrids involving the repulsion phase of linkage. Secondly, from the point of view of the development of breeding technique, it is essential to know the effect of linkage on the inheritance of quantitative characters. Thirdly, it is manifestly useless to spend time endeavouring to break associations between characters which are physiologically correlated. On the first point, very little information is available. In the Old World cotton the knowledge regarding it is summarised (from Hutchinson's papers) below :—

K	} Series	}
L		
Tuft modifier	}	
A gene for long lint		
A gene for low density of hair		
R Series	}	
Genes affecting lint length		
Seed weight genes		
Tuft	}	
Seed weight genes		
Y Series	}	
Lint length genes		

H—h, AB, Ne-ne, do not belong to any of the above groups.

Harland (1929c) and Thadani (1923) record several cases of linkage in New World cottons. While reviewing the work of the Genetics Department, Trinidad, Harland (1932a) describes five factors that have been identified affecting the distribution of fuzz on the seed coat. An important discovery in this connection is that both fuzz and lint are not to be considered alone, but as part of the general hairiness mechanism of the plant.

Concerning the effect of linkage on the inheritance of quantitative characters nothing of importance is yet known except the chromosome numbers.

There are a few observations scattered in the literature which are probably to be interpreted in terms of physiological correlation. The most decisive data are those given by Hutchinson (1931) for the correlation between intensity of yellow colour in the corolla and petal length, which he showed held between flowers of the same plant as well as between those of different plants in segregating families. A rather different type of physiological correlation is the negative correlation between node number and bud shedding observed by Evelyn in Sea Island cotton (see Hutchinson 1934b). In this case it appears that the development of fruiting branches before a certain stage in the growth of the plant is compensated by increased bud shedding. Brown's (1935) negative correlation between ginning percentage and seed weight may perhaps also be included in this group.

On the group of problems included in this section, the plant breeder has wider opportunities of collecting information than the geneticist, and it is very much in his own interest that he should study and publish all relevant data that may be gathered from his material.

(b) *Inheritance of disease resistance* :—

Few problems are of such direct interest to the plant breeder as the genetic analysis of disease resistance. Fusarium wilt (Fahmy 1931-34, Ware 1932, McRae 1922-23), Blackarm disease, (Stoughton 1928), aphid attack (Burt and Haider 1921), etc., are among the more serious causes of damage to the cotton crop. Fahmy (1931-34), has carried out an extensive investigation on the inheritance of resistance to wilt disease of cotton. He started with the hypothesis that the inheritance of wilt resistance was controlled by a single factor pair. Even in his first paper, however, he reported results which were in conflict with so simple a theory, and in his later publications he assumed multiple factor inheritance. Understanding of his results and their genetic interpretation is somewhat hampered by misleading use of the term heterozygous. It is essential to remember that "heterozygous" defines the genotype, and not the phenotype. Fahmy's writings give the impression that he regarded as heterozygous any plant the progeny of which gave under controlled conditions more than one type of reaction to wilt infection. While heterozygotes will usually give offspring showing more than one type of reaction to wilt infection, similar results can quite easily be obtained in progenies homozygous for a group of factors which confer resistance but not immunity.

Conclusive evidence of the insufficiency of the single factor hypothesis to explain the behaviour of a wilt immune \times wilt susceptible cross is given by Fahmy (1934) in his Table IX. On the single factor hypothesis, the resistant and susceptible plants

occurring in F_2 and later generations should be simple recessive (differing, presumably, in minor factors), and should therefore give no "immuneness" among their progeny. Fourteen F_4 families were raised from resistant plants in F_3 families which segregated in a manner similar to the F_2 . In only one family were there no "immune" plants, and in six of the fourteen, over 50 per cent of the plants were "immune."

A simple scheme can be devised on the multiple factor theory of inheritance which will cover satisfactorily all available data. In Fig. I is a diagram illustrating a linear relationship between number of genes (assumed to be of equal value and to show no dominance) and the phenotype resistance of the plant. There are assumed to be ten factor pairs for resistance, giving a maximum of 20 genes in the homozygote with the greatest resistance. The extent of resistance is plotted on a scale with unknown units from 0 to n , since the only available estimate of resistance is percentage of "immunes" which depends on the conditions of infection. Accordingly, four scales of percentage "immunes" are included for different intensities of attack. The first is for where infection is absent, and naturally gives 100 per cent "immunes" at the base line (no resistance). The second (normal field virulence) is taken to represent normal virulence in infected fields, and for the sake of illustration it is assumed that plants carrying eight genes will be "immune" to attacks of this intensity. Below eight the percentage of plants apparently "immune" is assumed proportional to the number of genes present. Plants with more than eight genes are assumed "immune" in all cases at this level of virulence. Plants with 12 or more genes are assumed to give 100 per cent "immunes" under conditions of heavy plot infection, and with 16 or more genes under the most virulent conditions obtainable, and similar scales are plotted for these levels of infection. Then the percentage of "immunes" in a population of plants carrying a given number of genes can be determined by drawing a horizontal line from the point on the resistance line corresponding to that number of genes. The points where it cuts the immunity scales will then give the expected percentage of "immunes" under the corresponding infection conditions.

Though such a diagram is no more than a very much over simplified illustration of the type of behaviour which may be expected, it illustrates satisfactorily the main points to be noted in the available data concerning the genetics of wilt resistance. The first point to note is that plants carrying more than 16 genes for resistance have a margin of safety under all conditions, and if, for example, there were 16 factor pairs for resistance, the F_1 between the complete dominant and the complete recessive would be 100 per cent "immune," even in the absence of dominance. Secondly, within such a framework gene systems can be devised which will give 100 per cent immunity in the F_1 of an immune \times susceptible cross, and 75 per cent immunes : 25 per cent resistants + susceptibles in F_2 without in any way conflict-

ing with the interpretation of the multiple factor-inheritance observed in crosses between resistant and susceptible. Moreover, it will now be clear why it is not possible to say from the behaviour of a progeny whether the parent was homozygous or heterozygous. A plant carrying 10 genes for resistance may be a 5×5 homozygote, or any kind of a heterozygote up to 10×0 . If it is a homozygote, among its progeny grown under conditions of maximum virulence, 62.5 per cent will be "immune." The distribution of the number of genes for resistance per plant in the offspring of a 10×0 heterozygote can be obtained from the binomial distribution $(\frac{1}{2} + \frac{1}{2})^{20}$,²⁰ and is given below. The percentage of "immunes" under conditions of maximum virulence is given for numbers of genes from 0 to 20 in the third column below, and in the fourth column is given the contribution of each class to the "immune" component of the progeny. These are obtained by multiplying together the figures of the second and third columns.

Number of genes.	Frequency.	Per cent. of "immunes."	Contribution to progeny "immune" class. (%)
0	0.0000	0.00	0.00
1	0.0000	6.25	0.00
2	0.0002	12.50	0.00
3	0.0011	18.75	0.02
4	0.0046	25.00	0.11
5	0.0148	31.25	0.46
6	0.0370	37.50	1.39
7	0.0739	43.75	3.24
8	0.1201	50.00	6.00
9	0.1602	56.25	9.02
10	0.1762	62.50	11.02
11	0.1602	68.75	11.01
12	0.1201	75.00	9.01
13	0.0739	81.25	6.00
14	0.0370	87.50	3.24
15	0.0148	93.75	1.39
16	0.0046	100.00	0.46
17	0.0011	100.00	0.11
18	0.0002	100.00	0.02
19	0.0000	100.00	0.00
20	0.0000	100.00	0.00
	<hr/>		<hr/>
	1.0000		62.50
	<hr/>		<hr/>

In all, 62.5 per cent of the progeny will be "immune" which is exactly the same as if the parent were a 5×5 homozygote. A similar calculation shows that if the plant were a 6×4 heterozygote the percentage of "immunes" in the progeny would be 50.75. Only by growing a group of F_3 progenies will it be possible to decide whether the original plant was homozygous or heterozygous. In the former case, the F_3 families will form a homogeneous group with approximately 62.5 per cent "immunes" in each family. In the latter, they will be heterogeneous, the percentage of immunes depending on the number of genes for resistance carried by the F_2 parent.

It remains to comment on the interpretation of partial failure of "immunity" in homozygotes exposed to infection under conditions of maximum virulence. It is often argued that if conditions of maximum virulence are ensured genetically, immune plants will survive and all others will succumb. The illustrations given above are based on the assumption that even under the most virulent conditions a "proportion of a group of plants homozygous for partial resistance will be apparently immune." This appears to be a reasonable expectation, and one that can be fairly easily checked. It is well known that even with the most uniform genetic material and the most favourable environmental conditions, fluctuation still persists in all plant characters, and it is only reasonable to suppose that where genotypic resistance and disease virulence are delicately balanced, small differences in, for example—seed weight in the host or strain virulence in the fungus will tip the balance between immunity and breakdown.

It may be noted that some evidence has been obtained of correlation between wilt resistance and plant characters. Ware (1932 a) found susceptibility associated with earliness. Ansari (unpublished data) in cotton wilt studies at the Institute of Plant Industry, Indore, found strong correlations between certain root characters and percentage of survivors in the substrains of Malvi 9. The progenies with a higher percentage of survivors had (a) greater number of laterals and (b) longer and thicker laterals throughout the length of the tap root, particularly in the upper region. Such knowledge is of value in facilitating selection for wilt resistance.

(c) *Back-crossing.*

The principle involved in the use of the back-cross technique is the simple one of reducing the amount of genetic variance in the material in which selection is to be practised. It is of value when it is desired to breed a strain deriving a great preponderance of its genotype from one parent, and only a small proportion from the other.

There are two main applications of the back-crossing technique. One is in intervarietal crosses, when it is desired to improve one strain by the introduction of one, or a few genes, from another. The best example is that given by Evelyn

(1934a) of the transference of red plant body from the perennial Red Kidney to the annual Sea Island V. 135. The second is in interspecific crosses, where the enormous variability of F_2 and later generations reduces almost to nothing the chance of obtaining balanced, vigorous, stable types. In such cases Harland (1934b) has shown that single genes or small groups of genes can be transferred from one species to another by back-crossing without serious disturbance of the specific balance.

(d) *Pure Lines.*

In cotton attainment of 'pure lines' is a difficult task. The recent improvements in plant breeding technique have shown that the so-called "pure lines" respond to selection.

In V. 135, pure for 59 mm. lint length, a strain resistant to Angular leaf spot disease was evolved and the mean number of bolls per plant was raised from 50 to 70, without impairing the length and quality of the lint (Evelyn 1934b). Another instance of the effect of selection in a strain selfed for several generations is provided by Malvi 9 at Indore, in which the mean number of bolls per plant of the selected progenies was significantly higher than of all the progenies examined in the same year. Vigour in Malvi 9 and ginning percentage in Malvi 1 are other characters which still respond to selection (Hutchinson and Kubersingh 1936).

The exploitation of the potential response of a population to selection depends on the efficiency of the technical methods employed. If the methods applied are not sensitive enough much of the genetic variability may remain undetected. That is what happened in Malvi 9. There was a large amount of genetic variability available in 1923, for characters on which selection was being practised. It was not exploited and remained undetected until more sensitive methods were adopted in 1934-35. Much of it was lost from within families by increasing homozygosis.

(e) *Acclimatization.*

Modern genetics has shown the importance of genetic variance in successful acclimatisation. Much of what is usually called "new place effect" is change by selection in residual variance present in what may have appeared to be a "pure" strain. This residual variance is ascribed to heterozygosis in factors of no selection value in the environment from which the strain was brought. Student (1934) believes that a type having only a limited genetic variation may with change of environment be changed very considerably by selection. The history of the introduction of American cotton into India and Africa (Harland 1932d) clearly demonstrates the inadequacy of this residual variance in fairly pure commercial varieties to allow of adaptation to a large change in environmental conditions. Almost all successful

few world types in Africa and India are descended from introductions made before American varieties were stabilized and purified when their genetic variance was sufficiently great to allow of very considerable adaptive changes. Fresh introductions into new areas should consist of variable material from near the centre of origin of the type or hybrids made with the definite object of providing a large amount of genetic variability.

IV. INTERSPECIFIC HYBRIDIZATION.

Opinions differ regarding the utility of interspecific hybridization from the economic point of view. It is claimed by Russian workers (Vycotskii 1930, Vycotskii 1932, Kanash 1932) that interspecific hybrids particularly between Upland and Egyptian cottons offer great possibilities. Harland (1934b) came to the conclusion that even the best of the Upland and Egyptian hybrids were seldom as good as either parent. It is now realised that much fundamental work in genetics has to be done before the value of interspecific hybridization to practical plant breeding can be realised. Part of the difficulty felt by cotton breeders in dealing with interspecific hybrids lies in the fact that very little work had been done until recently to indicate the degree of genetic relationship between the various species.

(a) *Genetic concept of the species.*

The work of Harland (1932a and 1936a) is of particular importance in this connection. The transference of genes between different species of New World and Old World cottons carried out by Harland (1934b) and Hutchinson (1934a) respectively lend support to the view that specific differences result not from differences in any particular factors but from differences in average gene content and that the latter must be in dynamic and not in static equilibrium. The individual genes drift into or out of the species according to their selective value relative to the genotype as a whole and to their mutation pressures (Hutchinson 1934a).

(b) *Species crosses and polyploidy.*

The wide distribution of the genus *Gossypium* under diverse cultivated and wild conditions in different regions of the world has necessarily resulted in the evolution of a number of species, the mutual relationships of which may be anything from close to very remote.

More closely related species cross with each other with facility while the others either fail to cross or give sterile hybrids.

Fertile crosses : The Old World cultivated species *G. arboreum* and *G. herbaceum* hybridise freely with each other and yield perfectly fertile hybrids.

Similarly the New World cultivated species *G. barbadense*, *G. hirsutum* and *G. religiosum* inter-cross with ease and the hybrids are fertile.

The cultivated American species cross freely and give fertile hybrids with the 26 chromosome wild species, *G. tomentosum*, *G. Darwinii* and *G. taitense*. They hold out the possibility of the introduction through back-crosses, of genes for hardiness and disease resistance into the cultivated New World types.

Sterile crosses: Apart from the interspecific crosses mentioned above species crosses in the genus *Gossypium* were regarded as perfectly sterile. Recent work, particularly that of Harland (1932 and 1935) and Skovsted (1935), has shown that many other interspecific crosses are partially fertile.

Crosses between Asiatic cultivated species × American cultivated species have been made: Zaitzev (1922-23), Desai (1927), Nakatomi (1931), Longley (1933), Patel (1933), Kanash (1932) and Feng (1935). Their hybrids were sterile. Harland (1932c and 1935) obtained two hybrids between *G. barbadense* and *G. arboreum*. One had 52 chromosomes while the other had 39. The former was sterile but the latter gave some good pollen which was used to cross back to the American parent. By this process of back crossing to the New World species he obtained plants with chromosome numbers varying from near 52 to 65. Many of the forms so obtained were sterile either on the female, the male or both sides. The fertility of the progeny increased with further back-crossing so that in the fourth back-cross selfed progeny all the plants were fertile and were by then stabilised on the 52 chromosome basis. By this process of repeated back-crossing Harland was able to transfer the Asiatic gene R on to the American background and found that it is a member of the spot allelomorph series of the latter.

Thus the above work has demonstrated the possibility of introducing an Asiatic gene or a part of an Asiatic chromosome into an American cotton.

Hutchinson (Skovsted 1934a) successfully crossed the Asiatic species *G. arboreum* and *G. herbaceum* with the wild African species *G. anomalum*. These hybrids have been successfully back-crossed repeatedly to *G. arboreum* with the result that balanced fertile types have been evolved. These show certain *anomalum* genes on the *arboreum* background.

Skovsted (1935) points out that the following hybrids between New World cottons ($n=26$) and three wild American 13 chromosome species have proved sufficiently fertile to afford material for the use of practical plant breeders:

$$\text{New World } \times \begin{cases} G. aridum & n=13 \\ G. Armourianum & n=13 \\ G. trilobum & n=13 \end{cases} \\ (n=26)$$

These partially fertile interspecific hybrids offer the chance of introducing xerophytic habit and capacity for disease resistance into the New World cultivated group.

Completely sterile crosses: Leake and Prasad (1914a), Afzal and Trought (1933), Hutchinson (1932, 1934) have reported that hybrids between the cultivated Asiatic species of *Gossypium* and *G. Stocksii* a wild species from Sind were perfectly sterile.

Skovsted (1935) has explored extensively the possibilities of species hybridisation in the genus. All interspecific hybrids which he tried other than the ones mentioned above were perfectly sterile, died in the seedling stage, or were impossible to obtain.

Polyploidy: The occurrence of sterile hybrids opens up another field of activity for an optimistic plant breeder. The rare occurrence of a tetraploid by duplication of chromosomes in experimental cultures has been observed in other crop plants. Cotton breeders may look upon the sterile hybrids as precursors of the amphidiploid forms that may originate from them.

The role of polyploidy in plant breeding must be viewed with caution. There is no doubt that polyploids in some crop plants are distinctly better than diploids and that a true breeding type of cotton with a higher chromosome number than the normal may prove useful. But it will not necessarily be so. The best that can be said is that an attempt at polyploidy is a shot in the dark.

V. DISCUSSION.

In the preceding pages the contributions of theoretical genetics to the equipment of the cotton breeder have been summarised. It is now necessary to discuss the more general bearing of genetics on the control of plant breeding material. In breeding work the control of variability is the main factor. To quote Hutchinson (1934a) "where there is no genetic variability there is no gain to be made by selection and conversely where there is considerable genetic variability the risk of deterioration is always present." This variability is not made up of large and easily identified gene differences and the geneticist has so far contributed little to an understanding of the laws of its behaviour. Fisher (1930) has established the fact that the fluctuating variation usually associated with the inheritance of quantitative characters can be satisfactorily explained by the Mendelian laws. He has further shown that "the greater part of the variability which provides the material upon which natural selection and the human breeder work should be made up of the contributions of gene differences of small individual magnitude." Fisher and his co-worker (1932) have discussed the statistical methods by which the evaluation of genetic

variance and the extent of dominance and the estimation of the number of genes concerned in the inheritance of a particular character may be attacked. That is all that has been done in this direction, but even at this stage the plant breeder can obtain guidance. The possibilities of selection are directly proportional to the genetic variance of the material and therefore care should be taken to conserve the variance until the mean value has been raised to the required value. Much valuable material has been lost by the misguided selection of lines with low variance and it is rather fortunate that the attainment of a "pure line" is a difficult matter.

The phenomenon of dominance enters as a complicating factor in plant breeding work, reducing the efficiency of the breeder's estimate of the genetic value of an individual. Associated with this is the problem of hybrid vigour. In cotton hybrid vigour or deterioration as a result of self-breeding is only important in interspecific crosses. Two theories have been put forward to account for hybrid vigour (1) that it is due to the accumulation of a large number of dominant vigour factors in a single heterozygote and (2) that it is due to the fact that in general the heterozygotes of vigour factors are more vigorous than their corresponding homozygotes. The relative absence of hybrid vigour in cotton as compared with other plants may be the consequence of the absence of dominant factors (Hutchinson 1934a). A proper understanding of it is of great importance if interspecific hybrids are to be exploited successfully in breeding work, and the problem merits the close attention of geneticists.

The analysis of the cotton crops of the Malwa and Nimar tracts of Central India recently carried out by Hutchinson and Ghose (1937) opens up further possibilities of improvement in plant breeding efficiency. They have extended the study of genetic variance to include an investigation of the influence of two different environments on the relative frequencies of the main crop constituents, and have shown that a crop survey is likely to provide extremely valuable evidence concerning the types best suited to a particular tract. In opposition to current plant breeding policy, which favours *Verum* strains for the production of quality cotton in the Central Provinces and Khandesh, they concluded that selection should be carried on in the *Malvense* component of the Nimar crop, and the *Verum* component should be discarded on account of its low survival value. In Malwa their analysis revealed serious errors in the current estimates of the composition of the crop, and demonstrated the powerful effect of natural selection in maintaining the crop composition against the pressure of the introduction of *Roseum* seed by human agencies. The value of such information for the planning of breeding work was recently demonstrated when a scheme for the improvement of the *Dholleras* cottons of Western India was drawn up on the basis of information gathered in the course of crop study tours in the *Dholleras* tract.

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SUBJECT—4. Inheritance of Wilt Resistance in Indian Cottons.
Questions arising out of the Plant Breeders' Conference held in August, 1936.

DISCUSSION.

Dr. Uppal opening the discussion said that the subject of cotton wilt breeding had aroused a certain amount of controversy as regards the best method of selection for wilt resistance, although it appeared from the lucid note of Mr. Hutchinson that the points of difference were not fundamental. This controversy originated as early as 1929 when the question of formulating a general policy for breeding for wilt resistance was discussed in a Conference of officers of the Bombay Agricultural Department held at Poona. There were two divergent points of view, and by mutual agreement Dr. Burns and the speaker referred this matter to two scientific workers, one a geneticist and the other a plant pathologist. Both these scientific workers had themselves done a considerable amount of work on breeding for disease resistance, and in one case on wilt resistance in particular. Both these workers expressed themselves generally in support of the speaker's (Dr. Uppal's) point of view. In the meantime he was called upon to breed sann hemp for wilt resistance, and wilt in sann hemp was caused by the same fungus as in cotton. Using the technique developed in connection with sann hemp wilt which he would describe further on, he obtained a new variety of sann hemp immune from wilt. In 1931, he was engaged on cotton wilt breeding work and two years later, thanks to the Imperial Council of Agricultural Research and the Indian Central Cotton Committee, he had an opportunity to study firsthand the same problem in Egypt, and the associated work on cabbage, peas, etc., in the United States.

*A wilt in cotton was caused by *Fusarium vasinfectum*, a fungus which leads a saprophytic existence, but on the return of favourable conditions resumes parasitic activity. This was a fundamental conception in plant pathology and on this basis his whole technique was based. This conception had been very vaguely understood with the result that there was much confused thinking as to what really wilt resistance was. Wilt resistance was affected by two important factors, one was the degree of soil infestation by the parasite and the other was the soil temperature. Assuming that there was a uniform soil infestation by the parasite under unfavourable temperature conditions, a temporary resistance in plants of susceptible varieties might be brought about almost resembling the resistance shown by an immune variety. On the other hand, if a susceptible variety was grown in an infected soil under optimum temperature all plants wilted.*

It had been argued that although complete immunity for wilt resistance was an ideal, selection under field conditions was quite satisfactory. He opined that this was based on a wrong assumption since the cotton wilt fungus which, under ordinary conditions lay quiescent in the soil, assumed parasitic activity when environmental conditions were favourable and not otherwise. That meant that the definition of wilt immunity or wilt resistance must give the respective standard environment under

which complete death of the plant could be brought about. The relation of environment to the development of wilt resistance was fundamental to the whole question because resistance assumed a different meaning when standard environment varied. If this was so, then it followed that the field selected strains must vary in their resistance according to seasonal conditions and the amount of infestation of the soil. For example, the resistant strain of pigeon pea developed at Pusa when tested on Arbhavi Farm suffered mortality up to 30 to 40%, showing thereby that environmental conditions and infestation of the soil at Arbhavi were quite different from what the conditions were at Pusa. It appeared to him that it would not be possible to distinguish a really resistant from an apparently resistant strain unless selection for wilt resistance was done under standard conditions of environment. It was very important to have a standard technique under which selection for wilt resistance could be done so that these results could be compared at all times. Another important matter was in relation to the air temperature; the plant which was susceptible might pass off as a resistant plant under adverse temperature conditions. Still another factor involved was the genetic variability of the parasite. It was found, however, that there was no evidence that the causative organism showed selective pathogenicity and this simplified the breeder's work of selection.

Passing on to his method of testing, he said that there were three stages. The first stage began with the selection by the cotton breeder of strains which were wilt resistant and agriculturally desirable in other respects. The satisfactory strains were then passed on to him at Poona where these strains were tested in a series of soil temperature tanks and in glass-houses under optimum conditions. The progeny of each resistant plant was then tested separately in infested soil in small tubular pots, each pot containing not more than two or three plants. These were kept for 45 or 50 days under conditions of optimum infection, and any plants showing wilting or clearing of leaf veins or mottling were pulled out. Only those plants which did not show any symptom of wilt either in the form of death or of mottling of leaf veins were transplanted in a uniformly wilt infected bed. By this process he had isolated a new and very highly resistant strain after one year's work from highly resistant material selected under field conditions. He said that he had obtained strains which, when tested at Poona in glass-houses, showed very little death. Last year there was hardly 5 to 10 per cent death, though most of the plants showed leaf mottling but such plants were rejected. Out of about 12,000 plants tested this year under these conditions 17 plants which did not show any symptom of wilt had been transplanted and their reaction would be tested next year. If it were found that after a few generations selection was no longer able to modify the character of wilt resistance, the conclusion would be obvious that the genes in the race or strain had become homozygous and no further change was possible. He would then cross with another resistant strain to introduce different genes belonging to the series of multiple factors determining resistance. In this way a large number of genes would be introduced with the result that the

character of wilt resistance would be established on a much higher level than in the parent plants. He would then pass this strain on to the cotton breeder for final test.

Dealing with the genetic basis of wilt resistance he said that resistance to wilt disease was of two kinds. The first type was represented by pea wilt in which the resistant and susceptible plants fell under two discontinuous classes while the second type was more commonly represented by flax wilt. It has been shown that in certain plants like cabbage these two types of resistance were possible, one resembling resistance in peas to wilt, and the other resembling flax or tomato wilt. Whatever be the mode of inheritance of wilt in cotton, he opined that if strains having a wide margin of safety were to be secured, selection must be done under optimum conditions.

Mr. Hutchinson introducing his paper explained that the main idea of the authors in writing this paper was not to provide yet another summary of the present state of Mendelian characters in cotton, but to give an indication of the lines on which genetic work on cotton had been and would be of value to plant breeding.

As regards the inheritance of quantitative characters he emphasised that, in so far as characters which were of vital value to plant breeders were concerned, such characters were expected to be controlled by a large number of genes of small individual effect with cumulative action, and it would not be possible to get large jumps. A point of fundamental importance was that the theoretical geneticist was tempted to go off on simple genes that worked out very easily. He thought that it was partly due to the fact that those who rediscovered the Mendelian theory were not mathematicians and that they consequently stuck to things which minimised mathematics in genetics and were unconsciously tempted to overlook the fundamental aspect of the Mendelian theory, viz., that it is an application of statistics. He continued that it was no good being an economic geneticist if statistics were to be avoided. It was found in nearly all cases that the characters concerned were controlled by a large number of factors of small individual effect and it was not possible to identify them. He thought that it would be no good to have a complete chromosome map of cotton. If, however, the location of every gene in the whole chromosome map affecting the plant was known, it might be impossible to sort them out at one time. If it was not possible to sort them out, because of their smallness in relation to the environmental variation, it was no good to spend time on trying to deal with them one at a time. The laws of mass action on genes should be understood and it was only by the application of such laws that genetics could be applied to plant breeding. One such law was obviously the law of linkage. When many genes were concerned they must be grouped into 13 independent groups; and within those groups there was no genetic independence. The main thing being investigated at the moment at the Institute of Plant Industry was to study the genetic variance or the magnitude of the variability on account of genetic causes. Another fundamental part of the work was to sort out the genetic part of the variability from the environmental part as uniform conditions

could not be obtained. No accurate methods of determining whether there was any genetic variability remaining in pure strains were available. If there was genetic variability the strains would respond to selection and if there was no selection they might deteriorate. That this was a real economic menace was shown by what happened to the West Indian Sea Island strains when the control by the Imperial Department of Agriculture was relaxed. In four years the Sea Island cotton was considerably deteriorated and the types of cotton became unsaleable in the market, and that was due to internal genetic deterioration. It took about two years to get it back again and this showed the rate at which deterioration set in in comparatively pure strains. It was desirable to be able to determine the magnitude of the genetic variation both from the point of view of safety to avoid possible deterioration and also to determine whether further selection could be attempted. No answer could be given to the question whether selection should go on further unless it could be determined whether genetic variability which would give the possibility of improvement remained in the strains or not. Another thing in which the study of genetics had been of great importance in cotton breeding was the study of the species as related to genetics. It was only possible by breeding and hybridisation to see what the genetic relationships were between the different forms of economic crops, and it was necessary to supplement the economic classification with the genetic classification. He thought that in that respect cotton was far ahead of most other crops, and more was known about genetics of cottons than of any other tropical crop. Largely as a result of Harland's work in the West Indies it has been possible to build up a scheme for the re-classification of the genus on grounds which would give confidence to the plant breeder in his choice of material or crossing within different species. He said that so far as he was aware there was no well-authenticated case of success in crossing what were known as genetically different species. It was known that crosses between Uplands and Egyptians had always failed. The Russians claimed considerable success in this direction, but Harland differed. There was evidence which showed that success could only be attained by a very special technique of regular back-crossing gradually to get a few good factors from one species attached to the genotype of the other. If interspecific crossing was to be tried it had to be first decided as to which species were to be improved, and the amount which would be brought in from the other species should also be reduced to the minimum.

Coming to the problem of wilt resistance he said that there was no great fundamental difference between Dr. Uppal and himself. Dr. Uppal's opinion was based on the fact that genetics had shown that in some cases wilt immunity behaved as a unit character, but the figures for cotton did not support it. If single factor inheritance were to be demonstrated only one type of behaviour should occur. If three dominant genes were present the behaviour in F_2 might be very likely single factor segregation. In F_3 of the immunes, one-third must breed true, and two-thirds must segregate in one ratio, viz., the F_2 ratio. From Fahmy's data it would be

seen that the ratio in segregating F_3 varied from 5 to 95% immunes. As far as the fundamentals of this problem were concerned, he said that it seemed to him that there were two needs, the first was to determine whether the material was homozygous, and the second was to set up standards of testing. As far as homozygosity was concerned, it was quite possible that a strain might be homozygous which would accord a certain amount of wilt susceptibility, either on Dr. Uppal's classification of anything which showed any discoloration or in a classification of plant which died of wilt. It was worthy of consideration whether for commercial purposes, strains which were homozygous for complete immunity from wilt even under the most rigid conditions of weather should be aimed at. If B.D. 8 which was highly resistant, proved to be homozygous even with the most rigorous selection, it would not be possible to get beyond 5% discoloration. It appeared to him that it was not necessary to inter-cross the various strains of B.D. 8, because for all practical purposes and under commercial conditions the strain would serve the purpose well. One more point of importance was that interdependence had been shown between wilt resistance and commercial characters, and therefore it was said that it should not be difficult to breed the commercial characters and wilt resistance in one and the same strain. Supposing there were ten factors for wilt resistance and ten factors for staple length, only one in a million could combine all these factors. He said that it was just from that point of view of the overwhelming difficulty of successfully introducing all the factors into one type that he was emphasising the fact that these strains with 5% mortality, provided they were homozygous, would suit very well. He continued that one of the things that this Conference might very well recommend to the Agricultural Research Sub-Committee was that strains should not be distributed until some test had been made of the homozygosity for wilt resistance. It was interesting to know that though the Bombay Department of Agriculture was all for immunity, the Department actually practised it by breach. The Department had put up a scheme for the extension of a resistant strain and presumably the Department was of the opinion that the resistance of the strain which was one of its most important characters, would be retained. He expressed the hope that it would be possible for Dr. Uppal to improve that strain and get it immune. In the meanwhile provided that 'Jarila' cotton was practically homozygous for wilt resistance, it might be extended by all means. Taking 25 single plants of 'Jarila' some having shown discoloration in roots and others having shown complete immunity, if these were grown in replicated plots in highly infected fields and if there was a difference in heterozygosity, different proportions of infection in different plants would be obtained. He wanted to emphasise that it was a matter of standards of comparison. It did not matter very seriously how intense the wilt infection was. If wilt infection was high and uniform, it was not necessary that it should be optimum, because there was every reason to believe that strains which succumbed to a certain extent under one condition would succumb more under more intense conditions. Provided the resistance was sufficient for commercial purposes, the plant might be regarded as a commercial

proposition. Where pure sulphuric acid would be preferred, in very many cases commercial sulphuric acid, 95% pure, would be acceptable; similarly in the case of wilt resistance, 95% would do provided there was no breaking down. In the Central Provinces strains had maintained high resistance for a number of years. He thought that Dr. Uppal's standard of comparison being a plant pathologist's standard under optimum conditions of infestation, was definitely the best, but it was a more expensive standard of comparison than the standard of comparison of the behaviour of a susceptible strain in alternate rows. What he wanted to emphasise was the need for standards of comparison in such wilt breeding work under field conditions. Another point of Dr. Uppal was that the Type 80 developed at Pusa, suffered from 40 to 60% mortality from wilt when tested in wilt sick soil at Arbhavi Farm in Bombay, wherefrom he (Dr. Uppal) had concluded that it must have been a mixture. The speaker disagreed and failed to see how it could be a mixture as under different environments it behaved differently. Environments changed and it was not necessary to presume that the genotype was not pure. The cultivator could be benefited by getting strains which were completely immune, but the first stage was the most valuable one. An extra 5% would not make a great difference. The reason for having an extra 5% was that there was a risk of the 95% resistant strain breaking down but he thought that this could be overcome by tests for homozygosity. Regarding the remarks of Mr. Kottur about the necessity or otherwise of a central breeding station for distribution work, the speaker understood that Sir Albert Howard was in favour of breeding all cottons at Indore. The speaker was emphatically of opinion that it was not possible. He considered that in these matters it was much more important to know the behaviour of a strain in the area in which it was to be grown than to know what it would do at a central station. The answer to such pleas for a central breeding station was whether it would be possible to specify the conditions and whether they could be reproduced at the central stations. He concluded that it was much easier to go to the place where the thing was to grow and to let nature do its own selections.

Mr. V. G. Panse observed that a new technique was advocated to ensure uniform and severe conditions for testing the material thoroughly. As regards uniform conditions, if progenies were tested in replicated experiments for resistance to wilt and the results showed significant differences in wilt mortality, then possibly they really differed in resistance and there was no danger of disease escapes being multiplied. Therefore, to ensure uniformity, he believed that replicated tests would answer the requirements. The second point was regarding the severity. Dr. Uppal had said that he got only seventeen plants out of several thousands that he tested. The difficulty lay in the fact that commercial characters were as important, or more important in certain cases, than a 100 per cent wilt resistance. Regarding the Central Provinces and Jalgaon strains, it was quite plain that their mortality in their native tracts had never exceeded 6 or 7% and he believed that such

strains were economically more valuable than any 100% immune strains with inferior commercial characters. The fact that these strains broke down at Indore or other places did not decrease their value in their areas, because the environmental complex differed in different tracts.

Rao Saheb G. L. Kottur said that field selections were supposed to be temporarily resistant, but he had obtained a dozen wilt resistant selections in about 12 years which were being tested for wilt resistance at Dharwar and none of them had broken down in resistance. They showed a resistance of 95 to 99%. It was therefore sufficient to say that even when field selections were made it was possible to get homozygous strains which would retain their wilt resistance. Another point was that the selections made in the Central Provinces and other places broke down when transferred to different places. He had obtained selections made in the Central Provinces and Broach and when they were tested at Dharwar for a number of years their behaviour was not much different from their original places. As regards field selections, in the beginning he obtained Verum 262 which was not as pure as it ought to be. Continuing he said that he made 24 selections out of which two showed more wilt than the others. There was a serious situation of wilt when distribution was begun in Southern Mahratta Country and there was some hesitation in taking a cotton which was not wilt resistant, but later on the cottons proved successful. About the standard of selections, it appeared that Dr. Uppal rejected all plants that showed mottling. The speaker had selected strains in pot culture which showed mottling, but at a further stage two strains were resistant. To find out the resistance the fungus should enter the plants and the plants should be able to stand them and kill the fungus. Some strains that were tested showed the entry of the fungus but the latter was not able to do any damage to the plants. Dr. Uppal had given stages for the selection of the material to be supplied by the breeder and that material should be evenly selected. The breeder would ultimately have to take to crossing, though all the stages to be followed when crossing had not been given. At any rate to combine all the characters of wilt resistance was a very difficult and expensive proposition.

Mr. Ramiah said that after listening to Dr. Uppal and Mr. Hutchinson, as a breeder with some experience he had to admit that the ideal immunity which Dr. Uppal was trying for was the thing to be worked up to. But breeders could not ignore the possibility of utilising the field resistance in the available material. Speaking from his experience with another crop, rice, he said that even the genic composition with regard to the resistance to certain fungus seemed to vary with different varieties. When an apparently susceptible variety was crossed with different resistant types, the results showed that the inheritance of resistance was simple in some and complicated in others. That showed the ideal form of breeding immune types would prove rather a laborious process. A particularly apparently immune type which might be bred in one tract might fail under different conditions. He suggested, as a sort of compromise, whether it would not be possible to improve the conditions of suscep-

tibility even under field conditions, i.e., making the conditions not so rigorous as could possibly be managed in a laboratory under ideal conditions, but certainly more rigorous than what was usually obtainable in the field. He instanced a particular form of providing conditions favourable for the plant to get the infection evolved in consultation with the Mycologist in Madras. The method consisted in surrounding each progeny with infected material and also spraying the progenies of crosses with spore suspensions at different stages of the crop so that the progenies that stood out absolutely resistant until the end might be selected. The result was that within the short period of 8 or 9 years it was possible to isolate absolutely resistant forms not only under the conditions they were bred for but also in different parts of the province. The particular disease he was referring to was **Picularia Oryzae**. Summing up he said that though the breeding of immune strains under ideal conditions might be a thing to be worked for, he felt that there was a definite case for making use of the field resistance which breeders came across.

Mr. Dabral wished to know whether under standard conditions immunity was tested in getting the fungus into the plant or into the soil only as real immunity was obtained when fungus got into the plant and then died or became ineffectual.

Mr. Wad queried as to what was the difference between resistance and immunity. Whether it was the ability of the plant to escape from the fungus, since if the fungus could enter the plant it seemed to be merely a difference in degree.

Rai Sahib Kalidas Sawhney, referring to **Mr. Ramiah's** point that in the field it might be possible to produce artificially rigorous conditions than were ordinarily met with, instanced a case of the importation of seed of a wilt resistant type from Jalgaon. It so happened that one portion of the seed was sown in the open in a wilt infected plot and the other portion under a tree in the same plot. The plants growing in the open showed a high resistance—their survival being 90 to 95%, while the plants under the shade of the tree succumbed to the extent of 15%. Further selections had been made from the plants surviving under the tree. Their resistance to wilt under similar rigorous conditions in the field will be studied in the next season in order to find out whether by this means it is possible to evolve a strain showing greater resistance than the parent which was itself fairly resistant to wilt.

Mr. M. L. Patel said that **Broach Desi 8** was selected as early as 1926. The breaking down of the plants due to wilt attack referred to by **Dr. Uppal** was due to the impurity of the seed and not due to the breaking down of wilt resistance. Cultivators imported seed illegally from the north of the river Nerbudda from the crop of the cultivators ginned in factories; when it was first tested by the Agricultural Department for wilt resistance, it showed high wilt resistance.

Mr. Ramanatha Ayyar referred to the tests carried out in Madras on wilt resistance in gram. The method consisted in sowing in each hole 2 seeds one from the

susceptible and the other from the standard strain having a different morphological character from the susceptible type and comparing the death rates. This method afforded an easy way of comparing two varieties under uniform conditions of infection.

Mr. Ansari thought that Dr. Uppal was not against testing under field conditions and he had gone a step further in making selections under optimum conditions, and one important objection to that was that a lot of valuable material was lost while testing under optimum conditions. In the second sentence of his paper Dr. Uppal mentioned that "whilst cotton wilt has been shown to be due primarily to the parasitism of this fungus, the fact that severely diseased zones in a field shift in location from one year to another clearly indicates a relationship between the disease and environmental conditions, and the paramount importance of these factors in determining its severity." His own experience at Indore was that in the same field in the same zone a greater intensity of wilt attack was observed than in other zones from year to year. Again, Dr. Uppal had stated that he grew in 1935-36 what were found best in 1934-35 but it was not understood why he had taken cultures B.D. 8-14, B.D. 8-31, B.D. 8-43 and B.D. 8-44 when he had better ones in B.D. 8-8, B.D. 8-25, B.D. 8-16 and B.D. 8-24, which certainly showed greater resistance.

Mr. Andrews said that the work that Dr. Uppal was doing was undoubtedly the ideal to aim at. He thought that the method of field selection should, however, be carried on until satisfactory results had been obtained by the longer and more efficient process of Dr. Uppal. Field selection would provide for a particular district, strains that were wilt-resistant and satisfactory from the cultivator's and millowner's point of view. From these field selections, Dr. Uppal could then, by his special methods, select strains that would be immune under any climatic conditions.

Dr. Badami drew attention to Dr. Uppal's selection B. D. 8-6 which had no deaths as pointed out on page 6 of the paper, to further selections which gave mortality up to 87% as given on page 17, and still further selections which gave 97 to 100% mortality as mentioned on page 10, and said that from these statements he gathered that while trying to select plants resistant to disease only Dr. Uppal seemed to have selected plants that had escaped attack; out of the large number of plants selected, only 17 plants were taken, and B.D. 8 and its progeny might altogether get wiped out in the process. Similarly in one or two years more the other strains also might disappear and in the course of four or five years and after spending so much money under ideal conditions the work might have to be started over again. On the other hand what Mr. Hutchinson said was to let nature do its own selections, which was practically ideal. In Mysore work was started on five typical commercial varieties which were planted on latin squares. If immunity ratio was adopted it might vary from year to year, but the link was practically the same and the variation of wilt attack was from 5 to 95%. Some of the varieties were supposed to be very

good from a commercial point of view and crosses were giving very interesting results. He suggested that for the present breeders might get on with their work on selections which were not highly susceptible. That was, in his opinion, more useful than undertaking problems of an academic character.

The President observed that the outcome of the discussion went back to a letter from Mr. Hutchinson in which he had brought to the notice of the Indian Central Cotton Committee that there were certain different points of view in regard to breeding for wilt resistance and that work could be done from both the standpoints. There had been a considerable difference in the two points of view but the discussion had led to a point which had very much in common. What the Indian Central Cotton Committee wanted was a sort of statement as to where they stood from the point of view of theory as far as experimental evidence went at present, what were the sound lines to follow with regard to work in future, and whether the question was of breeding for 100% resistance in the most rigid conditions. The theory bore on a good deal of breeding problems and if from the final remarks of the two speakers a statement of the Committee's position could be got, he thought it would be very helpful indeed, not only with regard to wilt resistance but also with regard to the position generally.

Dr. Uppal dealing first with Dr. Badami's point regarding mortality of plants, said that all the experiments of 1934-35 were not made under standard conditions and his work began from the last season only. Whether field selection was a desirable test or not, was an important point generally expressed. He did not deny the desirability of field tests at all. Field selection was the basis of his own test. Without field selection all the plants would die in pot culture and he, therefore, built up their resistance under slightly more rigorous conditions. When a strain had attained a certain amount of resistance which was high enough, he went up a further stage and tested it under environmental conditions which he could regulate. Rao Saheb Kottur had certain strains which showed mottling which indicated that fungus had entered the plants, and if those plants were put in his glasshouse they would die. That could not be termed homozygosity. He was 'building up' his strains in pot culture as uniformly and thoroughly as possible. In a year or two, he said, he had selected a strain which was not possible under field conditions, as field selection did not give a sufficient margin of safety. In the case of B. D. 8, he had been able to select a strain from the very highly resistant material passed on to him this year. Seventeen wilt free plants had been selected under optimum conditions from very highly resistant material.

The most important thing to consider was that if the reaction of a particular strain was to be tested against another, the point of what was the standard of field test must be discussed. Testing under field conditions was being done in all sorts of manners and if the standard of field testing was once defined most of the difficulties

would disappear. If rigorous conditions of infection were provided and if the climatic conditions were suitable, any strain that stood up to those conditions was the material with which further work could be carried on. The optimum conditions of field test should be defined. If in a particular region wilt appeared more frequently or in early stages of plant growth, that was the region where test plots should be located.

Rao Saheb Kottur had raised the point that he had got certain strains which stood up to the extent of 99%. Those strains required testing under conditions where there was more uniform and rigorous soil infestation. There were certain regions in the Southern Mahratta Country where plants showed a higher amount of susceptibility and the test plots should be located in those areas. As regards the point that out of 12,000 and odd plants only 17 plants survived and the others died out, he said that all those plants did not die out; actual deaths amounted to 5 to 10 per cent, and the 17 plants were those which did not show even leaf mottling. As a result of the work during the last two years he could not put a strain in the district and in a year more possibly he might get better strains in which the number of plants with leaf mottling would be very small.

With regard to Mr. Patel's query, as to whether the plants showed a high amount of resistance and how far the commercial characters were interfered with, he said that he had not done any work on that problem.

He was thankful to Mr. Hutchinson for enlightening him on the subject. There were certain differences in their points of view which he had tried to reconcile as much as possible, but if Mr. Hutchinson could say that his homozygosity of 80%, 90% or 100% was with respect to a particular environment, then there was no difference between them. If that point was conceded wilt resistance must be talked of as under particular environments and in general environment. When all the strains were tested under a standard environment the maximum number of possible genes would be got and they would determine the character of resistance. He was only trying to improve on the method of field test since field test did not allow him to go further than that at present. If a particular strain survived under most rigorous conditions of infection, it possessed a higher margin of safety when grown under field conditions.

Mr. Hutchinson said that he had a resolution to move and that Dr. Uppal had agreed to second it. The discussion had been extremely fruitful in that they had come to an agreement. He entirely accepted Dr. Uppal's request to define environment for homozygosity. It was generally agreed that 95% resistance meant very nearly immunity. As practical breeders, they should accept 95% resistance provided it was safe. He suggested that strains should be tested and shown to be practically homozygous under the most heavily infected conditions in the field because it was necessary to be safe in distributing a strain. He also suggested that Dr. Uppal might help in providing breeders with highly resistant standards and possibly with a resistant but not immune strain of known behaviour under his own conditions. If he could get

a strain with 80% resistance, it might be a useful standard for breeders in testing homozygosity. That would enable them to tie up the two things together. They could ask Dr. Uppal as opportunity arose to provide them with standard strains against which tests under field conditions could be conducted. That would enable them to standardise the conditions under which they worked. Complementary to the testing for homozygosity it was not reasonable to ask Dr. Uppal to take strains and try and squeeze the maximum immunity into them unless they had the necessary variability to bear the same. He thought that in the resolution it should be put on record that Dr. Uppal was not expected to try and select for immunity in anything unless he could show that there was genetic variability to work with. He moved the following resolution :—

“This Conference agrees that the breeding of strains immune to wilt under optimum conditions is the ideal to aim at. For agricultural distribution, resistance of the order of 95% under heavily infected field conditions is satisfactory, provided that the strain has been tested and shown to be practically homozygous for that degree of resistance to wilt.

The Conference recommends that

- (1) tests for homozygosity should be applied before a resistant strain is released for distribution,**
- (2) the Pathologist should also conduct tests for homozygosity and need only select in material shown to be heterozygous,**
- (3) the conditions under which field tests are being carried out should be described and standardised as far as is practicable.”**

Dr. Uppal seconding the resolution said that there was really very little difference in his point of view and that of Mr. Hutchinson and that he was glad that Mr. Hutchinson had put them in the form of a resolution. If conditions under which field tests had to be done were defined he would have no difficulty at all. He was only concerning himself with strains which showed varying wilt reactions because they were not homozygous.

The President observed that the resolution was for a particular purpose and that the question had been referred to the Conference by the Agricultural Research Sub-Committee. There was no other subject in the whole of the agenda which required a resolution and the resolution in this case was the easiest way of crystallising the general opinion. He regarded it as a very good example of the way in which genetics and plant breeding were helpful in solving a baffling question. In this case genetics had been helped by plant breeding and he would suggest that members might, when they got home, study very carefully the conception of the relative themes which had been put forward so clearly by Mr. Hutchinson and his colleagues. There was one statement which seemed to bear very definitely not only on breeding but on evolution and that was in Mr. Hutchinson's paper on page 12 under 'Genetic concept of the species'; in the last sentence Mr. Hutchinson said that "the individual genes drift

into or out of the species according to their selective value relative to the genotype as a whole and to their mutation pressures." That seemed to go a long way to solve plant breeding problems. It bore upon the distribution of cottons and it was likely to affect the whole of the genetic technique.

The resolution was put to the vote and carried unanimously.

The following note was subsequently received from Mr. Hutchinson:—

A Note on Testing Cotton Strains for Homozygosity in Wilt Resistance.

Cotton plants react in three ways to the attack of *Fusarium* wilt. Some resist so completely as to show no signs of attack whatever. Others are attacked and show such symptoms as mottling of the leaf and discoloration of the vascular tracts of the root and stem, but survive and produce a crop. Others again are killed, death occurring at any stage from the seedling to maturity. Without making any assumptions concerning the relative importance of environment and genotype in determining the reaction, plants may be classified into 'free', 'surviving' and 'killed' according as they fall into the first, second or third of the above classes.

In a constant environment, a pure line would be expected to give only one type of reaction, the type depending on the factors for resistance carried and the virulence of the parasite attack. Unfortunately, the attainment of absolute constancy in environmental conditions is impossible, and all that can be achieved is the reduction of environmental variation to a minimum. There will always remain beyond control such factors as differences in embryo weight and germination vigour, and where the balance between resistance and parasite attack is close, these factors will result in two or three types of reaction even in homozygous strains. It follows that the occurrence of more than one type of behaviour in a progeny is no proof of heterozygosity.

To test for homozygosity it is required to know whether plants in the same progeny giving different wilt reactions differ genetically, or were merely subjected to slightly different environmental influences. If the strain is homozygous, the difference between the 'free' and 'surviving' classes can be due only to environmental causes affecting the virulence of attack, and no significant differences in the proportions of the three classes are to be expected between progenies of 'free' and 'surviving' plants. If, on the other hand, the strain is heterozygous, the 'surviving' class will contain a greater proportion of segregates with few resistant genes than the 'free' class, and in a test involving a number of progenies, those from 'surviving' parents will give on the average a higher proportion in the 'surviving' and 'killed' classes than those from 'free' parents.

It is first necessary for the plant breeder to determine whether his strains are sufficiently homozygous for wilt resistance to be distributed without risk of breakdown, by segregation under field conditions. For this purpose a replicated progeny

row trial (see Hutchinson and Panse, in press*) is the most suitable form of test, and should be carried out under heavily infected field conditions. It may be suggested that if a number of families or sub-strains of the same strain are available, they may be tested in a "compact family block trial" (Hutchinson and Panse, loc. cit.) in the hope of isolating (a) homozygous families which may be bulked for immediate distribution and (b) heterozygous families which will respond to further selection under controlled conditions.

Material selected for resistance under such field tests can be passed on to the pathologist for further selection. Tests for heterozygosity can then be made by simpler methods, since uniform conditions for infection are provided throughout the testing period and environmental differences will be minimised. The most suitable test is probably a simple $\times 2$ test for homogeneity.

The use of the $\times 2$ test is illustrated below on fifteen progenies from Table II of Dr. Uppal's paper.

Culture.	Results of Pot Cultures of B. D. 8, 1935-36.				Contribution to 2.
	Effective plants.	No. of plants infected.		d	
		Obs.	Exp.		
BD8-6-27	10	5	8.5	-3.5	9.6
BD8-6-28	47	22	39.9	-17.9	53.5
BD8-6-35	17	4	14.4	-10.4	49.8
BD8-6-38	29	13	24.6	-11.6	36.4
BD8-26-81	72	69	61.2	+7.8	6.6
BD8-26-82	138	137	117.3	+19.7	22.0
BD8-26-84	20	19	117.0	+2.0	1.8
BD8-26-89	42	41	35.7	+5.3	5.3
BD8-26-92	43	42	36.5	+5.5	5.5
BD8-5-26	18	15	25.3	-0.3	0.0
BD8-14-66	15	11	12.7	-1.7	1.5
BD8-31-42	29	24	24.6	-0.6	0.1
BD8-39-116	20	17	17.0	0	0.0
BD8-43-131	26	16	13.6	+2.4	2.8
BD8-42-132	25	24	21.2	+2.8	2.5
Total	541	459	459.5	-0.5	197.4

$\times 2$ for homogeneity = 197.4

n=14

P very small indeed.

There is, therefore, conclusive evidence of heterogeneity in reaction to *Fusarium* attack. The progenies fall into three groups. All progenies of B.D.8-6 gave large

* Hutchinson, J. B. & Panse, V. G., Studies in Plant Breeding Technique: II. The Design of Field Tests of Plant Breeding material. Ind. J. Agric. Sci., in press.

negative deviations from the mean percentage of infection (higher resistance). Progenies of B.D. 8-26 gave large positive deviations (higher susceptibility), while the remainder were about average in reaction.

Progenies with less than ten effective plants have been omitted from the example for simplicity. In using the X_2 test where small progenies are included, it is important to use Yates' correction where the expected number in a class is less than five (see Fisher, Statistical Methods, Edn. V, Section 21.01). Where a three-fold classification (into 'free,' 'surviving' and 'killed') is being tested, the expectation in one class is likely to be small even when the progenies are fairly large, but the additional information provided is likely to compensate for the slightly greater labour involved in using Yates' correction.

It is worthy of note that the temperature conditions of the 1935-36 experiment reported by Dr. Uppal, which were several degrees below the optimum, were much more suitable for demonstrating heterogeneity than the optimum conditions of 1936-37, which were severe enough to result in almost complete infection. Separating the 'killed' from the 'surviving' class would probably give satisfactory data for a test of heterogeneity on the 1936-37 data, but the comparison provides a good illustration of the fact that while optimum conditions for infection provide the most rigorous basis for selection, controlled conditions which are below the optimum may give a better test of whether or not selection is worth continuing.

PLANT BREEDING

Paper No. 3,

SOME ASPECTS OF COTTON BREEDING WORK IN INDIA

BY

V. RAMANATHA AYYAR,
COTTON BREEDING STATION, COIMBATORE.

Lack of adequate demand for the short stapled cottons produced in India has now created a situation which calls forth serious considerations from all persons interested in this industry for finding a solution. When this question is examined from the point of view of a breeder, there emerge two important points on which an authoritative opinion from a body of cotton workers will be valuable.

(a) It is obvious that longer stapled types are to be evolved. In doing so, the breeder has to take into account that his new types will have to face very severe competition from other countries. It should not be deemed that such a condition is only a temporary phase. The present indications are that it is likely to persist for a considerable period. Russia, China, Brazil, Peru, Argentina and Australia are focussing their attention in extending the areas. Large regions are being opened up rapidly in Africa for cotton production. A five year plan has been programmed in Manchuria by Japan with a view to make herself independent, if possible, of other countries in her requirements of lint. The United States of America cannot for long continue the present self-imposed restriction in production. Along with such extensions in the total area, many countries are forging ahead in augmenting the yield per acre. It is reported that attempts made in California to produce three bales of lint per acre have met with success over large areas (Davidson 1936).

In this world-wide race for the production of quality cotton, it is only the countries that can raise cotton at the lowest cost can stand out to the end. If India is to keep her head above water, improvement of quality alone will not be adequate. She must strive by every means to reduce the cost of production per unit area. In-

creasing the yield per acre, lowering the picking charges and reducing the cost of irrigation in the case of irrigated cottons are the main directions in which developments can be sought. It is needless to point out that of these, enhancement of yield is the most effective. The paramount and constant aim of the breeder should, more than ever, be to effect improvements in quality in conjunction with those of yield. To attain this end, it is imperative that selections are made even from the beginning on the basis of final yield which could have been brought about by earliness or drought and disease resistance or inherent high productivity or by some other factor.

I would not have stressed this commonplace subject, but for the existence of a school of thought in India which holds that betterment of quality must be the first concern of the breeder and that it will prove in the long run most profitable to the grower. I have only to state that the latter principle does not work well in actual practice. At any rate such has been the experience in Madras. Strains with high quality were evolved and grown in large areas in 'Karunganni' and 'North-erns' tracts. But the premia obtained by the grower were not adequately encouraging to extend their areas rapidly. Kapadia (1936) has shown by studying the relationship between cotton prices and fibre length in various varieties, that "marginal premia paid in respect of quality tenders are more apparent than real, for the yield and ginning outturn of these varieties are so low as to nullify the advantages of higher prices per pound."* Jackson (1936) reports that only a premium of 15% was obtained for his cottons with large improvements of quality. I may also mention that such a condition does not seem to be peculiar to India. In the United States of America, where the farmers are more educated and progressive, and where marketing methods are highly developed and organised, studies made in the local markets of Texas, Louisiana and Arkansas States have revealed a similar state (Ashton 1935).

(b) All the short stapled cottons grown in our country belong to the Asiatic group. Numerous breeding experiments conducted on this group at the several Research Stations barring perhaps those done in the Central Provinces and Berar and Surat seem to indicate a general tendency for improvements in lint length to be attended with a reduction in yield or ginning percentage. These are suggestive of the poor limits inherent in the Asiatic cottons with regard to the combination of lint length and yield. According to Todd (1934) 89.5% of the Asiatic group is below 7/8" while only 9.7% is under this length in the Americans. The above distribution gives room to interpret that in schemes of improvement of quality, work on American types will prove more profitable. A study of the world's trend with regard to the types favoured for cultivation in new areas points out to the same direction.

* The correctness of this statement has been questioned by Mr. R. S. Koshal and Prof P.C. Mahalanobis on the ground that it has been from biased data.

In Sudan the cultivation of native cotton was prohibited when American types were begun to be grown on a large scale (Huddleston). Countries like Russia and China which were once having large tracts under Asiatic cottons are changing over to the American types. Wherever cotton cultivation is being extended as in Brazil, Argentina and Manchuria, attention is being concentrated only on the latter group.

Besides, investigations made by Iyyangar and Turner (1930) have shown that the number of fibres per seed in the standard cottons derived from the Asiatic group ranged from 2500 to 10600, while those from the Americans have from 7000 to 14900 fibres per seed and that the former types do not show much improvement in fineness with increase in fibre length, while in the latter, fibres of longer lengths generally possess less fibre weight per inch. Again the fact that cultivated American varieties are allopolyploids with twice the number of chromosomes of the Asiatics is just suggestive of the possibility of their being physiologically more advantageous than the diploid Asiatics, and also of meeting with duplicate genes for lint length and yield which will not show the association we find now between these two characters in the Asiatic cotton. The existence of several varieties characterised by high yield and long lint, as in many of the types grown in Egypt and California, lends support to the conclusion that Americans as a group are better lint producing machines than the Asiatics. In addition, the picking charges for the American types are, on account of their bigger boll size, lower than in the Asiatic strains, which is an important consideration from the point of view of the grower. Efficient production demands the utilisation of efficient varieties. The Indian sugarcane industry would not have been what it is to-day but for the transfer of our allegiance from the indigenous types to Coimbatore crosses, whose main point of superiority is their high acre yields.

Against these favourable points, certain disabilities experienced in the growing of American cottons have to be examined. It is commonly reported that they are less hardy, later in maturing, more susceptible to waterlogged conditions, more prone to 'cotton failures' and red leaf blight, and more inclined to be neppy. Besides they are found to require earlier sowing, larger number of irrigations and greater care in general cultivation. A stronger argument against their adoption is furnished by the fact that several attempts made in acclimatisation since 1788 at great expense of time and money by the East India Company and by the several Local Governments have all ended in failure except in the case of the Punjab and Dharwar Americans. Direct hybridisation experiments carried out recently at Dharwar and Coimbatore have met with the same fate. The recommendations of Mackenna's Indian Cotton Committee of 1919 on the question of expansion of American cottons were advisedly cautious. The Royal Commission on Agriculture in India emphasised that work on the improvement of indigenous crops should take precedence over those of exotics.

These valuable experiences and weighty statements might make us halt and ponder. We have to remember, however, in that connection that most of the types imported in those days were from the Southern States of the United States of America where they were under cultivation for a number of years. During the course of such acclimatisation they would have lost, as pointed out by Harland (1932), many of the genes that would have been useful for adaptation to Indian conditions. It is also doubtful whether any attention was paid to compare the ecological conditions of the respective regions prior to their introduction into India. The history of the successful development of Cambodia in Madras and Egyptians in Sind indicates that if that had been so, such trials would have yielded more fruitful results. The disappointment met with in the hybridisation experiments should not be wondered at as they were between species with different genic makeups which failed to establish the harmony amongst genes necessary for proper development (Harland 1936 ii) and as no back-crossing was tried.

Our knowledge on the breeding technique has advanced considerably since these trials. Breeding centres and workers on cotton in India have of late increased in numbers. There is also at our disposal a wealth of highly useful plant material made up of different geographical races not known before. The Russian expeditionists have reported that they came across in Mexico, Guatemala and Columbia "numerous early and productive types, forms suited to mountainous tracts, maritime lowlands and sandy places, ecotypes growing on the banks of rivers, lakes and also in swamps" (Mauer). Harland 1936 (i) and Kearney (1936) speak of the existence of valuable forms in South America and around the Gulf of California. Some of these types may be useful for the evolution of American forms which will be able to withstand the saturated soil conditions obtaining in the black soils during the early phases of plant development. Again if the hardiness of indigenous cottons is to be transferred to the American cotton, the availability of the *arboreum hirsutum* crosses effected by Harland (1932) and possibly also of the Asiatic American crosses obtained at Broach and Surat may be exploited to the full by further crossing and back-crossing. All these facts place the problem of improvement of American cottons on a new footing. Incidentally I may mention that the crosses made by Harland were distinctly early, though susceptible to jassids when grown at Coimbatore, and are worthy of trial in other parts of India.

It would thus appear that one of the solutions for the problem of short staple cottons in India is to replace the Asiatic types by suitable American strains and that with this object in view it will be necessary to assemble an exhaustive collection of cultivated and wild American types and test their potentialities both by themselves and as parents for crossing.

This leads me on to the subject of choice of parents for hybridisation. The breeder circumscribed as he is with regard to time, space and staff, is at his wit's

end at that time. He is handicapped for want of a well tested method to enable him to say early with confidence that a particular crossing would give him desirable combinations in the F_2 and later populations. The time honoured method of trial and error is too time consuming. Russian workers advocate that extreme geographic races and the corresponding wild ancestors of the cultivated plants should be selected as parent for crossing (Plant Breeding in the Soviet Union 1933). It is often said that threeway and double crosses lead to valuable results. Further appreciable differences are noticed even among reciprocal crosses. I have generally found that whenever Cambodia strain Co. 2 is used as mother, the progenies are more vigorous. Similarly the nature of the pollen source may influence the behaviour of the later generation. Some crossings result in transgressive variation which is claimed by a few workers as highly valuable for selection. The problem of heterosis complicates the position still further. East (1936) states that crosses between unrelated autogamous varieties show more of heterosis. The problem in such cases reduces itself into one of finding the best way to assess the effects of heterosis. Is there any simple and quick method to follow in such cases? My experience is that it is desirable to concentrate work among crosses that do not manifest heterosis. Again we are at a loss to know the methods that will be most useful and speedy for the study of the progenies. The bulk sample method of Harland (1932) has the merit of simplicity; but the problem here is how to eliminate the worthless with reference to yield. Good yielders cannot be spotted out early for selfing. Dependence on vigour alone is too risky while making bulk samples for raising next generation. In such cases the breeder has to wait for selection till the bolls develop. This often leads him to choose naturally pollinated plants, the performance of which is of doubtful nature. A comparative study of the performances of brothers in replicated rows (Mendelian method) even from F_3 onwards will be a better criterion for the selection of the good yielders, but it is time consuming and labour exacting.

In this connection it seems desirable to deal with the question of standardisation of breeding technique. During my visit to the several cotton breeding centres in India I found wide differences in the methods adopted. I fully realise that there exist weighty reasons for such a condition, that there are large lacunae in our knowledge which make breeding as much an art as science (Hutchinson and Kubersingh 1936) and which may justify to a certain extent the existence of variation and that differences in the aims of the breeders and in the nature of the material handled necessitate resorting to diverse plans of work. I still think that there are directions where standardisation of method will prove beneficial and lead to saving of much time and energy. I may suggest for the present the following points:—

Sampling methods for the determination of lint length and ginning percentage, the level of importance to be attached to the study of phenotypic characters in breeding schemes, and the type of observation to be made on them, selection of ancillary characters to yield, general method of selection of plants in the segregating popula-

tions, the best procedure for obtaining good stand in progeny row trials, the degree to which purity in characters is worth pursuing. In cases where definite lines cannot be chalked out, at least a rough working plan may be drawn.

Another point which requires elucidation is the level of fertility that has to be maintained in the breeding plots. The higher standard of cultivation practised in general on the agricultural stations sometimes affects the performances of the strains when they are tested under cultivators' conditions. It was experienced at Coimbatore that two gram strains while being tested on Government Farms for three seasons gave increases from 15 to 25% over the control. When they were tried on a village 8 miles away from the farms, they did not show their wonted superiority over the control. The chief reason for the divergence in behaviour was that on the farm the previous crop of cotton was pulled out earlier and a fallow period intervened, while on the cultivator's areas, the cotton plants were removed only a few days prior to the sowing of the gram. Similar differences occur with regard to the rotation, manuring, preparatory cultivation and the frequency of irrigation between the method practised on the farm and by the ordinary farmer. These operate as selective agencies in heterozygous populations with the result that some of the strains selected on a well cultivated farm proved to be misfits when tried outside. It may be said that such types will stimulate the cultivator to adopt a higher standard of cultivation, but the various factors that influence the Indian cultivator in his husbandry preclude him from taking the anticipated step. It would therefore seem desirable to grow the several cultures in environments akin to those obtaining in the neighbourhood on a careful farmer's land.

A similar precaution seems to be essential with regard to the preservation of seeds of economic strains. It is certain that when these are under cultivation for a number of years, their genetic constitution will not be the same as what it was at the time of their isolation on account of the sieving effect of natural selection. In some cases it may lead to a cry of deterioration. Such contingencies can be easily met by holding a portion of the original seed material and by carefully multiplying them whenever their vitality is likely to be lost by ageing. A practice like this will not only save much breeding work later on, but also lead to the maintenance of uniformity in quality for a long time.

To sum up, the following points are presented now for your serious consideration.

1. Whether it is not desirable, in view of the low potentialities of the Asiatic cotton types with regard to the combination of quality and yield, to re-examine the question of evolving suitable American types by taking up on all stations extensive work in crossing the existing American varieties grown in India with different geographic races and wild types.

2. What is the method for selecting parents that will give desirable combination in their progenies ?

3. Is it advisable to standardise the breeding methods practised in India and, if so, on what lines can it be done efficiently ?

4. Is it necessary to maintain high degree of fertility in breeding plots ?

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DISCUSSION.

Mr. Ramanatha Ayyar opening the discussion made a brief survey of the trend of cotton production in the world and referred to the attempts being made in many countries to reduce the cost of production of cotton. He instanced the trials being made in the U. S. A. to introduce cotton picking machines and said that the potentialities of cheap African native labour was also a factor to be reckoned with, which might result in the cost of production of cotton in Africa being much lower than in India. Considering the total world area under cotton and the tendency in many countries to produce more cotton from unit area and to reduce the cost of production he was of opinion that unless India also made parallel attempts at reduction in cost of production her position as a cotton producing country would be threatened. It was therefore necessary to take stock of the position to see whether cotton work in India was proceeding on right lines. Referring to the two groups of cotton, the Asiatics and the Americans, he said that it seemed to him that the Asiatic group had not got as much potentiality with regard to combination of quality and quantity as the American group. In the Asiatic group attempts at increasing the length of staple generally resulted in a general fall in the yield at least so far as his observations in the Madras Presidency were concerned, whereas in American cottons there was always a good combination of yield and quality. He drew attention to the world trend in regard to the development of cotton types as shown by countries like China, Russia and also Africa, which were once growing mainly Asiatic groups of cotton to give up Asiatic cottons in favour of American cottons. He therefore put it for consideration whether in India also it would not be fruitful to examine the field for the study of American types along with studies on Asiatic cottons. He ascribed the failure of various attempts at introducing American cottons in India to the introduction of types acclimatised in the U. S. A. or in South America or in Egypt, as during the course of acclimatisation it was very likely that they might have lost many of their genes which would have been helpful for adaptation to Indian conditions. He suggested that trials might be made in India with certain types grown in Central America and northern parts of South America and reported by the Russian Expeditionists to be very good with regard to quality and yield.

The choice of parents for hybridisation work was another point for consideration. as the breeder was often confronted with the difficulty of deciding as to which parent would give the favourable material in the progenies for selection. It was true that much difficulty might not be experienced if breeding work was confined to only parents which differed in one or two genes but in such cases there would not be variability sufficient to give a good combination of yield and quality. He suggested that the cyclic method of crossing between different parents adopted in U. S. S. R. appeared to be more promising. He added that from his visit to a number of breeding centres in India where he happened to see several breeding methods adopted, he felt that it was worth while to standardise certain methods, especially in regard to

the points mentioned at the bottom of page 5 of his paper as it would save much time and energy. The last point on which he required elucidation was whether it was desirable to have the breeding plots in a high level of cultivation as was done at present in the experiment stations. As strains selected under very favourable conditions, when transported to ryots' fields, did not behave in the same way as they did when tried in the experiment stations, he considered that the standard of cultivation of the breeding plots should be only on a level with that of the ryots' cotton fields.

Mr. Hutchinson commenting on the points raised said that he could not altogether agree with Mr. Ramanatha Ayyar that the Americans were so superior in potentialities. He also dissented from the view that attempts made by the East India Co. in introducing American cottons into India suffered seriously from the importation of too uniform materials as at that time there being no systematic plant breeding work in the U. S. A. it was to be expected that there would have been sufficient variability in the material that came to India to indicate roughly at least where American cottons might be expected to succeed. He thought that the present extension of American cottons in India probably indicated the limits of successful cultivation of American cotton in India. He considered that the amount of time and energy that had been spent on searching for improved material in American cottons was far greater in proportion to the results obtained therefrom than what had been spent on looking for improved and superior types or of exploring the range of variability available in Indian cottons. Again it was quite right to condemn the Asiatic cottons because in most of their cultivated types longer lint was associated with lower yield. From statistics it was found that there was no negative correlation in F_2 between lint length and ginning percentage, and it was indeed encouraging for the man who hoped to combine the two. Referring to the statements that Russia, China, Brazil, Argentine and Manchuria were all concentrating on American cottons, the mistake was realised at least in the case of Russia as evidenced by recent summaries of Russian work admitting the mistake of throwing away indigenous cottons, and foreshadowing a reversal of policy. As regards China he said that he learnt from a reliable source that it was extremely difficult to introduce American cottons in rotations because of their long growing season. In the face of these facts he thought that Mr. Ramanatha Ayyar's plea that everybody was going in for American cottons was not altogether justified. In Argentine only American varieties were cultivated but he however pointed out that where the two species occurred in nature, it was probably correct to say that by far the most satisfactory improvement in cotton cultivation has resulted from the selection of annual types in Barbados rather than from the introduction of the hirsutum from North America. He was also of opinion that the best even of the annual Brazilian cottons were mostly predominantly religiosum in ancestry. He felt that there was a great deal to be said in favour of studying the variability of indigenous cottons more not only in India but in Burma and in Africa. Studies at Indore showed that the potential yielding capacity was at least as great in the

northern neglectums under black soil conditions as it was in the best acclimatised American cottons, and the neglectums realised a greater proportion of their potential yield under ordinary conditions than American cottons could do. It was true that this did not apply under all conditions, as in the case of Cambodia in South India. At the same time he would not dream of substituting an American in the black soil areas, because he thought that there was a very wide range of conditions in India for which the Indian cottons were far more suited for yield and quality than American. He contended that there was far more potentiality for improvement in the indigenous species than in the introduced ones. As regards the choice of parents in hybridisation which was an important matter, efforts were being made to provide material for studying this question in the Bengals Cotton Improvement Scheme at Ganganagar. He said that Dr. Fisher had told him some years ago that this question might be approached by the diallel crossing method. He suggested that after crossing the types the relative values of which were to be investigated, with two or three common parent types only those which raised the lower parents most in F_1 were to be retained. Describing the experiment designed at Ganganagar he said that the procedure was to take Mollisoni, A. 19 and C. 520, three Northern Bengals types, and use all the finer quality Burmese types as parents in crossing with all the three of them and then to compare the F_1 's of all the three crossed types and see which of the Burmese finer types raised the value most on the average of the three crosses in F_1 . This method, so far as he was aware, had not been tried out in plant breeding. As regards the level of potentiality of a particular plant it was important to note that unless a fairly high level of fertility was ensured uniformity of conditions at least in black soils which was necessary to get any kind of comparative tests, could not be controlled. For instance at Indore the practice was to have the experimental plots free from perennial weeds, with a very high level of minimum fertility free from waterlogging, and a spacing of two feet between rows and one foot in the rows was adopted, which was greatly different from the commercial spacings, simply because it was necessary to have uniform conditions which would enable the plants to be examined satisfactorily. He thought that it would be necessary to maintain in the experimental plots a considerably higher standard of cultivation than that of the cultivator in order to preserve the requisite conditions for comparative testing in selections. He concluded that certain definite limitations had to be accepted in plant breeding work in order to ensure uniform conditions for comparative purposes.

Mr. Nanjundayya drew attention to page 3 of the paper under discussion where reference was made to the investigations of Ayyangar and Turner (1930) in regard to the number of fibres per seed in the standard cottons derived from the Asiatic group as against those from the Americans and said that it would be seen from that bulletin that the number of fibres per seed had little or practically no relation to ginning percentage. As regards the other point that in Asiatic cottons as the fibre length increased the fineness did not improve whereas in Americans, fibres of longer length

possessed less fibre weight per inch, he said that this observation referred to different group lengths only in the same cotton. Further he suggested that it was possible that the staple length of cotton might increase without the hair weight per unit length showing any decrease. He requested Mr. Ramanatha Ayyar to enlighten him as to the exact bearing of his statements on the subject matter under discussion.

Dr. Badami said that so far back as 1920 he had tried the method suggested by Mr. Hutchinson, taking many American types for the purpose of crossing. The best results were obtained by crossing Cambodia with Peruvianum. He considered that the suggestion was a valuable one and if put into practice would lead to good results. Referring to the question whether it was necessary to maintain high degree of fertility in breeding plots he said that if ordinary fertility was kept in the soil, usually those plants that had a very vigorous root system explored a larger area giving a higher yield. When such strains were distributed to the ryots for two or three successive seasons, the soil became exhausted and the cry of deterioration of the variety was raised. If a vigorous variety were to be distributed, a better system of cultivation and manuring had to be advocated. He continued that if experiments were carried out on fertile plots generally those strains whose root system of the surface was much more than the deep root system would give higher yields. This would result in the elimination of deep-rooted strains in many cases, on putting them into poorer soils. When a drought occurred the plants would suffer and would give poor yields whereas the local varieties would thrive. He opined that a stage must come in breeding operations when strains should be tested under the two systems in the experimental plots to see whether they were capable of growing in both the conditions of ordinary and higher fertility. Provided time and facilities were available it would even be better always to study the development of the root system of the strains under test.

Mr. Dabral desired to know whether a high level of fertility should be maintained while breeding for normal conditions. He thought that multiple experiments might be designed for each variety laying down definite conditions of growth for each variety. Supposing a variety had been evolved with a certain rate of watering and a certain grade of nitrogenous manuring and a certain sowing date, by having a table of such factors for each variety it would be possible to know the effect of the various conditions on it and its capacity to utilise the treatments to its advantage.

Mr. Mohammad Afzal thought that the multiple experiments suggested by Mr. Dabral were theoretical and highly improbable propositions from a practical breeder's point of view. The reason was that most of the zamindars to whom the varieties were given out knew nothing about cultivation as understood by the breeders and if one holding contained both rich and poor lands it would not be possible for Agricultural Departments to recommend a type No. 1 to be sown on a very rich land with ten waterings, and a No. 2 type to be sown on a medium land with five

waterings, and a No. 3 type to be sown on a poor land, etc., as these types would be mixed in a year or two.

Mr. Koshal referring to the conclusion of Mr. Kapadia (1936) in regard to the relationship between cotton prices and quality of cotton quoted on page 2 of the paper, invited the attention of Mr. Ramanatha Ayyar to the recent issue of *SANKYA*, Vol. 11 No. 4 where the speaker had written that this conclusion of Kapadia was based on incorrect data and defective statistical methods. He therefore suggested that the relevant statement in the paper under discussion might be modified accordingly.

Mr. Wad reverting to the point raised by Mr. Dabral said that if the idea was to secure a strain which would stand a normal cultivator's conditions and at the same time would respond to intensive cultivation wherever it might occur, the object could be achieved by choosing a strain which would do well both under poor and fertile conditions; he did not think that there should be different strains for different soils in the same region.

Dr. Nazir Ahmad enquired whether it was not a fact that apart from the areas which were already under certain American types, many types had been tried in other areas and proved a failure. His impression was that at present there were greater chances of success by selecting from the indigenous types rather than by trying imported types. It sometimes happened, as in the Central Provinces and Sind, that when a new type was tried in a given area, and the samples are sent to the Laboratory, in the first year or two it gave very encouraging results but afterwards it gradually fell off; whereas there were other types which may not give equally good results in the first few years, but on the whole gave more constant and uniform results. He, therefore, suggested that in selecting new varieties some attention should also be paid to those which gave more uniform results over the experimental period.

Mr. Ramanatha Ayyar said that while he was glad to know that the potentiality in Asiatic groups of cotton was as wide as in American types, his experience was otherwise and that he would be thankful if Mr. Hutchinson could supply such materials. With regard to China he pointed out that he had received a letter only a few days ago from Mr. Chen stating that they in China were definitely going in for American types because in sandy loamy soils American types were found to do better than Asiatic cottons.*

Mr. Mohammad Afzal intervening said that those might not be American types because as far as he was aware American types could not grow on sandy soils.

*Subsequent to this Conference, a letter was received by Mr. Ramanatha Ayyar from the Director of the All-Union Scientific Cotton Research Institute, Sojus Nih, Tashkent, wherein the Director writes "In the cotton industry of the U. S. S. R. the Asiatic cottons had been substituted by the American and Egyptian cottons of our selections since 1925. In our conditions, the Asiatic cottons which were available to us up to the present time could not compete with our selected, high yielding, and long stapled American and Egyptian cottons."

Mr. Ramanatha Ayyar continuing said that the method suggested by Mr. Hutchinson as to the choice of parents might be tried. With regard to the maintenance of a high level of fertility, which was being done in the breeding stations in Madras, he said that there were instances where the strains did not thrive well under very stringent conditions. Regarding the point raised by Mr. Nanjundayya, he explained that he had referred to the bulletin of Ayyangar and Turner only to show that the limit was higher in regard to Americans as the number of fibres per seed in Americans was 14900, whereas in the Asiatic cottons it was only 10600. The other point that Asiatic types did not show much improvement in fineness with increase in fibre length was stressed by Mr. Hutchinson in his paper and if importance was to be attached to the solution of fibre dimensions the fibre should not be thick in diameter. Replying to Mr. Koshal's point he said that he had not seen Mr. Koshal's contribution and that only after seeing it would he be able to say whether it was necessary to modify the statement under question. As regards the contention that American cottons had been tried in a number of places and found to be a failure, he said that there was no reason why fresh attempts should not be made as he believed that the material tried in the early stages was perhaps limited. He instanced the success in Madras of Cambodia cotton, a recent introduction of American type, and suggested that if fresh materials were tried, good results might possibly be obtained.

Mr. Ansari observed that a tendency to introduce American types, as in Persia should not be taken to support the idea that American cottons had more genetic variability than the indigenous cottons. His experience was that American cottons did not do so well in Persia as the indigenous cottons. The examination of the materials showed that indigenous cottons in Persia had more genetic variability and were more resistant to disease than the American cottons. American cotton was being grown in Persia simply more out of fancy than for their intrinsic value.

PLANT BREEDING

Paper No. 2.

ADVANTAGES AND DISADVANTAGES OF THE BACK-CROSS METHOD IN PLANT BREEDING

BY

S. J. PATEL,

BROACH COTTON BREEDING SCHEME.

The back-cross method has come in plant breeding practices very recently. Its usage for fixing the desired characters in animals is of long standing. We have known it under different names of "grading," "improvement of scrub cattle by intensifying the blood of a particular sire," etc.

The original usage of back-crossing was for determining the genotype of an individual in relation to the parental constitution, and also for testing linkage intensities in the repulsion or coupling phase. Usage preferred the recessive parental form for certain genetic reasons. This usage still holds world recognition. Its analytical use, however, has been considerably expanded by geneticists in recent years.

The object of this paper is to discuss mainly in broad terms the desirability or otherwise of the adoption of the back-cross technique in crop improvement by synthetic breeding.

BRIEF REVIEW OF LITERATURE.

Harlan and Pope (1922) have shown its utility in plant breeding and specially in the breeding of small grains. Briggs (1930) has pointed out its utility in breeding wheats resistant to bunt. Harland (1932) has emphasised its necessity in crosses involving wide genetic differences where the object is to secure only a few acclima-

tization genes from the wild or indigenous parent. Some discussion on this subject is seen in papers of Watkins (1934) and Harland (1934) read at the Second Conference on Cotton Growing Problems held in London. Savitzky (1934) has shown some important achievements due to its use in sugar beet crosses. Briggs (1935) has described the theoretical aspect as well as the advantages of this method. Its use in the improvement of cotton has been discussed in the minutes of the Plant Breeders' Conference held at Bombay on the 14th August 1936 under the auspices of the Indian Central Cotton Committee.

DISCUSSION.

It is a matter of common knowledge that a back-cross increases the proportion of the genes of the back-cross parent in the population of the hybrid material, and repeated back-crosses make the whole population to a considerable extent like the recurrent parent. Before adopting back-cross method for the improvement of any crop, one has naturally to enquire as to whether a high proportion of genes of one parent alone is absolutely necessary or not, while synthesizing the best qualities of two pure lines and whether it would be possible or not to secure the same from a straight cross? The answer to this enquiry would depend considerably upon the types of crosses involved. The crosses mentioned below need consideration in this connection :

- (1) Intra-varietal.
- (2) Inter-varietal.
- (3) Inter-specific.

The necessity or otherwise of following the back-cross technique for each of the above mentioned crosses will now be considered separately.

(1) *Intra-varietal.*

Crosses involved here are between two pure lines of the same variety. The differences between the two parents met with here are in few characters only as the parents possess many things in common. The object of such a cross can be the replacement of a few characters in the desirable parent or to synthesize the best qualities of both. The bringing in of a few characters in the desirable parent would require back-crossing once or twice but the nature of variations in the intra-varietal crosses is generally so simple that straight crossing alone will achieve the end in view in most of the cases.

(2) *Inter-varietal.*

Here two types of crosses are generally involved, one between closely related varieties and the other between widely related ones. In the former the variations in physiological, morphological and economic characters though more than those found in the intra-varietal hybrids would be much less than those found in crosses

between widely related ones. Crosses between closely related varieties, therefore, stand on a footing more or less like the intra-varietal hybrids. The breeder is generally anxious in maintaining the main varietal characters of the local or the more suitable variety in crosses between widely related varieties. It is in such a case that the back-crossing with the desirable parent once or often according to the necessity is going to help the breeder in maintaining his main varietal characters and stabilizing them.

It is worth while to consider here the possibilities of achieving the desired results only by the straight cross method as against back-crossing. Theoretically it is possible to secure in F_2 of a straight cross the desirable combinations provided the population is large enough. In practice, however, one finds many handicaps in time, staff, and space for work on a large scale. Back-crossing helps in this respect as it is enough if the breeder grows proportionately a smaller population due to considerable reduction in genetic variability brought in by it.

The transference of specific characters like resistance to disease, insect pest or an easy diagnostic character from a widely related variety or from a different species to a variety which has been found good in all other respects has been proved to be easy by back-crossing by some workers. With the exception of factors linked with the characters to be transferred, it is possible to preserve the original characters of the variety by following this method. Even in the case of linked factors, continued back-crossing would afford an opportunity for the occurrence of cross-overs as the linkage is rarely absolute.

Its use is specially advantageous to keep up many intangible physiological and morphological characters which break up so much in segregating generations that it is difficult to recapture them in desired combinations.

(3) *Inter-specific.*

This also stands on the same footing as the crosses between widely related varieties with the main difference that the gulf in the physiological, morphological and economic characters would be here still much wider.

Here also two types of crosses are involved as mentioned under inter-varietal hybrids. Crossing between closely related species is found at times very easy, while it has been found very difficult between widely related ones even after laborious trials. The hybrids coming under the latter category have been found mostly incompatible *inter se* and generally self sterile. The use of back-crossing has been found indispensable in such cases to maintain specific balance and establish fertility. Haldane (1934) has opined that "the technique of back-crossing is particularly valuable in species crossing in which the F_2 from a species is hybrid, when the progeny are definitely poor doers and of little economic value."

Often in plant breeding schemes on account of the limited varietal wealth of the local resources, it becomes necessary to introduce outside types. These exotic types may not be—and generally are not found—suitable when introduced in tracts having different environmental conditions. It, therefore, becomes necessary to cross endemic forms with the exotic ones both for acclimatization and for the improvement of the local material. Both the objects can be speedily achieved by back-crossing keeping in view in selection the desirable characters in back-cross generations.

The workers in the field of cotton are particularly interested in a successful cross between Old and New World cottons. Hutchinson has clearly explained in the Plant Breeders' Conference (1936) citing Harland's work that the breeding of stable, vigorous intermediates from an interspecific cross is not practicable without regaining most of the genetic balance of one parental species and that it could be accomplished with reasonable speed and efficiency only by the back-cross method. New World cottons have been shown by Skovsted (1934)¹ to be amphidiploid—allopolyploids. Skovsted (1934),² therefore, recommends a parent with a higher number of chromosomes for back-crossing to secure fertility in view of the fact that the maximum amount of pairing of non-homologous chromosomes derived from different parentage is facilitated thereby.

The whole field of inter-specific hybridization in *Trinicums*, *Secale*, *Avena*, *Prunus*, *Primula*, *Nicotiana*, *Roses*, *Zea*, *Euchlena*, etc., is full of examples of the repeated use of back-crossing. Due to its use derivative types have been obtained in many cases, and it has become possible to get an insight into the real nature of related plant organisms.

The back-cross technique, however, has certain limitations. It would have a limited use in crops which show harmful effects of inbreeding. Its application is difficult in crops wherein the production of seed by artificial crossing is limited and, therefore, requiring considerable time and expense. Unless sufficient back-cross seed is grown, there is always a danger of losing some genotypes which may ultimately prove a limiting factor in the achievement of the goal. Even in crops wherein the crossing may not be difficult, there will not be as large a back-cross population as an easily obtained population from a "selfed" generation of a straight cross. The appearance of the characters due to recombination or due to factor interaction is also likely to be delayed to subsequent generations by the back-cross method. It considerably reduces the genetic diversity of the hybridized material and hence limits to a certain extent the scope of selecting characters appearing due to recombination or due to factor interaction.

According to Skovsted (1934)² one point to be borne in mind in repeated back-crossing of inter-specific crosses is that one missed any chance of getting new polyploids,

CONCLUSION.

The technique of back-crossing though of long standing is new so far as its application in the improvement of crops by breeding is concerned. It may be possible to get by a straight cross the combination of a few desired characters simple in their nature of inheritance. Back-cross method, on the other hand, is specially advantageous in the following cases :—

- (1) The transference of a few genes from one species or variety to another. This can be greatly facilitated if the heterozygotes can be distinguished in a vegetative stage.
- (2) Regaining specific balance.
- (3) Keeping up many intangible physiological and morphological characters which break up so much in segregating generations that it is difficult to recapture them in desired combinations.

There does not seem any disadvantage of the back-cross method except certain limitations in its use. Intelligently followed, this method may give quicker results in the breeding of certain crops particularly in those wherein hybrid seed can be easily had.

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DISCUSSION.

Mr. J. S. Patel *read his paper.*

The President *said that as a considerable number of Plant Breeders had much experience of the method dealt with in the paper, no discussion on it was necessary.*

PLANT BREEDING

Paper No. 1.

THE DISTRIBUTION OF GOSSYPIUM AND THE EVOLUTION OF THE COMMERCIAL COTTONS

BY

J. B. HUTCHINSON,
INSTITUTE OF PLANT INDUSTRY, INDORE, C.I.

- I. INTRODUCTION.
- II. OUTLINE.
- III. NEW WORLD CULTIVATED SPECIES.
- IV. OLD WORLD CULTIVATED SPECIES.
- V. WILD SPECIES.
- VI. DISCUSSION.
- VII. SUMMARY.
- VIII. ACKNOWLEDGMENTS.
- IX. REFERENCES.

I. INTRODUCTION.

The recent emphasis by the Russian school of plant breeders on the importance of thorough studies of the origin and distribution of crop plants has directed attention to the phytogeography of the genus *gossypium*. Zaitzev (1927), Harland (1932 and 1936) and Hutchinson and Ghose (1936 in press) have clarified the more important specific distinctions among the cultivated cottons. The nomenclature used in this paper is that of Hutchinson and Ghose (l.c.). Harland (1932) and Skovsted (1935 b) have contributed to our knowledge of the limits of the genus by their studies of wild species, and Skovsted (1933, 1934, 1935a, 1935b, 1935c), Davie

(1933, 1935) and Webber (1934 & 1936) have revealed the main outlines of its cytology. Sufficient information is available, therefore, for a review of the present state of our knowledge of its distribution and recent evolutionary trends.

II. OUTLINE.

Gossypium is exceedingly widely distributed, and representatives of it are found in all continents of the world, and truly wild species in all continents except Europe. It falls naturally into three main divisions, (1) The wild and cultivated cottons of the Old World, with $n=13$ chromosomes. (2) The cultivated American cottons and three wild species from islands in the Pacific with $n=26$ chromosomes. (3) The wild cottons of the New World, with $n=13$ chromosomes.

The changes in the distribution of the cultivated species which have resulted from the spread of cotton cultivation in historic times have caused much confusion in the literature of cotton botany. The two most important theories involved in this confusion are that the Levant cotton (*G. herbaceum* L.) has contributed by hybridisation to the modern stock of *G. hirsutum* L. (Watt 1907), and that types of the New World cultivated species are indigenous in Africa [Watt (1907) and others]. The discovery that Old World and New World cottons will only cross with extreme difficulty, giving sterile hybrids, and the determination of their chromosome numbers, effectually disposed of Watt's theory of hybridisation. Disproof of the theory that some New World types—chiefly of *G. religiosum* L.—are indigenous in Africa is more difficult, but all the available evidence indicates that they were introduced after the discovery of America. Zaitzev (1927) concludes as follows: "It is true that *Gos. punctatum* [*G. religiosum* L. of Hutchinson & Ghose (1. c.)], is widely spread in Africa but it is doubtless a species brought over from America, though partly it has run wild in some places of Africa (similar to other American species). The living samples from Nigeria and Abyssinia in our collection show the perfect similarity and identity of the African forms of *Gos. punctatum* with the forms of Columbia and partly Venezuela. The greater diversity of forms of this species in Columbia shows, however, that this country is the first source." Similar arguments apply with equal force to the problems of the origin of New World species now to be found in other parts of the Old World. All introductions too old to be definitely traced lie on the track of the early Portuguese and Spanish navigators, and are more satisfactorily explained as having originated in the New World countries visited by them than as having arisen locally.

Once it is recognised that the 26 chromosome types now naturalised in the Old World are post-Columbian introductions, it becomes clear that the Atlantic Ocean forms a sharp natural division in the distribution of the genus. No such natural division exists in the Pacific region. Primitive, probably wild, types of *G. arboreum* have been collected in the Philippines, the Malay Archipelago, Java and the Celebes [Watt (1907), described as *G. obtusifolium* and *G. Nanking* var. *Bani*, and

Zaitzev (1927)]. The wild *G. taitense* Parl. is native in Fiji, New Caledonia, and Tahiti. Watt (1907) regards Baron's specimens from Madagascar, and Vidal's No. 2185 (wild) from the Philippines as belonging to this species. Baron's specimens are undoubtedly *G. religiosum* L., and are not indigenous, so that the distribution of *G. taitense* can be confined to the Pacific region. Under the circumstances a re-examination of Vidal's specimen is necessary before it can be said with confidence that the distributions of *G. arboreum* and *G. taitense* overlap in the Philippines. In Hawaii, *G. tomentosum* Nutt. is endemic. On the American side of the Pacific, *G. Klotzianum* Andss. and *G. Darwinii* Watt are endemic in the Galapagos Islands. Furthermore, the wild cottons of America with 13 chromosomes are indigenous in the Pacific coastal, and neighbouring regions of the United States of America and Mexico.

The distribution of the species of *Gossypium* is shown on Maps I-IV. Post-Columbian extensions of the distribution of New World species in Asia and Africa have been omitted.

III. NEW WORLD CULTIVATED SPECIES.

The researches of Zaitzev (1927) and Mauer (1930) based on collections made by S. M. Bukasov and others in Mexico, Guatemala, Columbia and Venezuela in 1925 and 1926, and of Harland (1932), based on the collection at the Cotton Research Station, Trinidad, have added greatly to our knowledge of the relationships and distribution of the cultivated 26 chromosome species. There are two main groups of these: (1) The Central American group, which the Russian workers include in a single species, *G. hirsutum* L.. Its region of greatest variability is on the central plateau of northern Mexico, and the Pacific coastal regions of Mexico and Guatemala. On the plateau the population is made up of early annuals of the American Upland type. Further south, and on the coast, the perennial types referred by Harland (1932) to the "Bourbon group" (*G. religiosum* L.) predominate. From the State of Chiapas, in Mexico, Mauer (1930) describes a wild type which he identifies as the *G. Palmerii* of Watt (1907) and the *G. microcarpum* of Todaro (1877). On morphological characters and on the fertility of crosses with Upland, he refers it also to *G. hirsutum* L. (2) The South American group. Mauer (1930) states that in Columbia the cottons of the Central American group preponderate at lower altitudes (below 1,000 m.) and east of the Central Cordillera. Above 1,000 m. and west of the Central Cordillera, the South American group, which he, Zaitzev and Harland agree in referring to *G. barbadense* L., preponderates. The area of the South American cottons extends south on the western side of South America to Ecuador and Peru. East of Panama, the South American group and perennials of the Central American group occur together along the Spanish Main, in the West Indian islands and south to the cotton growing tracts of Brazil [Mauer (1930) and Harland (1932)].

The spread of cotton into most of what at present constitutes the American cotton belt was brought about by the early English settlers [Kearney (1930)].

According to Watt (1907), the first cotton grown was the Levant species (*G. herbaceum* L.) but this was rapidly replaced by *G. hirsutum*. There appears no reason to doubt that the original stock of *G. hirsutum* on which the cultivation in the American colonies was based [See Watt (1907) p. 19] was Central American in origin, and it was not long before further improvement was gained by direct introduction of seed from Mexico, a process which has continued ever since and has provided many of the more important American varieties now in cultivation. The success of the annual forms of the Central American group (*G. hirsutum*) in the American cotton belt has caused the perennial forms (*G. religiosum*) to be neglected. They are of little importance in commerce, only contributing the Marie Galante cotton of the West Indies and the Moco of Brazil. Harland (1932) separates them as *G. purpurascens*, Poir., but an examination of the types in the Linnean herbarium showed that the name *G. religiosum* L. must take precedence.

All the wild species of *Gossypium*, and all the more primitive forms of cultivated species are perennial. Except on the Mexican plateau, the widespread pre-Columbian spinning and weaving of cotton [for details, see Kearney (1930)] must have been based on the cultivation of perennial types. The distinction between the annual and perennial forms in the Central American group is a natural result of evolution in response to environmental stimuli. To the south of the Caribbean sea and in the coastal regions of Central America, perennial cottons flourish. On the central plateau of Mexico and in the southern United States, in a continental climate, with cold winters, only annual cottons can survive. A similar development of annual types has gone on in the South American group, but in response to the stimulus of human, rather than climatic, selection, has resulted in the development of the annual Sea Island and Egyptian varieties. Sea Island is the result of the selection by natural and human agency together, of annual cottons from the variable perennial *G. barbadense* stock. The stock was imported into the Sea Islands and neighbouring coastal regions of South Carolina and Georgia by European settlers who migrated from the colonies of the West Indian Islands to those of the main land. The superiority of the selected annual strains of the Sea Islands over the perennial types of the West Indies was realised by Sir Daniel Morris, and they were brought back by him, and their cultivation was developed by the Imperial Department of Agriculture in the West Indies. The success of the Department in the struggle against the pests and diseases which had destroyed previous cotton cultivations in the West Indies was largely due to the close season rendered possible by the adoption of the annual type.*

The first New World cotton to be cultivated in Egypt was Jumel's perennial *G. barbadense*. The introduction of Sea Island from Georgia and Carolina resulted

* The establishment and protection of Sea Island cotton in the West Indies is one of the finest achievements of scientific control of an agricultural crop. It is recorded in detail in the volumes of the West Indian Bulletin.

in natural crossing, and the advantages of the annual habit for ease of cultivation and control of pests led to the selection of annual types from the hybrid material [see Balls (1919)].

IV. OLD WORLD CULTIVATED SPECIES.

The cultivated cottons indigenous in the Old World belong to two species, *G. arboreum* L. and *G. herbaceum* L.. Their distribution and development have been subject to the influence of man for so long a period that it is not possible to determine with certainty their original limits. The existing knowledge of the subject is summarised by Watt (1907) and from his work the following conclusions are drawn :

Cotton (*G. herbaceum* L.) is not indigenous in the Mediterranean region, and probably owes its introduction there to Mahomedan conquests in the 9th and 10th centuries.

Cotton (*G. arboreum* L. var. *neglectum*) was unknown in China until the 7th century.

All the old records agree in stating that the early cultivated cottons of India and Abyssinia were perennials, and not annuals.

Evidence of the antiquity of cotton manufacture in India is given by Gulati and Turner (1928) who identified cotton fabrics from Mohenjo-daro, the date of which is estimated as about 2750-3000 B.C. and in the Sudan by Griffith and Crowfoot (1934) who brought together references to and descriptions of cotton fabrics of the Meroitic age. Those found by Prof. Reisner in 1922-23 were in graves dated by him approximately 300 B.C. to 300 A.D.

G. arboreum and its varieties are distributed throughout the rain-fed savannah countries between the Sahara and the Congo forests in Africa, in Abyssinia and Madagascar, throughout India, Assam, Burma, Malaya, Siam and French China, the East Indies, China and Japan. Truly wild perennial types are found scattered throughout the range of the species, except where cold winters or long dry seasons prevent perennial growth. They have been recorded from Abyssinia and neighbouring regions of the Sudan, Arabia, Madagascar, India (Kathiawar, Gujerat and the Deccan), Malaya, Java and the Philippines. Cultivated perennial forms are found in the same areas and the relationship between them and the wild, sub-scandent forms with worthless lint which are found in hedgerows, on abandoned ruins, and on waste lands, are so clear as to have led the older botanists to the conclusion that the latter are the degenerate descendants of escapes from cultivation. The annual forms classified as var. *neglectum* and var. *cernuum* are found in regions where cold winters, or a monsoon climate with a long and hard dry season make the cultivation of perennials difficult or impossible. Truly wild annual forms are not known,

Evolution within the species has followed the same course as within the New world species, namely the development of annual varieties in response to the selective forces of cultivation in areas of short season. A study of the distribution of the various forms of *G. arboreum* var. *neglectum* reveals the existence of a series of separate centres of development of annual types (Hutchinson and Ghose, in press). In *G. arboreum* forma *indica* of South India, most of this development is recent, and has resulted more from human selection for agricultural convenience than from any unsuitability of the climate for the growth of perennials. It resembles in this respect the development of Sea Island and Egyptian cottons. It is possible to trace with some confidence a developmental series from perennials of the Nadam type to the annual Karungannis in the south, and to Coconadas, then Northern, and finally to Bani in the northern part of the Madras Presidency. Except in Bani, development has not progressed so far as in the northern India *neglectums* (of forma *bengalensis*), which are adapted to a more extreme type of season, and when grown in Central India, most of the annual cottons of Madras develop into bushy, much branched shrubs resembling the perennials from which they sprang. It is interesting to compare this behaviour with the behaviour, when grown in Russia, of New World cottons adapted to a short day [Mauer, (1930)], and it is strong evidence in favour of the independent origin of the *neglectums* of forma *bengalensis* in northern and forma *indica* in southern India.

The *neglectums* of forma *bengalensis* appear to have developed in Assam, and Bengal, from the same perennial stock as gave rise to var. *cernuum* and to have spread throughout the Ganges basin and Central India. In their evolution in response to the selection pressure of a short season they resemble the Upland cottons. Perennial cottons are common in parts of the Chittagong Hill Tracts, and are found along the foothills of the Himalayas as far as the eastern districts of the United Provinces, where the type assigned by Gammie (1907) to *G. intermedium* Todaro is still grown on small scale. The cotton from which the famous Dacca muslins were made was of this type. It was fine, but short in staple and low in ginning percentage, and was triennial (Price in Return 1847). Price (loc. cit.) states that in 1844, when the Dacca muslin industry was rapidly declining, both the triennial and the coarse annual cottons were being grown in the Dacca district, and it is a safe inference that the invasion of the Gangetic plain by coarse annuals of *G. arboreum* var. *neglectum* forma *bengalensis* from the hilly tracts of eastern Bengal and Assam commenced when cheap machine-made cotton goods from England began to compete successfully with the fine hand-made local muslins. The area covered by the *neglectums* of forma *bengalensis* has been very greatly increased in the last century. The introduction of power gins resulted in a premium being readily offered for high ginning percentage. No corresponding premium was obtainable for better quality, and even to-day, when the great bulk of coarse cotton on the Indian market is causing considerable anxiety, an increase in ginning percentage from 30 to 31 pays the cultivator as well as an increase of about 20 per cent in spinning value. The narrow-

leaved, white-flowered Roseum type common in *neglectum bengalensis* had much higher ginning percentage than the southern Bani. The *bengalensis* mixture was therefore favoured and encroached on the southern (*indica*) area, and a great cotton growing tract, comprising the Central Provinces, Berar, Khandesh and Nimar, changed over from medium-staple to coarse-staple. This raises an interesting point of contrast between forma *bengalensis* and forma *indica*. In general the southern types (forma *indica*) are from medium to fine in staple, with a comparatively low ginning percentage, while the northern types (forma *bengalensis*) are medium to coarse in staple, with a high ginning percentage. Hutchinson and Govande (1936 in press) have recently shown that the differences between forma *bengalensis* and forma *indica* in hair characters and spinning value are as great as occur between species.

At the beginning of the present century the northern *neglectum bengalensis*, which had displaced the southern *neglectum indica* so successfully in the Central Provinces and Khandesh, was introduced into the *herbaceum* tract of Kathiawar, and, under the name Matthio, has spread until it contributes a very large proportion of the Dholleras crop. In the Punjab the development of the canal irrigation system has resulted in a great increase in the area under cotton, and this has been divided between the northern *neglectum bengalensis** and introduced types of *G. hirsutum* (Upland). These extensions have all involved increases in the amount of coarse-stapled Indian cottons, and at present constitute a source of serious weakness to India's position in the cotton markets of the world. In considering means of improving the position, it should be remembered that, while the types of *neglectum bengalensis* are predominantly coarse in staple, and high ginning, these characteristics have been greatly favoured by the selective agencies of the last hundred years, during which period a premium was always obtainable for ginning percentage, but was much less readily given for quality. Ginning percentages higher than 28 were very rare in India in 1840. [See Return (1847).] The types of *neglectum indica* of south India usually gin at present from 25 to 30, whereas the range of ginning percentage in northern India is now from 28 to 40, showing a much greater response to selection than in south India. There is no reason to doubt that selection for quality in *neglectum bengalensis* will lead to considerable improvement [See Hutchinson and Kubersingh (1936)] but the plant breeders engaged on the problem will do well to remember that the recent increase in ginning percentage has been gained largely by an increase in hair-weight, which involves coarseness. If success is to be obtained in the improvement of quality without incurring serious losses in ginning percentage, selection for hair-fineness must be accompanied by selection for an increase in the number of hairs per unit area of seed coat.

* It is an interesting example of the confusion into which the nomenclature of cotton had fallen, that Mollisoni, the broad-leaved, white-flowered northern *neglectum* predominant in the Punjab, has usually been assigned to *G. indicum* a name only applicable to the south Indian types now included in *G. arboreum* [see Hutchinson and Ghose (1936 in press)].

There appear to be two other centres of development of annual types of *G. arboreum* concerning which less information is available. The *neglectum* cottons of Burma and Indo-China (*G. arboreum* var. *neglectum* forma *burmanica*) have been developed by selection for the annual habit from among perennial *G. arboreums* of the same area. Somewhat inadequate collections of material from Burma revealed a great range of habit-types from perennial (*G. arboreum* var. *typicum*) to annual (*G. arboreum* var. *neglectum*), and also great variability in quality. In comparison with the two groups of *neglectums* found in India, the *neglectums* of forma *burmanica* are of interest and value in that types have been selected from them which combine ginning percentage up to 40 with lint up to 1" in staple, and reasonably fine.

The introduction of cotton cultivation into China took place between the 11th and 13th centuries (See Watt 1907), and it is stated in Chinese records that it was introduced from India by two routes. The northern cottons of the valley of the Yellow River were carried overland, from Bengal and Assam, while the more southern cottons of the Yangtse valley were brought by sea from Indo-China. In response to the short growing season of China and neighbouring regions the development of the annual habit has proceeded to a degree only exceeded by the earliest forms of *G. herbaceum* var. *typicum* from the equally short season tracts on the north slopes of the Pamirs. Monopodial development is completely suppressed, and sympodial fruiting branches arise at a very early stage.

The northern types of the valley of the Yellow River are very coarse, as would be expected in view of their introduction overland from Bengal or Assam, and they may be placed between *G. arboreum* var. *neglectum* forma *bengalensis*, and *G. arboreum* var. *cernuum*. The cottons of the Yangtse valley, which were introduced by the sea route, are finer, and belong to *G. arboreum* var. *neglectum* forma *burmanica*.

In Africa *G. arboreum* var. *typicum* forma *soudanensis* occurs in Abyssinia, the Anglo-Egyptian Sudan, and the French Sudan. *G. arboreum* var. *neglectum* forma *soudanensis*, clearly closely related to *G. arboreum* var. *typicum* forma *soudanensis*, is also found in the French Sudan, Oubangui Chari, and South of Lake Chad, and in French West Africa (Dahomey & Mossi) and Nigeria. [Chevalier (1936) Rev. de Bot. Appl. d' Agr. Trop., in press]. Chevalier (1936) records that *neglectum soudanensis* was formerly cultivated, but its lint is no longer often used. The plant is regarded as a fetish, and is used medicinally.

Finally, of two perennial types of *G. arboreum* obtained from Madagascar, one produced its first sympodium at about node 20, while the other did not develop a fruiting branch on the main stem until about the 50th node. I am indebted to M. Perrier de la Bathie for the information that the former (earlier) type is that originally cultivated by the Malagasy before the introduction of New World types, while the latter is truly wild. This illustrates the first stage in the development of a *neglectum*.

The distribution and relationships of the African forms of *G. herbaceum* L. have been greatly clarified by Chevalier (1936), who re-arranged his material according to Hutchinson and Ghose's (1936) classification. He did not find typical *G. herbaceum* L. var. *africanum* Watt in the French African colonies. The typical form of this variety is confined to the bushveld regions of South Africa from Bechuanaland to Mozambique. The *herbaceum* cotton of North Africa is *G. herbaceum* L. var. *frutescens* Delile. Chevalier (1936) states that this is the cotton which was cultivated by the negroes of the whole of tropical Africa (except those of the great forests) before the introduction of American species. He records its survival in the cultivations of the negroes in the French Sudan, the regions south of Lake Chad, Dahomey and neighbouring territories, Senegal, Nigeria, and oases in the Sahara, and adds that it still survives in Nubia, where Delile first collected it. The most important of Chevalier's observations, however, is that in fallows and abandoned cultivations, types intermediate between var. *africanum* and var. *frutescens* are constantly to be found, especially in north Bornu, showing that the two varieties are as closely related as the wild and cultivated forms of *G. arboreum*. As in the latter, the development of the cultivated species has been by selection of forms which produce fruiting branches earlier in their life history, and have better lint. Chevalier's description of intermediates explains the records of the occurrence of *G. herbaceum* var. *africanum* from Bornu and Kordofan. There is no doubt that *G. herbaceum* var. *africanum* is wild in the South African bushveld, but Chevalier (in correspondence) states that it certainly is not wild in West Africa, and var. *frutescens* is always found either in, or in association with, negro cultivations. The absence of any record of indigenous wild or cultivated cottons in Tanganyika is remarkable, and I have been unable to find any record of an indigenous cotton between Zambesia and Nubia.

In India, *G. herbaceum* var. *frutescens* is distributed throughout the cotton growing tracts of western India from Cutch to Madras. The centre of variability in India is Gujerat [see Patel (1920) and Hutchinson and Ghose (1936 in press)] where there occurs almost the whole range of forms found in the variety. In Gujerat the predominant types are bushy, with a number of monopodial branches. The Wagad type, typical of northern Kathiawar and Cutch, has much less monopodial development, and round bolls which hardly open when ripe, characteristics which indicate an approach to *G. herbaceum* var. *typicum* of the areas north and west of the Indus river. South of Gujerat in Kanara, the Deccan, and Madras, the *frutescens* cottons (Kumpta and Uppam) have also developed an earlier and much less branched habit than is exhibited by the Gujerat types. *G. herbaceum* var. *typicum* is found in Afghanistan, Iran, Russian Turkestan, Baluchistan and Iraq, and has been distributed since the Mohammedan invasions of the 9th and 10th centuries, in the countries round the Mediterranean [Watt (1907)]. Its centre of variability has been located by the Russian workers in northern Iran, and Afghanistan [Chernyakovskaya (1930)]. Its early habit and lack of monopodial development, together with its northern distribution, indicate relatively late development. The Wagad type

of *G. herbaceum* var. *frutescens*, with the closed boll and early habit so common in *G. herbaceum* var. *typicum*, provides a link showing the line of development by which the latter has developed from *G. herbaceum* var. *frutescens* or its close relatives in response to the selective influences of a northern climate with a short season. In *G. herbaceum* var. *typicum* are found the earliest fruiting types of cotton known. Some strains from the northern slopes of the Pamirs develop the first fruiting branch as early as the first node above the cotyledons.

The distributions of *G. arboreum* and *G. herbaceum* overlap in India, and in parts of the Madras Presidency the two species are grown together in mixed crops of Uppam and Karunganni. It is a striking fact that, even though the F_1 hybrid between them is remarkably vigorous and productive, hybrids of later generations are rare, and the integrity of the two species is maintained unimpaired. Evidence obtained from F_2 s and later generations of similar hybrids grown under experimental conditions leads to the conclusion that the breakdown of the specific balance by segregation [see Harland (1936)] results in the appearance of types, the great majority of which are unfit to compete with the parental species.

V. WILD SPECIES.

Two wild species of *Gossypium* are indigenous in Africa, *G. triphyllum* [*Cienfugosia triphylla* (Harv.) Hochr.] of South West Africa, and *G. anomalum* Waw. & Peyr. Concerning the former little is known. It is assigned to *Gossypium* by Chevalier (1933) and Skovsted (1935 b). *G. anomalum* was originally described by Wawra and Peyritsch [in Sertum Benguel., S. 11 (1836) vide Wittmack (1928)] from material collected in Benguela, but subsequent records of its occurrence are from the arid steppes, thorny zones, and stony lands on the southern borders of the Sahara [Chevalier (1933)]. Chevalier (1933 & 1935) gives a good account of the present state of knowledge of the species, but it is not possible to assent to his speculations concerning its relationships with the cultivated Asiatic cottons.

G. Stocksii is indigenous in Sind and south eastern Arabia.

G. anomalum & *G. Stocksii* have a similar chromosome complement to that of the Asiatic cultivated cottons [Skovsted (1935 b)], and they will hybridise with them. Hybrids of *G. Stocksii* with cultivated Asiatic cottons are completely sterile. Hybrids of *G. anomalum* are slightly fertile. These species are of particular interest, in that *G. anomalum* resembles *G. arboreum* in many characters and *G. Stocksii* resembles *G. herbaceum* in the same ways. The parallelism is striking, and forms an admirable example of the "law of homologous series" referred to by Zaitzev (1927) in his discussion of the relationships of cotton species.

All the other wild species at present assigned to *Gossypium* are indigenous to the lands bordering on the Pacific. Of 13 chromosome species, Skovsted (1935 b) places *G. Davidsonii* from Southern California and *G. Sturtii* from Australia in isolated classes. Presumably *G. Robinsoni*, also a wild Australian species, is related

to *G. Sturtii*. *G. trilobum*, *G. Harknessii*, *G. Armourianum*, *G. aridum*, and *G. Klotzchianum* form a group to themselves. Hybridisation between cultivated New World cottons (26 chromosomes) and *G. aridum* and *G. Armourianum* is easy, and gives fertile hybrids [Skovsted (1935 b)].

The wild 26 chromosome cottons are all found on islands in the Pacific. *G. tomentosum* is endemic in the Hawaiian islands, and *G. Darwinii* in the Galapagos islands. *G. tailense* is indigenous in Fiji and Tahiti, but the limits of its distribution are not well defined owing to confusion between it and wild, or escaped, naturalised forms of *G. religiosum*. All three species give fully fertile hybrids with the cultivated 26 chromosome cottons.

Of great interest and importance is the problem of the origin and relationships of the 26 chromosome cottons. From crosses between them and different types of 13 chromosome cottons, and from a comparison of their meiotic behaviour with that of a triploid Asiatic cotton, Skovsted (1934) concludes that the set of 26 consists of a set of 13 homologous with that of the cultivated Asiatic cottons, and a set of 13 homologous with that of the wild 13 chromosome New World group. He supposes that the 26 complement has arisen by chromosome doubling in a hybrid between types related to the Asiatic, and wild New World 13 chromosome cottons respectively. Gates (1934) and Davie (1935) favour the view that the formation of the 26 complement is the result of crossing between New World 13 chromosome species. Davie (1935) finds difficulty in accepting the theory that Asiatic cottons or their close relatives have entered into the ancestry of the New World Cottons, in view of the fact [well established by Kearney (1930) and others] that cotton was cultivated and spun in America before its discovery by Columbus, and he puts forward the suggestion that they may have arisen as a result of crossing between *G. mexicanum* or *G. brasiliense* and wild American cottons. As *G. mexicanum* is only a form of *G. hirsutum*, and *G. brasiliense* a form of *G. barbadense*, this suggestion falls to the ground. Harland (1935) argues that the New World allopolyploids probably arose in the manner suggested by Skovsted, in the Pacific region when there was a land connection between South America and the East Indies. The cytological evidence, and the distribution of the species in and around the Pacific agrees better with this theory than with any other. Consideration of the distribution of species having a complement of 13 chromosomes of the Asiatic type leads to the conclusion that only *G. arboreum* or its prototype is likely to have existed in the Pacific region at the time of origin of the 26 chromosome cottons.

VI. DISCUSSION.

The history of the cultivated species of cotton provides an example such as is not often obtainable, of considerable evolutionary progress in historic times. Annual cottons of the Upland group have probably existed on the Mexican plateau for a long period, but the course of evolution is clear. From perennial shrubs, glabrous

or nearly so, with small leaves, small bolls, and scant lint (exemplified by the *G. Palmerii* of Watt, *G. microcarpum* of Todaro) two lines of development have taken place. In the moist tropical regions of the Pacific coast of Central America, the Spanish Main, and the West Indies, the perennial habit remained, and the evolution of *G. religiosum* was primarily by selection for better cropping power, larger bolls, and better lint. On the plateau, however, the perennial habit is at a selective disadvantage, and there the annual *G. hirsutum* arose, and with the modern demand for its product, intense selection for earliness, hairiness (for pest resistance), cropping power, boll size, and fineness and abundance of lint, produced the varieties of commerce.

On *G. barbadense*, the tropical cotton of South America, the selective forces associated with large scale cultivation did not impinge until later. It was then under environments outside its natural range—South Carolina and Egypt—that development took place. The response to selection for the annual habit, cropping power, and lint quantity have led, in less than 300 years, to the evolution of types almost as early and as high yielding as any, and of better quality than all other cottons.

The main line of evolutionary progress—development from highly monopodial, perennial, sub-scandent bushes to sympodial, annual, erect small shrubs—has been the same in both cultivated Old World species as in those of the New World. The details of the process have been very different in the two species owing to a great difference in the distribution of the wild forms from which those of cultivation have been derived.

Wild types of *G. arboreum* are to be found in all countries from Abyssinia and Madagascar to the Philippines. The demands of cultivation have influenced them at many points in their distribution, and it is possible to identify at least four centres of development of annual cottons. Of these, probably that in Assam and Bengal is the oldest, and has given rise, in addition to the northern Indian types of var. *neglectum* (forma *bengalensis*) to the distinct var. *cernuum*, which appears to be specialised in response to the environment of hill cultivation under heavy rainfall, and probably to the coarse cottons of the northern sections of the Chinese crop. The commencement of the development of the Burma-Indo-China-China series of *neglectums* (forma *burmanica*) can be dated with confidence by records of the time of introduction of cotton into China, which is given by Watt (1907) as between the 7th century, when it first became known there, and the 13th century, when its cultivation was undertaken. In South India much of the development of early types has taken place during the last century.

All the early literature on cotton in India speaks of the cultivation of perennials, [see Watt (1907)] and it is fairly safe to hazard a guess that in the tenth century, annual cottons were practically unknown in India, except possibly in the hill tracts of Bengal and Assam.

The development of the *herbaceum* cottons differs from that of the *arboresum*, in that the distribution of the primitive wild perennial types was probably limited to the bushveld regions of South Africa. Chevalier is emphatic that the types of *G. herbaceum* var. *africanum* and var. *frutescens* and their intermediates, with which he is familiar, are not wild in the French African colonies. Chevalier's analysis and interpretation of the African types justifies Zaitzev's designation of *G. herbaceum* and its varieties as the "African group." *G. herbaceum* var. *africanum* is a wild, perennial, highly monopodial sub-scandent bush, almost glabrous, with small leaves, small bolls, and sparse, worthless lint. From it, Chevalier records a series of intermediate types grading to cultivated forms of *G. herbaceum* var. *frutescens* which, with their erect, annual, moderately sympodial habit, intense hairiness, large leaves, large bolls, and abundant lint, are indistinguishable from the forms of the variety now cultivated in India. In India, further development of the sympodial habit has occurred, in both the southern and the northern extensions of the distribution. Information concerning the African types is scanty, but so far as can be discovered, the closed boll character arose first in the northern part of the Indian distribution, and has become the commonest type in *G. herbaceum* var. *typicum*, which represents the climax in this species of the development of the early sympodial habit, and contains the earliest types of cotton known.

Such information as it has been possible to collect indicates that the introduction of *G. herbaceum* into India must have taken place in fairly recent times. Watt (1907) summarises the reports of travellers, and until the advent of the British in India there appears to be no record of the cultivation of annual cottons, and Marco Polo (1290 A.D.) specifically refers to the cotton trees of Gujerat as attaining the age of 20 years. From the fact that Rozi (*G. arboresum*) is still cultivated in Gujerat, and is known to have occupied a larger proportion of the cotton area there in the past, it is legitimate to assume that the Gujerat cotton of Marco Polo's time was *G. arboresum*. There would certainly be no inducement to replace the indigenous Rozi with a *G. herbaceum* resembling any of the perennial forms of the species now known. Watt (1890) states that cotton was not known in Persia before the Christian era. It may be suggested that *G. herbaceum* var. *frutescens* was introduced from Africa into India when the value of annual cottons began to be appreciated, and was then carried to Persia and Afghanistan by those who realized that the annual habit made possible its cultivation in regions with cold winters. This probably took place some centuries before the displacement of perennial cottons in India occurred on a large scale, as the incentive to grow annuals was much less in India than in more northern countries.

The evolution of the 26 chromosome group of species is too old to be subject to such an analysis as it is possible to make of the developments within species. Skovsted's (1934) analysis of the chromosome complement of the New World cottons together with the known facts of geographical distribution and genetic homology point strongly to allotetraploid synthesis from relatives of the New World and of

the Old World 13 chromosome groups. Comparison of the distributions of *G. arboreum* and *G. herbaceum* suggest that primitive relatives of *G. arboreum* are more likely to have been involved than relatives of *G. herbaceum*. Zaitzev, however drew attention to the homology between *G. herbaceum* and the Upland—Bourbor group, and between *G. arboreum* and the Peruvian (*G. barbadense*) group, and the possibility of independent parallel origin of the two New World groups cannot be ignored.

VII. SUMMARY.

(1) Current opinions concerning the distribution and relationships of species of *Gossypium* are summarised.

(2) An account is given of the present state of knowledge of the phytogeography of the genus, in the light of recent revisions of its classifications.

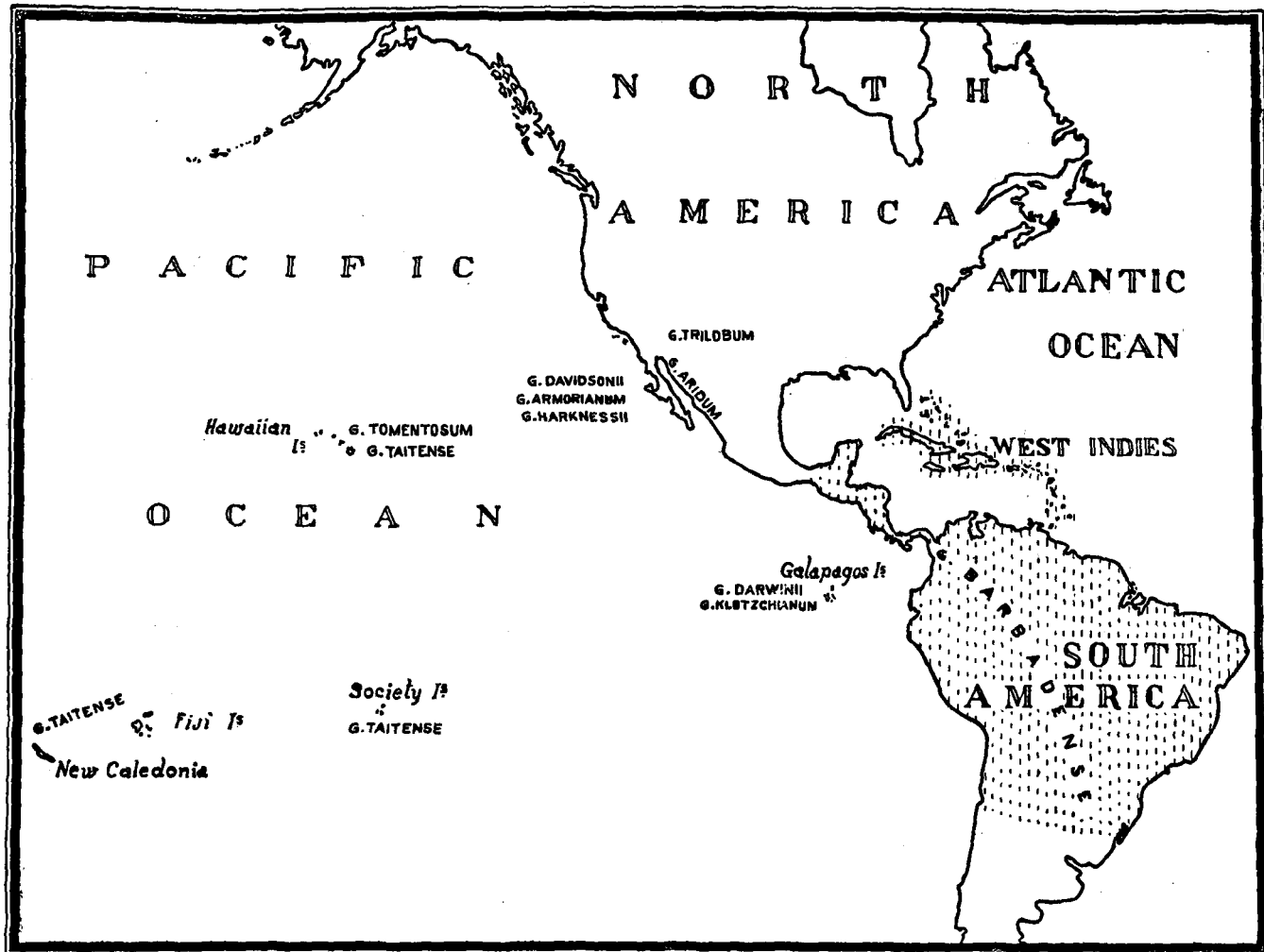
Great extensions in the distribution of the five cultivated species have taken place in recent times and it is shown that side by side with these extensions, four of the five species have undergone very rapid evolution. The course of this recent evolutionary process has been parallel in all species. In *G. hirsutum*, *G. herbaceum* and the northern Indian and Chinese forms of *G. arboreum* early annual, sympodial types have been developed from perennial, highly monopodial, bushy forms in response to the selective influences of short growing seasons and cold winters encountered in continental monsoon climates and in the recent northerly extensions of their distributions. The interaction of environmental pressure and evolutionary response must have been extremely close, invasion of short season areas being impossible without the annual habit which could only be developed in response to it.

In *G. barbadense*, and in the southern Indian types of *G. arboreum*, a similar development of annual sympodial types has taken place in the last few centuries in response to the demand of agriculture for the simpler crop management and better pest control which is possible with annual types.

(3) It is pointed out that the changes which have taken place in the cultivated species of cotton afford an excellent demonstration of the progress of evolution within historic times.

(4) The work of Skovsted on the analysis of the chromosome complement of New World cottons is referred to, and other recent theories on the subject are mentioned. Skovsted's cytological evidence, together with Harland's genetic evidence is considered to give strong support to the theory that the 26 chromosome cotton arose by allotetraploidy from a hybrid between two 13 chromosome types, one related to the wild 13 chromosome cottons of the New World, and the other related to the cultivated 13 chromosome cottons of Asia, the line of meeting of the two being across the Pacific and not across the Atlantic.

MAP I. DISTRIBUTION OF GOSSYPIUM



MAP II. DISTRIBUTION OF GOSSYPIUM

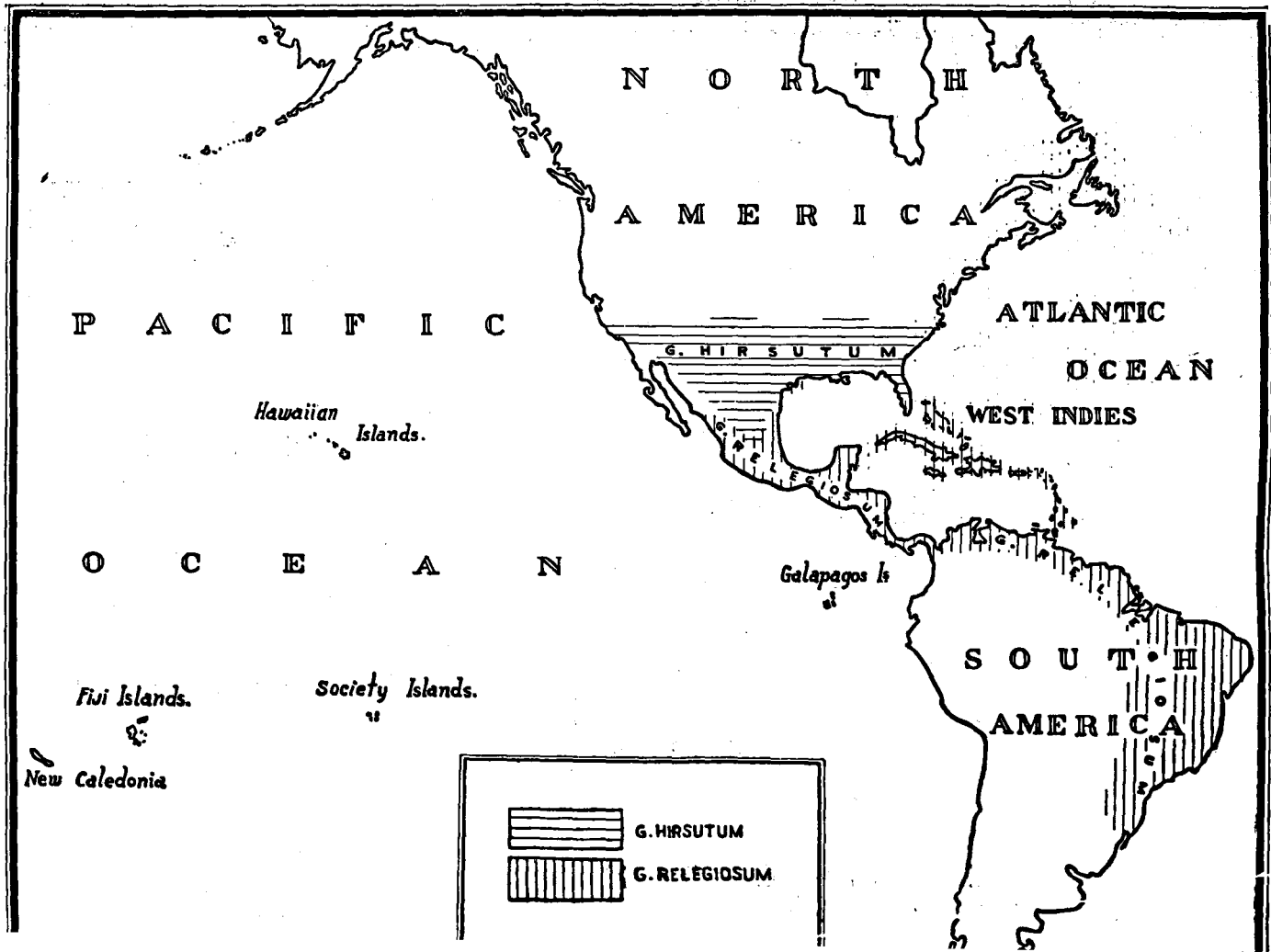
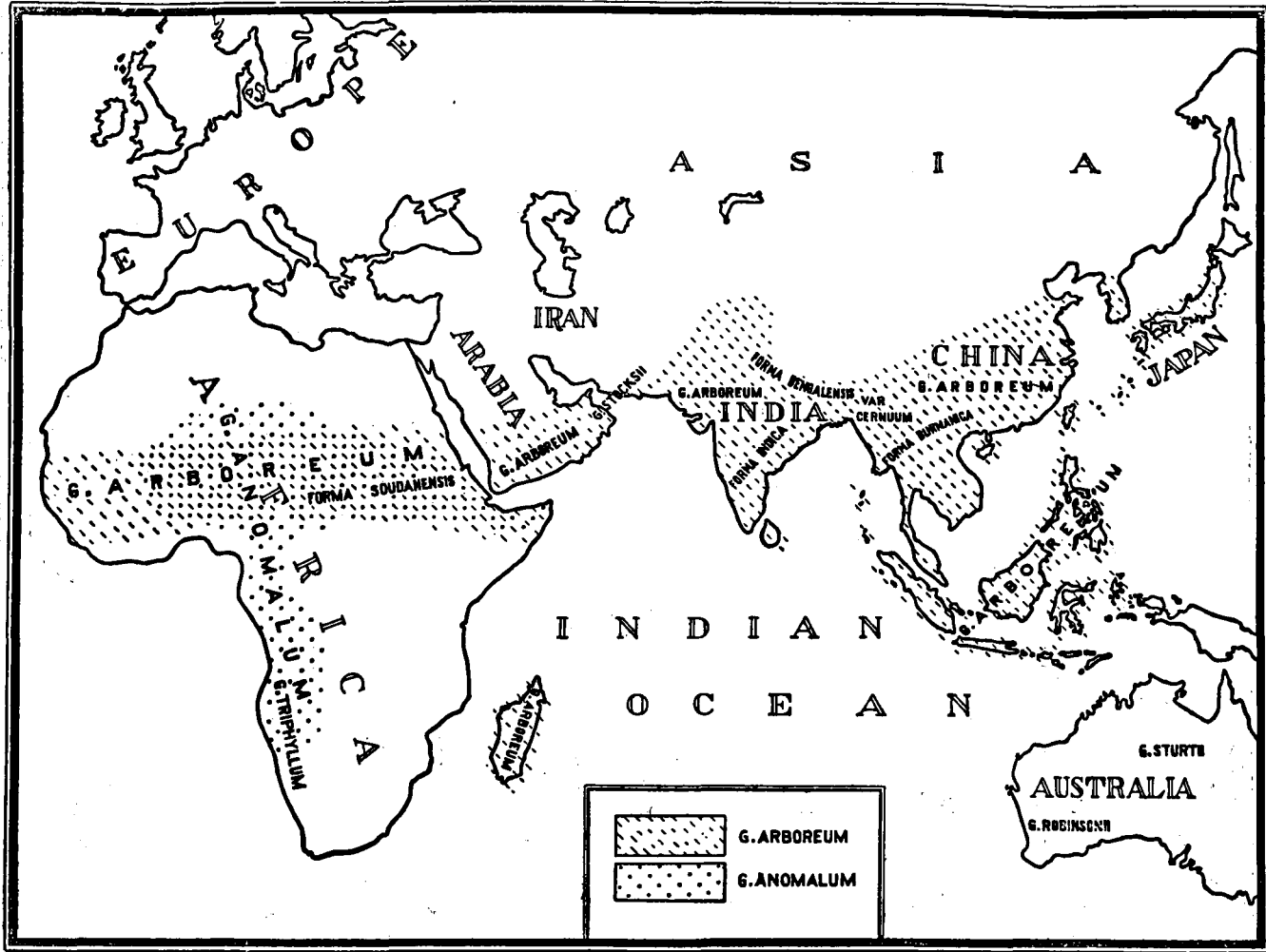
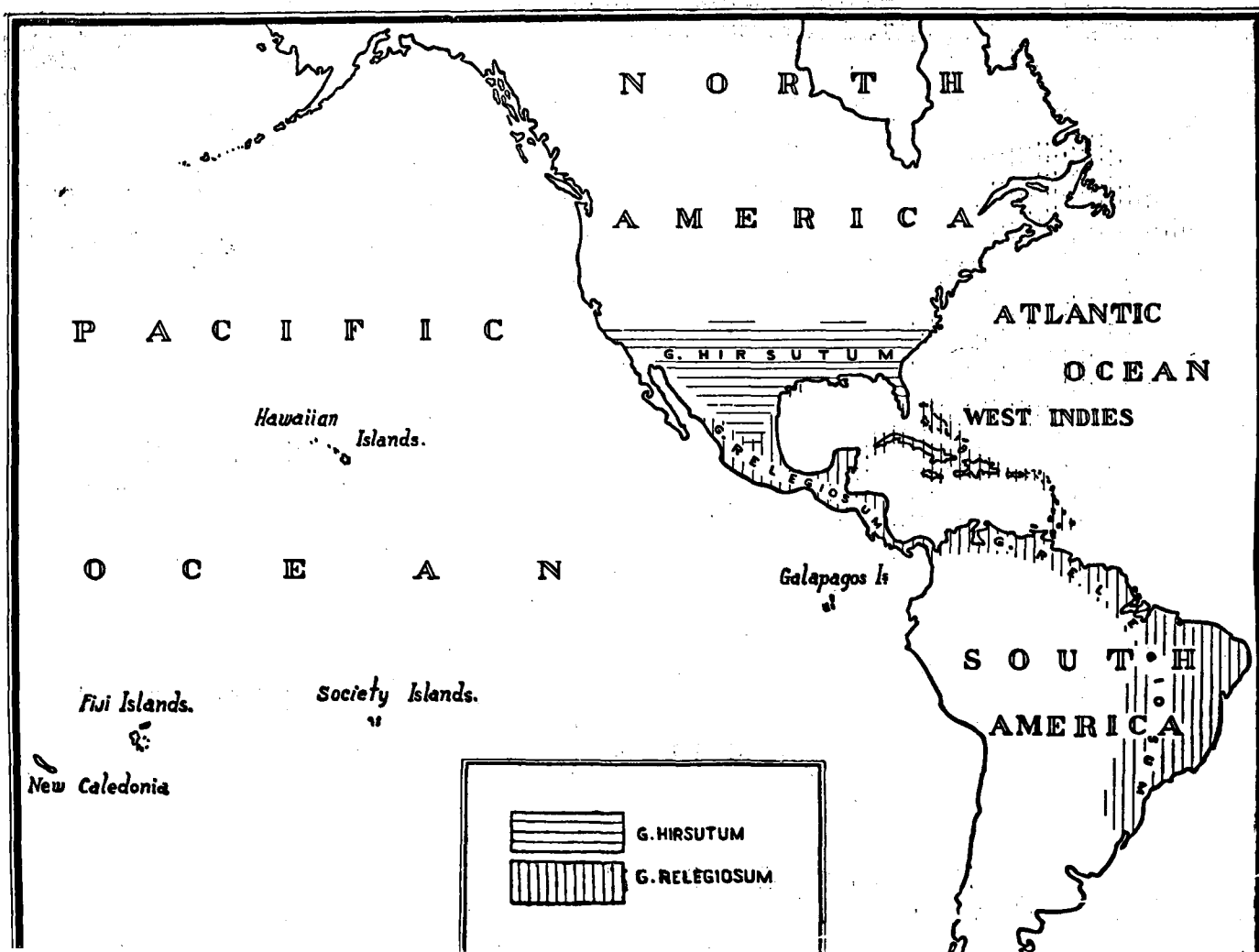


PLATE III. DISTRIBUTION OF GUSSEUM

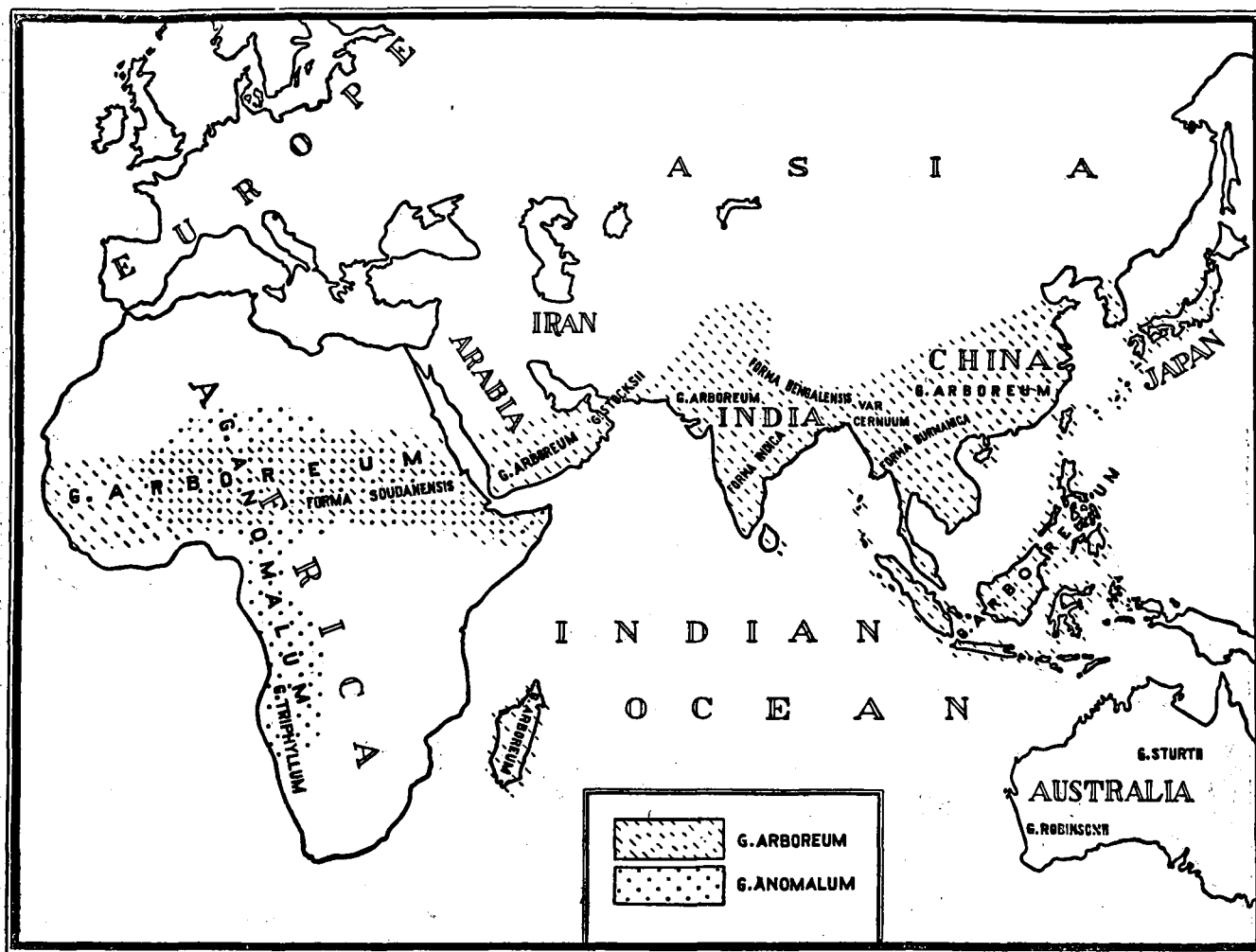


G. ARBOREUM & WILD OLD WORLD SPECIES

MAP OF DISTRIBUTION OF GOSSYPIUM

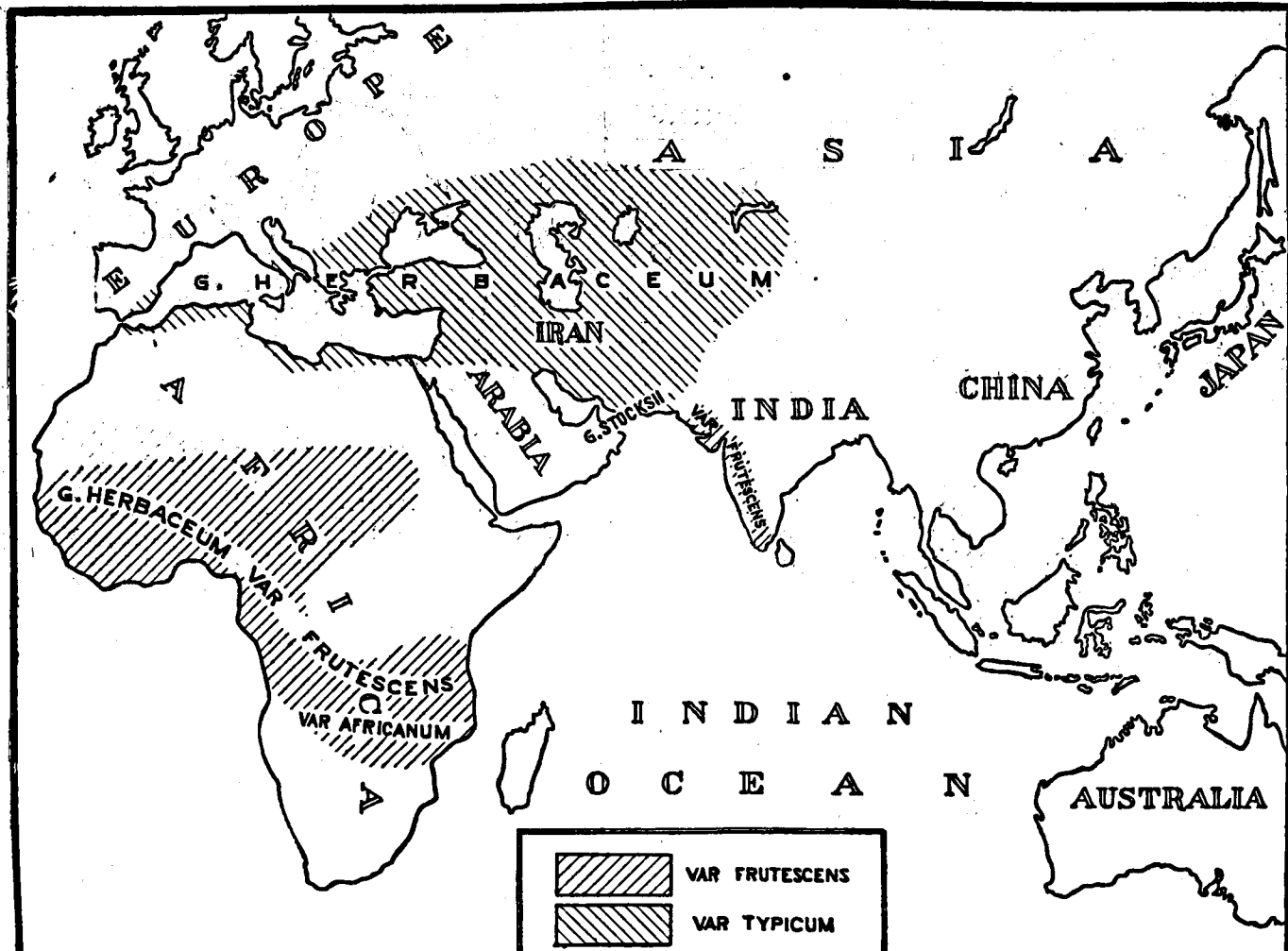


MAP III. DISTRIBUTION OF GUSSEIUM



G. ARBOREUM & WILD OLD WORLD SPECIES

MAP IV. DISTRIBUTION OF GOSSYPIUM



VIII. ACKNOWLEDGMENTS.

I am very greatly indebted to Prof. Aug. Chevalier of the Museum National d'Histoire Naturelle in Paris for invaluable information concerning the indigenous cottons of Africa, and I owe to M. Perrier de la Bathie my knowledge of those indigenous in Madagascar. Mr. Rāmanathan, Cotton Specialist to the Madras Government and Mr. R. L. M. Ghose of the Institute of Plant Industry, have provided much of the information necessary for the interpretation of the history of cotton in India.

I am obliged to Mr. Y. S. Chen, of the Central Cotton Improvement Institute, Nanking, China, for information concerning the routes by which cotton was introduced into China.

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DISCUSSION.

Mr. J. B. Hutchinson introducing his paper said that he would first take up the maps at the end and give his remarks. The first map showed the distribution of *G. barbadense* and roughly of all the wild cottons of the Pacific regions. One of the most important contributions to the knowledge of the distribution of *Gossypium* had been the sorting out of the distribution of the wild species in relation to the chromosome number. There had been a good deal of argument notably between Davie working in England and Skovsted in Trinidad in regard to the old world cottons and the new world cottons. Davie tried to show that Skovsted was not by any means right in his argument that the line of meeting of the old world and new world cottons was not across the Atlantic. The Atlantic forms a sharp natural division in the distribution of the genus. The distribution of the wild species made it very clear that the connecting bridge was across the Pacific and not across the Atlantic. As given in the paper the 26 chromosome species were the natives of the Pacific regions while on the western borders of the American Continent there was a group of 13 chromosome wild species and in Australia there were two wild species so that 13 and 26 chromosome cottons were to be found in the Pacific regions. The 13 chromosome New World group has been shown by Skovsted to be a set homologous to half the set of 26 of the New World cottons, the other half of the New World 26 being homologous to the Asiatic cottons so that it was a reasonable assumption that the New World 26 chromosome might have arisen as a result of a cross between an ancestor of Asiatic 13 and an ancestor of New World 13. Turning to *G. barbadense*, a South American cotton, he continued that Russian workers had shown that it had its centre of variability in the North-Western parts of South America notably Columbia and Equador and the western parts of Venezuela and that it extended right through the whole tropical regions of South America except in the great forests where cottons could not be grown. This species was almost entirely perennial but there had been separate developments of annual types in recent times from these perennials. The first was the development of the Sea Islands which resulted from the selection for the annual habit of *barbadense* cottons taken from the West Indies to South Carolina. They were returned to West Indies and they were a great deal better suited for growth than the perennials from which they had been developed on account of the fact that annual crops made it possible to work out a close season. The second development of annual types was the development of Egyptian cottons from the hybrid between Jumel's perennial *G. barbadense* and the introduced Sea Island so that there again the Sea Island stocks had a great deal to do with the development of the second group of annual cottons in *barbadense*. The third group was that at present grown in the irrigated valleys of the West Coast of South America usually known as Tanguis and was a very mixed lot. It was usually referred to as American and the photographs seen in the Peruvian bulletins showed a very considerable amount of variability and there appeared to be a large number of intermediates between it and the typical perennial South American *barbadense*.

He then turned over to the next map where the distribution of *G. hirsutum* and *G. religiosum* was shown. Regarding the meaning of *G. religiosum* he said that a re-arrangement of the classification of *Gossypium* would be out shortly, where *G. religiosum* was attached to the Bourbon cotton instead of to *G. purpurascens* adopted by Harland, because an examination of the types in the Linnæan herbarium showed that the name *G. religiosum* L. must take precedence. Russian workers Zaitzev and Mauer had mixed them together though their reasons required further substantiation. *G. hirsutum* and *G. religiosum* were closely related, *religiosum* differing primarily in the fact that it was perennial and in other minor characters and he invited Mr. Ramanatha Ayyar's opinion thereon. There was very little doubt that they had descended from a common stock from Central America of which probably *G. palmerii* was the wild proto-type, the annual type having been developed in the Central Plateau of Mexico where perennials had persisted all along the coast regions and along the east coast of South America and as far as cotton growing regions in Brazil. The distribution of *hirsutum* at the present time had resulted in a very large extension after the colonisation of America by the European race and practically the whole of the modern cotton belt was not within the region of natural distribution of *Gossypium*. There has been a good deal of argument about what was the first cotton taken over there. Mr. George Watt opined that it was *G. herbaceum* taken from the Levant, the Mediterranean region. The determination of chromosome numbers effectually proved that *G. herbaceum* had no part in the ancestry of *G. hirsutum*. There was very little reason to doubt that the latter resulted from the collection of Mexican cottons of various people and their despatch to Europe. Three Mexican cottons were subsequently sent to Carolina and other parts by botanists who were interested in the agricultural botany of the new Colonies. Referring to the map giving the distribution of *G. arboreum* and *G. anomalum*, he said that *G. anomalum* was a wild African species which had 13 chromosomes. Being the most widely distributed of any species of cotton *G. arboreum* was recorded from West Africa right across to Japan and Korea to the islands of Dutch East Indies to the South. All over that area wherever perennial crops were possible and even in Madagascar, wild primitive *arboreum* cottons with little lint which was difficult to get off the hard seed would be found and these apparently were the types from which cultivated *arboreum* cottons had been developed. Here again the general phenomenon of development of annual types would be noticed and this development had made too great extensions in area in the geographical distribution of the species. One great extension had been in China and Japan. Cotton was unknown in China in the 7th century and by the 13th century it had become a commercial crop of importance. He learnt from Mr. Chen that cotton reached China by two separate routes. Cottons of the Yellow River in northern China were taken overland from Bengal while the more southern cottons of the Yangtse valley were brought by sea from Indo-China. If that was so it was probable that the cottons of the Yellow River were coarser than the cottons of the Yangtse Valley, as it was to be expected that cotton sent from Assam would be

coarser than cotton sent from Indo-China. The development of annual habit had taken place independently in various parts of the distribution of the old primitive perennials. There was the development of annual cottons in Africa, Burma and Indo-China while in India annual cottons developed in two separate places. There were the Banis and Karungannis and the great mass of Oomras and Bengals cottons of fairly short staple with high ginning percentage, to which Mr. Ramanatha Ayyar would probably add further information. It was interesting to analyse somewhat the history of cotton in recent times in India. The development of power ginning industry at a time when the mill industry such as was in existence here was only concerned with coarse counts led to the development of an easy premium for ginning percentage as against the comparatively small premium for quality which was difficult to obtain under conditions existing 50 or 60 years ago. At any rate in old times premium for ginning percentage was obtainable and not premium for quality and staple and as a result there was a very heavy invasion of short staple cottons in the medium staple areas. This invasion took the form of Oomras in Central India and in the Central Provinces and Berar and in Kathiawar the invader was known as Mathio, a short staple cotton. In the Punjab, however, where there was not much cotton grown before, staple cotton extended, but at the same time there was also the invasion of short staple cotton so that at present the two invaders were side by side, fairly well balanced one against the other. He emphasised that the cottons which dragged down the reputation of Indian cotton were Punjab and Sind Desi, Rajputana and the United Provinces Desi, Oomras of Central India and the Mathios, whereas the Southern types and the American types and the bulk of herbaceum cottons which were of medium staple would always find a ready market. He was of opinion that there was a likelihood of getting back to a decent quality by selection among the best in a place like the Central Provinces, where the coarse cotton had swamped Bani, a fine cotton. It is a matter of experience that in the Central Provinces and Hyderabad State good medium staple cotton required was already available as a result of selection, whereas in the Punjab it has been necessary to resort to hybridisation before improvements could be obtained as in the case of Jubilee cotton. Passing on to the distribution of herbaceum he said that he was much indebted to a very prominent French Botanist, Professor Chevalier for assistance in elucidating the distribution of herbaceum. He (Mr. Hutchinson) thought that it would have to be accepted that herbaceum var. frutescens had been recorded in cultivation right up from Nyasaland, and Portuguese West Africa to the French Colonies of Equatorial Africa and right across Senegal to Congo. The native grown cotton from Bechuanaland to Mozambique was morphologically indistinguishable from the Goghari in the Bombay Presidency. In India *G. herbaceum* var. *frutescens* was distributed throughout the cotton-growing tract of Western India and the centre of variability was in Gujarat where the predominant types were more bushy than the southern types such as Hagari and Uppam. He preferred to call Wagad var. *frutescens* while Mr. Ramanatha Ayyar would call it var.

typicum. In Iran and Afghanistan, *G. herbaceum* var. **typicum** was found, and its early habit and lack of monopodial development indicated a relatively late development. The rough outline of the cultivated cottons showed a steady selection pressure of cultivated species in favour of the annual habit and consequent increased distribution. The distribution of **herbaceum** var. **typicum** was from Chinese Turkestan right away through the Mediterranean region, and as far as Chinese Turkestan was concerned the bulk of that distribution had been covered in the last 8 or 9 centuries probably by the Mahommadan invaders. When it got into Iran it was not known. There must be a very strong ground for agreeing with Zaitzev in calling **herbaceum** the African species. He believed that there was a tendency which exerted itself possibly through all cultivated species of cotton so that the more its cultivation was extended the more the annual habits came to be known.

Mr. Ramanatha Ayyar said that a comparison of the floral anatomy of the three American cottons, **hirsutum**, **barbadense** and **religiosum** pointed out that **G. religiosum** was not only a separate species but it was also more allied to wild species than the **hirsutum** and **barbadense** cottons. In the wild species the number of vascular strands was very much lower than that in the cultivated varieties and **religiosum** had a fewer number of strands in the thalamus than the other two. The anatomical studies further indicated the possibility that **herbaceum** cottons could have more likely been one of the parents for constituting the allotetraploid New World group than the **arboreum** forms. With regard to **arboreum** cottons in India, he thought that Mr. Hutchinson was right in concluding that the annual forms of south India differed from those in north India especially the **roseum** and **cernuum** group. Anatomical studies showed that all the south Indian forms had the **arboreum** type of anatomy. It was of interest to note that some of the Madras forms which had the similar morphological features like the north Indian **Roseum** and **cernuum** cottons had the **arboreum** vascular system indicating strongly that they had originated from **arboreum**. He added that Mr. Hutchinson seemed to be correct in his hypothesis that **cernuum** cottons were evolved in Eastern Bengal and Assam. For it was stated in the East India Company's letters of 1780 that a lot of fairly long stapled cotton was being cultivated in portions of United Provinces called Vizier's dominions. These were first imported into Allahabad and thence to Mirzapur, and finally to Calcutta by river. Nagpur and Amraoti cottons which were also annual types were carried to Allahabad on pack animals and from there to Calcutta. Referring to the foot note on page 7 of the paper that "it is an interesting example of the confusion into which the nomenclature of cotton has fallen, that *Mollisoni* the broad leaved, white flowered northern neglectum predominant in the Punjab, has usually been assigned to **G. indicum** a name only applicable to the South Indian types now included in **G. arboreum**," he said that he was unable to subscribe to that view. From anatomical studies he found that **G. sanguineum** had the same anatomical features as in *Banis*, *Karungannis* and *Nadams* and very probably formed the relics of **arboreum** cottons grown prior to the invasion by the

Assam neglectums. With regard to the spread of arboreum Cotton in Madras, he was of opinion that the centre of origin would have been somewhere in the Vizag-district where many types varying widely in morphological characters were yet to be found. It appeared possible that the broad lobed perennial cottons spread along the eastern coast as far as Tinnevely district. It was interesting to observe that the cotton called Podupathi in Vizag district was exactly alike to the Nadams of Tinnevely district in morphological and agricultural characters. He further opined that Karungannis should have been evolved from the Tinnevely Nadam about a century ago. He added that he disagreed with the suggestion that annual herbaceums should have first come to India and then spread to Persia, as he thought that it should have been the other way. Marco Polo reported that during his visit to Yarkand in the thirteenth century he came across annual types whereas he referred to Gujarat cottons as plants 20' to 30' high, hinting thereby that they were not annuals. Besides herbaceums were called by some of the earlier writers as *G. annuam* and in fact were known to grow in Asia Minor and Egypt much earlier than they were known to be cultivated in India.

As regards the view that Dacca Muslins were prepared from a perennial cotton, he said that from one of the letters written to the East India Company in 1789 he understood that Dacca Muslins were prepared not from perennial cotton but from an annual cotton called 'photee' grown in Assam, whose chief peculiarity was that when it was bleached its fibres did not swell. It was also said that kapas picked fresh from the plant was not useful for spinning fine Muslins and that it must be stored for one year before only it would be useful for preparing fine yarns. It appeared that the finest cottons in India at that time were the Broach cottons and next came Ansoti and the Nagpur cottons, and the coarsest were from Assam. So long as Bengal was manufacturing muslins, fine types were needed and in fact imported from other provinces in large quantities; but when machine made articles were imported from Europe the cultivation of fine cottons was reduced. The demand at that time was for short staple cotton for export to China and this factor accelerated the spread of Assam cotton, called Bhoja kapas throughout the northern and central parts of India and its high yield kept it on there, permanently.

Dr. Nazir Ahmad referring to tests carried out on Dacca muslin at the Laboratory as well as at the Shirley Institute said that the mean fibre length of the cotton used in the manufacture of this fine material was found to be just about an inch, the fibre-weight per inch was 0.12 to 0.15 × 10 oz. and the yarn was so fine that there were only 10 to 15 fibres in a cross section of the yarn. The cotton used resembled the Punjab American 289-F cotton. With regard to Mr. Hutchinson's remarks about the pulling down of the reputation of Indian cottons, he said that considerable loss of reputation of Indian cottons in England took place during the American Civil War when supplies of American cottons nearly came to an end and large supplies of Indian cottons were requisitioned as substitute by the Lancashire

mills. It is said that on one occasion a Lancashire spinner took a sample of Indian cotton, pulled it as they do for estimating the staple length and said "where's the other end?" The impression produced in the minds of the Lancashire spinners was so bad that it took them a long time to appreciate the proper performance of the Indian cottons, especially the good quality types. The Lancashire Indian Cotton Committee has been supplementing the efforts of the Indian Central Cotton Committee to push up the takings of Indian cottons by Lancashire and it was up to the members of this Conference to help both the Committees by not only maintaining but even improving the quality of the Indian cottons. Referring to the observations in regard to the effect of spinning, about 50 years ago, coarse counts on the premia paid for short staple cotton, he said that it was another instance of the way in which an economic factor can affect the relative prices of different types of cotton regardless of their intrinsic value. He might give yet another example. During the last year on account of the requirements of armament manufacturers for the manufacture of gun material the premia for short staple cottons has gone up considerably. All these factors should be taken into consideration when laying down the policy of cotton cultivation in a large area. He then drew attention to the attempts which are being made to extend the cultivation of cotton by Russia in Russian Turkestan, by Japan in Manchuria and Korea, and by Italy in Abyssinia. Some of these cottons would eventually compete with Indian cottons, and we should, therefore, be very circumspect in discarding our good quality cottons as it might give an advantage to these countries. Another interesting point brought out by Mr. Hutchinson was that the study of chromosome numbers in cotton showed that the connecting bridge between the New and the Old World was the Pacific and not the Atlantic. This view did not agree with Wegener's theory which took into account the geographical formation of the continents and the distribution of animals on them and according to which the connecting bridge between the New and the Old World was the Atlantic and not the Pacific Ocean.

Dr. Badami observed that it was very interesting to note that many chromosome wild species were found in the American Continent and only one in India, and that most of the Asiatic cottons were of the 13 chromosome type of the Pacific regions. The recent hybridisation work carried out at Bangalore showed that *Harknessii* was an interesting example. On the one hand it crossed fairly well with *Karunganni* and on the other hand it was freely crossing with Bourbon and Cambodia and the F_1 plants were very vigorous; *Harknessii* and Bourbon appeared almost the same except in the shape of their leaves. If these crosses were followed up he thought that they might throw some light on the original country of cultivation of *hirsutum*.

Mr. Ansari referring to the introduction of cottons in Iran said that in Persia the tradition was that herbaceum cottons came from India and his own observations also favoured this view as whatever cottons he came across in Persia were all early and highly sympodial types which took only five months to mature.

Mr. Ramanatha Ayyar drew attention to Dr. Ahmad's reference as to the link between South America and Asia and said that anatomical studies of the cotton showed that *G. hirsutum* was more related to the *hirsutum* than *arborescens*.

Mr. Hutchinson in closing the discussion referred to Mr. Ramanatha Ayyar's comment about *indicum* and said that when *indicum* was applied to South Indian types, only Gamble's description of *indicum* relating essentially to fineness was meant and by no stretch of imagination could Morrison be pushed to answer the description of *indicum*. As regards cotton used for Dacca Muslins his opinion was based on Price's reports to the Government of Bengal and he thought that it would not be possible to add anything at that stage. As far as Dr. Ahmad's enquiry was concerned regarding the possibility of growing cotton in Abyssinia and Manchuria, he understood that the two countries had indigenous cottons and that therefore they might be regarded as probably suitable places for cotton cultivation. Concluding he said that India had a greater range of cotton types and far more information than any other country in the world, and with the facilities offered by the Indian Central Cotton Committee, the Technological Laboratory, and the Agricultural Departments in the matter of improving Indian cottons it should be possible for India to keep ahead of other countries.

PLANT BREEDING

Paper No. 4.

FLORAL ANATOMY AS AN AID TO THE CLASSIFICATION OF COTTONS

BY

P. ABRAHAM AND V. RAMANATHA AYYAR,
COTTON BREEDING STATION, COIMBATORE.

In the course of investigations carried out at the Cotton Breeding Station, Coimbatore, in connection with studies of inheritance of boll dehiscence in cotton, it was noticed that the patterns of arrangements of bundles in the vascular skeleton of the flower varied strikingly in different species. This observation prompted the writers to pursue the studies further.

Flowers from a large number of varieties grown on the station were killed at 9 a.m. on the day of flowering and fixed in formacetic alcohol. For the sake of uniformity in comparison, only flowers with three carpelled ovaries were selected except in the case of *G. Harknessii* where a single five carpelled ovary alone was available. Free hand sections were taken at different levels of the thalamus and ovary and mounted in glycerine after clearing them with lactic acid for examination under a microscope. In the case of six varieties, viz., Cambodia, Sea Island, Wagad, Karunganni, Roseum and Cernuum, the specimens were paraffined, and transverse sections were cut to 15μ to 20μ thickness with the aid of Spencer's Rotary microtome. They were later on stained with one of the following stains, saffranin and light green, saffranin and Delafields haematoxylin, Delafields haematoxylin alone, and Haidenhains haematoxylin.

In some of the varieties, a large number of flowers from single plants were also sectioned and examined with a view to determining the constancy of the observations made.

FLORAL ANATOMY OF CULTIVATED COTTONS.

It was soon found that all the cultivated varieties examined so far (vide statement) could be classified into seven distinct types according to the plan of disposition of vascular bundles in the receptacle and the ovary.

Varieties conforming to the types.	The representative variety.	No. of flowers examined.	Name of the type.	No. given for the type in the description.
Cambodia, Gadag 1, Punjab Americans (4F and 289 F), U4, Buganda, Durango, 2 hirsutums from Russia, Hartsville, Lone-star, Khlay.	Cambodia.	60	<i>G. hirsutum.</i>	1
Ishan, Sakel, Sea Island, Ashmouni, Kidney.	Sea Island.	10	<i>G. barbadense.</i>	2
Bourbon.	Bourbon.	10	<i>G. religiosum L.</i>	3
Wagad, 2 big balled Russian types and a flat leaved Russian type.	Wagad.	20	<i>G. herbaceum.</i>	4 (a)
Uppam (2405 & 2919), Dharwar 1, Dharwar 2, Jayawant, 1027 A. L. F., I A long boll, Surti Broach.	Uppam.	103	Do.	4 (b)
Karunganni (C. 7, 546 and 2622), Nandyal 14, Mollisoni, Bani, Million dollar, Nadams, Coconadas, Red flowered arboreum, Sanguineum major and minor.	Karunganni.	114	<i>G. arboreum.</i>	5
Garohill cotton, Roseum, Verum.	Garohill cotton.	33	<i>G. cernuum.</i>	6

Plate 1

Sketch of a dissected gynaecium (*G. hirsutum*)
exposing one of the ovarial cavities
and two placentae .

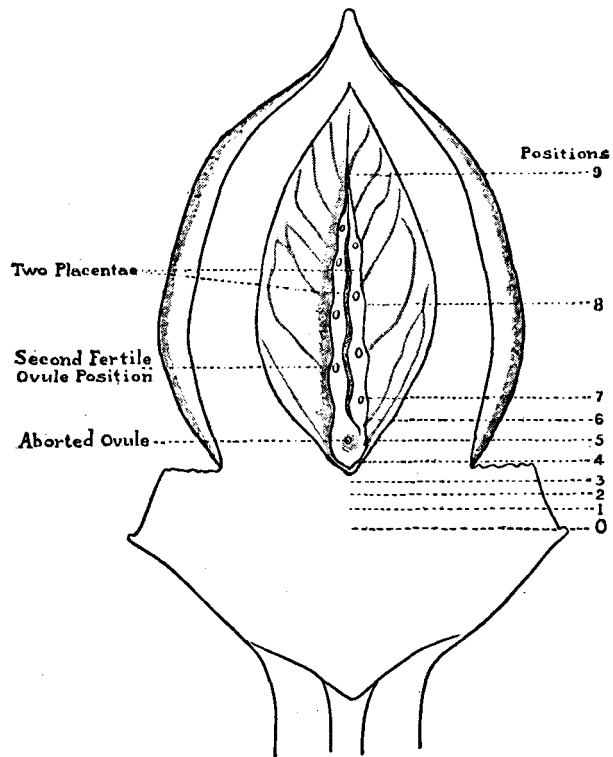


Plate 2.
Anatomy of the Gynoecium in New World Cottons

	Positions									
	0	1	2	3	4	5	6	7	8	9
<i>G. hirsutum</i> , Linn. (Cambaia)										
<i>G. barbadense</i> , Linn. (See island)										
<i>G. Religiosum</i> L. (Sourbon)										
<i>G. tomentosum</i> , Nutt. (Polynesian wild)										
<i>G. Harknessii</i> , Brandegee (California wild)										
<i>G. Davidsonii</i> , Kell. (California wild)										

Plate 3.
Anatomy of the Gynoecium in Old World Cottons

	Positions									
	0	1	2	3	4	5	6	7	8	9
<i>G. herbaceum</i> , Linn. (Weged)										
<i>G. herbaceum</i> , Linn. (Upper Asia)										
<i>G. arboreum</i> , Linn. (Karunganni)										
<i>G. Cerasium</i> , Tod. (Gannisi)										
<i>G. Stocksii</i> , M. Hest. (Asiatic wild)										
A wild cotton from Mumpi										

To facilitate clarity in explanation, the plan of the vascular system as seen in transverse sections of one of the varieties, *viz.*, *G. hirsutum*, taken at 10 different levels of the flower (marked in Plate I), will be described in detail. In the case of others, only the features which deviate from the above will be dealt with.

1. *G. hirsutum* (Plate 2). Twelve varieties were examined. Cambodia Strain Co. 2 has been taken to represent the type. Level 0 corresponds to the middle region of the thalamus just after the departure of the vascular strands to the stamens and the carpellary wall. It is seen here that the vascular cylinder is broken up into a number of strands which lie scattered about throughout the section, the middle portion of which is shown in the plate. At level 1, the scattered bundles attempt to arrange themselves in an orderly fashion. It will be noticed that in the two rows of bundles the outer one has the xylem elements facing inwards while the inner has them pointing outwards leaving a parenchymatous region in between. At position 2, three arc shaped groups with the bundles arranged in stele like fashion are distinctly seen. Obviously this is the first definite sign of the ovary getting three carpelled. Each of these three groups will split up later on into placental bundles of adjacent carpels. At position 3, these curved stele like groups of strands come closer and enclose a pith like region in the centre maintaining at the same time their identities. At the next level, 4, which corresponds to the bottommost region of the ovarian cavities, three pairs of vascular cylinders derived from the splitting of the three groups seen in position 2 are seen near the cavities. It is plain from the position of these pairs of cylinders that they are to be the placental bundles of each carpel. In addition to these bundles, two concentric rings of bundles are noticeable with the xylem elements of each facing those of the other. They are the remnants of the original vascular cylinder left after the supply to all the floral parts, and are termed by some writers as upper stelar vascular tissue. It has been noticed that such a feature is prominent only in certain types and that there is wide variation in its occurrence as well as in the length of its extension.

Position 5 is of interest as the pairs of vascular cylinders noticed in position 4 coalesce and form heartshaped stele-like groups. A few of the strands of the upper stelar vascular tissue are seen to persist at this level too. This position is also important in another remarkable feature, *viz.*, the intracarpellary fusion of the bundles described above is seen as a common phenomenon in all the cotton varieties observed so far and that such a fusion seems to lead to the abortion of the first formed ovule which can be identified by a knob in the placental wall and by the presence of a vascular trace branching off from the placental bundle to it. Higher up at position 6 which lies between the levels of the aborted and the lower-most fertile ovules, the fused bundles are found to separate. Attention may now be drawn to the fact that in this position, the xylem elements, unlike in the lower position, point outwards facing the ovarian cavity as a result of inversion. The three lines seen radiating from the

centre are the lines along which the placental axis will separate when the boll bursts. These are demarcated by two compact rows of small cells. Sections at the next level show the same arrangement of strands as at level 6. Position 8 which corresponds to the region of ovules of 4th and 5th positions counted from the first fertile ovule at the pedicel end, is characterised by the fusion of the placental bundles of the adjacent carpels in contra-distinction from the intracarpellary fusion of the bundles described at position 5. It may be stated, however, that this intercarpellary fusion of the vascular bundles does not seem to be a constant character, as flowers produced later in the season very often fail to show this condition. At position 9 the bundles once again separate and run along as such to the end of the stigmatic lobes.

The above observations were found to be common to all the flowers borne on the same plant as well as on different plants of the Co. 2 strain showing thereby their constancy in behaviour.

2. *G. barbadense*. (Plate 2.) Out of the five cultivated varieties examined under this botanical group, the Sea Island cotton has been taken as type. The general plan of arrangement of bundles is different from that of *hirsutum* type in positions 1, 2 3, 8 and 9. At position 1 the pattern of grouping is distinctly triangular. At the next level, crowding of bundles is noticed at the apices and the sides are mostly composed of single row of strands with their xylem pointing towards the centre. At position 3, they converge losing to a certain extent the triangular shape. The bundles at the corners rearrange themselves and form two projections foreshadowing thereby that they are the future placental bundles. At positions 4 to 7 the vascular dispositions are similar to those described in *G. hirsutum* type. The lines of dehiscences do not however appear till position 7 is reached. At level 8, it differs from the *hirsutum* in not showing the intercarpellary fusion of the placental bundles. This tendency is however noticed to a slight extent near position 9.

3. *G. religiosum* L. (Plate 2). Only one cotton, Bourbon, was examined under this group. The peculiar feature about this type is that it contains considerably smaller number of strands than the two types described above. Except at levels 1 and 2 the behaviour is almost similar to that of *hirsutum* but with no intercarpellary fusion of bundles at position 8.

At position 1 an attempt to form a circular cylinder with one row of bundles becomes visible. At position 2 the cylinder is broken and a pattern with three convex arcs facing each other is formed as in *G. hirsutum* type but mostly with only a single row of bundles.

4. (a), *G. herbaceum* (Plate 3, line 1). Four varieties were found to show the peculiar pattern. Wagad was chosen for the description of the type. It is of extreme interest to note that the pattern of arrangement of the bundles resembles

mostly that of *G. hirsutum* except for the fact that the grouping in this type is less clear cut and regular especially in positions 1 and 2. At positions 3 and 4 the groupings at the corners are more roundish than in the other *herbaceum* type to be described presently. At position 5, the fused placental groups of bundles have a kidney shaped pattern. The upper stelar vascular tissue noticed here is circular in shape. No intercarpellary fusion of bundles has been observed at higher levels even among the early flowers.

4. (b). *G. herbaceum* (Plate 3, line 2). Of the seven varieties studied, Uppam has been taken to represent the type. The disposition of the vascular strands particularly in positions 3, 4 and 5 is very peculiar and striking. At level 3, the configuration has a triangular ground plan with urn-shaped bulged corners. At position 4, the bundles at the corners rearrange and form beautiful diamond shaped patterns at the apices of the triangle. The entire outline is continuous and well defined. Such an arrangement makes it easily distinguishable from the rest of the types. Unlike in the Wagad type the placental bundles of each carpel remain fused. At position 5 the fused placental bundles of each carpel get separated from the triangular body. They however continue to maintain the diamond shape and the fused condition. The bundles that formed part of the triangular ground plan of positions 3 and 4 disappear leaving at times a few bundles which will at that position be called as the upper stelar vascular tissue. It may be noticed that the strands of this tissue are ranged in a triangular form in contrast to the circular pattern observed at position 5 of the Wagad type. Attention may be drawn to another distinguishing feature between Wagad and Uppam types at this level. In the former, the shape of the fused placental groups of bundles is kidney shaped while in the latter it is rhomboid. At higher levels they behave alike.

5. *G. arboreum* (Plate 3, line 3). Eleven varieties were studied. The features of Karunganni cotton have been drawn to represent the type. It differs from those described above in not showing the regular groupings in positions 1, 2 and 3. Even at 4, the placental bundles can be distinguished only after careful examination, as the strands that are to enter the placentae remain separate. It is obvious that the transition from the scattered condition to orderly grouped state found in the placentae is abrupt. The upper stelar vascular tissue is seen to extend unusually up to position 7. The usual intracarpellary fusion of the bundles observed in position 5 only continues up to position 6. These two traits are not so well developed in other types.

6. *G. cernuum*. Three agricultural varieties were found to conform to this type. Of the three, the outlines of arrangement of the bundles were more clearcut in the Garo-hill cotton. At positions 0, 1 and 2, the scattered condition of vascular strands has been observed as in Karunganni. But at level 3 the bundles come closer

and a confused mass of net work results. An attempt to form three corners is also noticeable. At level 4, a triangular pattern but quite distinct from what has been described under *barbadense* and *herbaceum* types becomes visible. The bundles that are to supply the placentae cannot even be distinguished. At position 5 the coalescence of the bundles is rather peculiar. At level 8 the intercarpellary fusion is clearly visible. The pattern of this fusion is also distinctive.

WILD COTTONS.

Floral anatomy was studied in four wild cottons. One of them *viz.*, *G. tomentosum* was grown on the Cotton Breeding Station while the flowers of the other three were kindly supplied by Dr. Badami of the Mysore Agricultural Department.

G. tomentosum (Plate 2). Only a few vascular strands are noticed in the sections. In position 1, they tend to form 3 groups. At level 2 the bundles fuse more intimately than in the types so far described, and result in three separate groups. In position 3 one of the three groups is seen with xylem elements pointing outwards. At level 4, bundles of adjacent carpels are found fused. It is remarkable to note that this intercarpellary fusion which has begun at a very much lower level than is the case with *hirsutum* and *cernuum* types is found to persist at all the higher levels. The xylem elements of all the three groups face outwards even at position 4. This is in marked contrast with the observations made in the cultivated types where such a phenomenon is seen only after level 5 is passed. At position 5, the usual intracarpellary fusion is found in combination with the intercarpellary fusion with the result a triangular skeleton with xylem elements pointing outwards attracts the attention of the observer.

G. Harknessii (Plate 2). Only one flower which happened to be five carpelled was studied in this species. The sections show that its floral anatomy is akin to that in *G. arboreum* type.

At levels 1 and 2, the bundles lie scattered and confused but at level 4, the placental bundles of the five carpels are easily identifiable. The upper stelar vascular tissue is present in this type. Intercarpellary fusion of the bundles does not take place at any level.

G. Davidsonii (Plate 2). In this species the grouping of the strands though irregular becomes visible even from level 1. As in *G. Harknessii*, the upper stelar vascular tissue has been observed at levels 4 and 5.

G. Stocksii (Plate 3) resembles *G. arboreum* type closely in all anatomical features in positions 0 to 6. At levels 7 and 8, intercarpellary fusion of the placental bundles is found to occur resulting in the same pattern as in *cernuum*.

DISCUSSION.

A tremendous amount of confusion exists in the classification of cotton species especially amongst the Asiatic sub-group. Hutchinson and Ghose (1936) have recently reviewed the various methods adopted by the previous workers in the classification and shown how each one of them was defective. Harland (1932) and Hutchinson and Ghose (1936) have adopted a simplified system which has done away with many of the baffling criteria used previously. If this system can be supplemented with a few more criteria, it is needless to say that they will prove valuable in the easy and correct identification of the several species—an important requisite—when hybridisation amongst several cottons is being planned for economic purposes.

Almost all the previous workers barring Zaitzev (1928) and Harland (1932) have based their classification mostly on morphological, geographical and ecological grounds. If internal evidence can be found to correspond to the external features of the different species, they will be of more lasting value, since they are more constant in nature. The anatomical studies reported in this paper seem to fulfil this object to a considerable extent. Anatomical variations have been known to exist between families and genera; but no serious attempt seems to have been made so far to use them for classifying a genus into species. Moore (1936) has recently divided the Papilionatae into two broad sub-groups according to the nodal relationships of the vascular traces to the perianth and stamens. In the present case the differences in the pattern of the vascular organisation among the types have been used as a tool for classification. They also have the advantage of occurring in a plant organ—flower—which is well known to be very conservative with regard to taking up new changes.

When all the patterns examined so far are considered together, it is seen that differences in the number of chromosomes have no distinct influence on the disposition of the bundles. When they are classified according to their being wild or cultivated, it is interesting to observe that in the wild types, the fusion of the vascular strands is more intimate and compact. In the cultivated cottons, on the other hand, rows of parenchymatous cells intervene, somewhat like medullary rays, when the bundles tend to coalesce. Further the number of strands is fewer in the wild cottons. The exact significance of this difference is obscure. Probably cultivation encourages branching and breaking of the vascular tissues. Amongst the cultivated cottons, Bourbon alone has a smaller number of bundles in the thalamus. This feature is suggestive of its being nearer to the wild cottons. Examination of more varieties in the *religiosum* L. type may throw additional light on this aspect.

From a critical study of the morphological features, Hutchinson and Ghose (1936) observe 'parallelism in many characters' between *G. Stocksii* and

G. herbaceum. It is of interest to note that in the vascular disposition in the flower *Stocksii* resembles *arboreum* more than *herbaceum*.

It may be mentioned here that one of the authors came across some Nadam-like plants with sparse brown lint growing wild in the ruins of Humpi. As such a type was not cultivated in the neighbourhood it was taken to be wild. Later studies with regard to their slow germination and subsequent tardy growth lent support to the above impression. But studies of floral anatomy indicated that they belonged to arboreum type and had greater resemblance to the cultivated than to the wild cottons (Plate 3, last row).

Coming to the cultivated cottons, it is found, as mentioned already, that all the varieties studied so far can be classified according to their floral anatomy into seven groups. It may be mentioned, however, a strong impression (which has to be verified by examining more varieties) is left in the mind when surveyed broadly that there are only three main groups—Americans, *herbaceum* and *arboreum*—and that each of these is divisible into two sub-groups—triangular and non-triangular—in the following way :—

American	{	Triangular typified by Sea Island
	{	Non-triangular typified by Cambodia.
Herbaceum	{	Triangular typified by Uppam.
	{	Non-triangular typified by Wagad.
Arboreum	{	Triangular typified by Cernuum.
	{	Non-triangular typified by Karunganni.

Bourbon type seems to go along with Cambodia under the non-triangular sub-group of Americans.

Zaitzev (1938) while classifying all the cultivated cottons under four groups, presumed that the differences between *arboreum* and *herbaceum* groups were on a par with those between *hirsutum* and *barbadense* groups. Further he placed Broach, Kumptas, and Uppam cottons under *arboreum* group. The present anatomical studies show definitely that the *herbaceum* cottons are far more fundamentally different from *arboreum* than the *hirsutums* are from the *barbadense*, and that Harland's inclusion of the above-mentioned Indian cottons under *herbaceum* is perfectly justified.

When the American group of cultivated cottons is considered it is clear that all of them come under three anatomical patterns. These are exactly in agreement with the three species *hirsutum*, *barbadense* and *religiosum*. *L.* into which all the cultivated American cottons were classified by Harland. *Barbadense* has a triangular pattern while *hirsutum* has arc-shaped group of bundles with pith-like region in the middle of each group. In *religiosum*. *L.* each group of bundles has usually only a single row in contrast to *hirsutum*. It may be reiterated that though Bourbon may in general pattern appear close to the *hirsutum* type, it merits on purely anatomical evidence, a separate status for itself. Kearney (1936) includes *religiosum*. *L.* and *tomentosum* into one sub-group. According to vascular anatomy they seem to be entirely different.

In the cultivated cottons of the Old World, *herbaceum* cottons seem to be more advanced than the *arboreum* and *cernuum* types, if the earlier initiation of the grouping propensity is taken as an index of progressive trend. On this standard, *hirsutum* and *barbadense* types are to be deemed more advanced than *herbaceum*, as the tendency to form groups is noticed at still lower levels. Another feature of some interest is the probability that the *herbaceum* species may have been one of the parents of American cottons. Skovsted (1934) has established cytologically that American cottons of 26 chromosome group are allopolyploids originated from a cross between an Asiatic and an undetermined 13 chromosomed species. The similarity in the stages of forming the anatomical patterns in the *herbaceums* and *hirsutums* suggests that the former has a greater probability of being the Asiatic parent than the *arboreums*. The observation made by Skovsted (1935) that the leaves of hybrids between *herbaceum* and *aridum* resemble those of Upland cotton is interesting in this connection.

Hutchinson and Ghose (1936) have classified the *herbaceum* species into three varieties, *typicum*, *frutescens*, and *Africanum*, mostly on the basis of habit and type of leaf. Unfortunately no Africanum form was available for the anatomical examination and hence nothing can be said of its place in the present classification. There are reasons to believe, however, that the morphological and anatomical classifications do not agree in the other two varieties. For instance Wagad and the other Indian *herbaceums* have been classified under *frutescens* while the Russian types are placed under variety *typicum*. But the plan of vascular arrangement in the flower in Wagad is found to be distinctly different from that in Uppam, Kumptas and Broach, but is similar to that in the Russian *herbaceums*. One would expect from this observation that it would be more legitimate to group Wagad under *typicum*. The closed type of boll in this type also suggests that it may be nearer to the Russian than the Indian. In any case the divergence in the morphological and anatomical classifications calls for a re-examination of the whole question.

According to the anatomical studies of the flower, arboreums are divisible into two sub-groups, *arboreum* proper and *cernuum*. *Cernuum*, *roseum* and *verum* cottons come under *cernuum* type. All the rest resemble Karunganni in the vascular skeleton. The above groupings are not in accord with those made by Hutchinson and Ghose (1936) as will be noticed in the following table. His conclusion that *cernuum* is different from others is justifiable on anatomical grounds too.

Name of the variety.			Morphological classification made by Hutchinson and Ghose.	Anatomical classification.
Nadam	..	..	Arboreum var typicum	Arboreum proper
Karunganni	..	..	„ var neglectum	do.
Bani	..	..	„ do.	do.
Mollisoni	..	..	„ do.	do.
Sanguineum	..	..	„ do.	do.
Roseum	..	..	„ do.	Cernuum
Verum	..	..	„ do.	do.
Cernuum	..	..	„ var Cernuum	do.

These emphasise again the desirability of making further anatomical studies on all the cotton varieties grown in India and elsewhere.

The present investigations have, however, proved that the differences in the general scheme of vascular arrangement in the flower can be validly used for classifying the cotton species and will also be, as Arber puts it, of extreme 'value in indicating the broader trends of race history'.

SUMMARY.

1. The vascular anatomy of the flower, with special reference to the organisation of the vascular skeleton in the gynaecium, in some of the cultivated and wild cottons of the Old and New World groups, is described in detail.
2. Specific differences are observed in the mode of origin, course and general disposition of the placental vascular system and also in their patterns as seen in transverse sections at various levels of the gynaecium. These differences seem to be useful in the classification of the genus.
3. Definite differences are observed between cultivated and wild forms. The wild types have a fewer number of vascular strands which fuse more intimately while forming bigger bundles.

4. The cultivated cottons are divisible according to vascular patterns into seven distinct types.

5. All the American cottons fall under three anatomical types which correspond exactly to the classification made by Harland. Bourbon seems to be nearer to wild types than the other cultivated types.

6. According to anatomical variations, the Old World cultivated cottons seem to fall under two distinct groups, viz., the *herbaceum* and the *arboreum*. Each of these groups may again be subdivided into two distinct sub-groups. Wagad cotton of Gujarat is different anatomically from other *herbaceum* cottons grown in India. It seems probable from the mode of grouping of the bundles that *herbaceum* would have been the Asiatic parent of the New World allopolyploid group.

7. *G. Stocksii*, Mast., the Asiatic wild cotton, seems to be nearer to the *arbo-reums* than the *herbaceums* from the anatomical point of view.

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PLANT BREEDING

Paper No. 5.

BREEDING OF IMPROVED STRAINS OF COTTON SUITED TO LOCAL CONDITIONS WITH PARTICULAR REFERENCE TO SIND AND THEIR EXTENSION

BY

K. I. THADANI, BOTANIST IN SIND,
AGRICULTURAL RESEARCH STATION, SAKRAND.

Introduction.—Sind is the most western part of India and lies between 23°—35' to 71°—10' East Longitude. It is a long narrow strip of land 350 miles long and 53,000 square miles in area comprising 30 million acres of land, of which half is cultivable. The annual cultivation in the non-Barrage period was about 3.5 million acres in a good year out of which about 3 lacs were under cotton and has now under Barrage conditions increased to 9.8 millions, the acreage under cotton being about nine lacs of acres. The chief features of Sind are the river Indus with its net work of canals and the scanty rainfall except in abnormal seasons. The cotton growing areas of Sind may be divided into three tracts, viz., (1) South East (2) Middle Sind both situated on the Left Bank of the Indus and (3) North Sind situated on the Right Bank of the Indus. Temperature and rainfall seem to be the dominating factors of the climate and are responsible for the seasonal variation of the crop. The South Eastern Sind differs from the other two tracts in having lower temperatures, higher relative humidity and higher rate of wind velocity, greater rainfall and longer cloudy weather. The Right Bank area is similar to the Middle Sind tract on the Left Bank except that the nights are close in the former area as compared to the cool breeze prevailing at night and stormy weather during day on the Left Bank. The climatological records maintained at Sakrand show that during the sowing season (April and May) the days are quite clear, there is bright sunshine, without any clouds, no rainfall, the maximum temperatures range between 100°-110°F and the relative

humidity is low. The first part of the growing season, *i.e.*, early June, is very hot and dry. The maximum temperatures begin to fall from 110° during end of June to 100°F by middle of October and 90°F by middle of November. The major period of growth from the end of June to Middle of August is characterised by less intense sunshine, high relative humidity, rainfall and cloudy weather, the maximum temperature remaining high (80°F) and steady. The period of fruit-setting commences from the middle of August and is marked by steady but low maximum temperature, rapid fall in minimum temperature and steady rate of evaporation; the days are clear and nights increasingly cool. Dew fall is common at this time. The picking season starts in the end of September and continues till end of December as a rule and may extend to January if frost does not occur.

Prior to the opening of the Barrage canals in Sind, irrigation water was available for four months, on the rise of the river Indus, *i.e.*, from June to September. *Desi* cotton (*neglectum* type) was grown in most of the area except in a small portion, *viz.*, Southern Jamarao Canal area, where American cotton (4F type) was grown. This tract commanded early supply of water which lasted for greater part of the year. With the advent of the Barrage canals irrigation water is available throughout the year with the exception of a few days when canals are closed for repairs.

Early attempts at introduction of high quality cottons in Sind.—From early times the resemblance of Sind to parts of Lower Egypt has struck many observers and hence attention has been directed from time to time to the trial of Egyptian and other exotic cottons in Sind. Experiments in this direction date from 1846. Egyptian, New Orleans and Sea Island cottons were cultivated in several places but with little success until 1854 when experimental work was abolished. A few years later the experimental work was again started and sustained efforts were made by Mr. Strachan in charge of the work for nearly 20 years with a very representative collection of cottons including Egyptian, American Upland, Sea Island and Indian types including Dharwar American, without leading to any definite results.

With the opening of the Jamarao Canal which was intended to give perennial supply of water to a portion of South-East Sind and the establishment of the Agricultural Department in Sind, the question of cultivating exotic cottons in Sind was taken up in right earnest. Four varieties of Egyptian cotton, *viz.*, Ashmouni, Mitaffifi, Abassi and Yannovitch, were tried in the first year (1904). Mitaffifi and Abassi were found to be more suitable, the former had shorter staple and brown colour of the lint but was hardier, while the latter had long staple white lint and was rather delicate. The cultivation of these varieties was pushed into the Jamrao area to the extent of about 5000 acres but was completely dropped after four years. Every year fresh seed was obtained from Egypt. The main reasons assigned for the failure of Egyptian cotton in Sind were late water supply, susceptibility of the plant to boll

worm, long period of growth so as to be affected by frost, inadequate marketing facilities and want of careful cultivation. The writer is inclined to believe that absence of any attempt towards acclimatisation and breeding of a strain suited to the local conditions is partly responsible for the failure of this experiment.

With the failure of Egyptian cotton in 1909 attention was directed to the trial of American Upland cottons owing to their shorter period of growth and consequently the possibility of greater chances of success under the irrigation conditions then prevailing in Sind. Several varieties of American Upland cottons, *e.g.*, Texas Big Boll, Triumph, Allens long staple, Griffin, Block Ralter, Peterkin Toole, etc., were tried and Triumph was considered to be the most suitable and its cultivation was pushed into the districts. In 1913 an area of 1680 acres was sown with seed of this variety imported from U.S.A. and the area increased to 2500 acres in the following year but in the following two years its cultivation dropped to 725 acres only and was ultimately abandoned in 1917. The main reasons for the failure of imported American cotton was the susceptibility to red leaf blight especially in years of heavy rainfall resulting in low yields of crop and the deterioration in quality of the fibre and seed. It may be noted that during this period of experimental work no attention was paid to the acclimatisation and breeding of strains which could resist red leaf blight in American cotton.

Breeding of improved Sind desi cotton suited to pre-Barrage conditions.—Sind *desi* cotton consists of a mixture of four *neglectum* varieties, differing in the colour of the flower which may be yellow or white and the nature of leaf lobes which may be narrow or broad in addition to several other characters. The yellow flowered types preponderate to the extent of 70%. The best cotton used to be grown in the past in a village near Bhitshah (Hala Taluka) where selected lots of *kapas* (seed cotton) were hand ginned and seed distributed to growers round about that locality; samples of seed were obtained from this and other places and breeding work was started in 1916 and the writer has been associated with cotton breeding work in Sind since then. The four prevailing types were isolated and unit selection was made in each of these types on the basis of high yield, bright colour of lint and high ginning outturn. It was soon discovered that the yellow flowered types, *viz.*, *verum* and *malvensis*, were not so hardy as the white flowered *roseum* and *cutchicum* types and were at the same time low ginners. The *verum* type had longer staple and softer feel. Of the white flowered types, the *cutchicum* type (white flower and broad lobed leaf) had definitely higher ginning outturn and rougher feel than the *roseum* type but did not give so high yield of *kapas* as the *roseum* type (white flower and narrow lobed leaf). Unit selection was continued in the *roseum* type for a number of years and resulted in the establishment of a few selected strains which were tested on a field scale and in comparative tests. Finally 27 W. N. now known as *Sind N. R.* was found to be the best and most suitable for inundation conditions. It is capable of

yielding over 15 to 20% more *kapas* per acre than ordinary Sind *desi* mixture, is earlier in maturity and gives a series of pickings at very short intervals, has higher ginning outturn by 5% over ordinary *desi* and rough feel and bright colour of lint. The last three characters bring greater premium in the market over ordinary *desi*. This improved strain is now the standard *desi* cotton of Sind. It is very hardy and resists variations in soil, climate and season. It is not affected by jassids and can stand late sowing which is not possible for any other American cotton. This cotton has a special market of its own on account of its bright colour and rough feel. Trade opinion in Karachi considers that the total *desi* crop which can be profitably consumed should not exceed 200,000 bales per annum. Any increase above this figure is likely to get the limited market and result in reduced prices to growers.

Breeding of improved strains suited to pre-Barrage conditions: Origin of Sind American cotton.—With the failure of early attempts to introduce the imported variety of American cotton, *viz.*, Triumph cotton in 1916-17 and the general experience gained about all imported American Upland types being susceptible to red leaf blight, it was decided to find a type which would resist this condition. Two cottons were suggested, *viz.*, (1) Cambodia (2) Punjab 4F. The former is a robust strong growing, cotton with hairy leaves largely resistant to red leaf blight but has a long period of growth, so much so it gets affected by frost and at the same time has low ginning outturn. As such it has no chance of successful cultivation in Sind. For these reasons attention was directed to 4F Punjab cotton in the first instance. This cotton had just then made a reputation for resisting red leaf blight and had made a phenomenal success in the Punjab. A few *zamindars* in Sind obtained seed from that province and about 78 acres were cultivated for the first time in the year 1917-18 and the cultivation steadily increased to 13,000 acres in 1923. This cotton was found to be an early ripener and hence could stand June sowing and at the same time permitted of irrigation water being utilized for *rabi* crops much earlier than in the case of *desi* cotton. It gave high yield owing to greater resistance to red leaf blight than other American cottons and stood floods and water logging conditions better than the *desi* cotton.

Simultaneously with these field experiments and district cultivation, the work of single plant selection was started with the result that an improved strain known as Sind 4F—18 was established. It possessed high yielding capacity, resistance to red leaf, 34% ginning outturn and short staple (6/8") and can spin 22 counts. This improved strain soon spread in the country and was the most suitable and hardy type of Sind American cotton long before the Barrage canals were constructed.

This strain has now been abandoned for distribution in the district. It has been used as a parent in crosses. The plant is bushy and hairy with long fruiting branches. The boll is medium sized and conical in shape. The chief difficulty in the rapid

spread of 4F cotton was the fluctuation in the prices from year to year. The premium obtained in the market for this cotton over *desi* was good in the beginning but in subsequent years fluctuated from season to season until in the year 1922 4F cotton fetched the same price as Sind *desi* and in some years was valued less than *desi*. This condition necessitated finding a better stapled type of Punjab American cotton. For this purpose 285F cotton was imported from Punjab in the year 1922 and tried on the Government Seed Farm, Mirpurkhas, where it yielded equally well as 4F. The ginning outturn of 4F was 33% and that of 285F was 29%, staple of 4F was 6/8" while that of 285F was about an inch. 4F cotton fetched a premium of 10-16% over *desi* in favourable years and 285F about 16%. 285F cotton, however, soon proved to be less hardy than 4F cotton under climatic conditions prevailing in South East Sind. Simultaneously with the field trials of 285F Punjab American cotton, botanical selection was made and a number of pure strains evolved among which 285F strain No. 2 was found to be the best in point of earliness combined with high yield. The plant was a sympodial habit of growth and the staple is long and fine. This strain, however, under conditions of South East Sind is susceptible to red leaf blight in unfavourable years *e.g.*, heavy rainfall and hence it has not been introduced in the district.

289F Punjab American cotton was first introduced on the Experimental Farm, Mirpurkhas, in the year 1924-25. It was found to be late in maturity. Botanical selection was started and the work was soon transferred to Sakrand where arrangements for perennial irrigation were made in order to carry out experiments, the results of which would be applicable to post-Barrage conditions.

Breeding of improved strains of cotton for post-Barrage conditions.—This work has been carried out in the Botanical section of the Agricultural Research Station, Sakrand, which was established in the year 1926. Four main classes of cotton have been dealt with, *viz.*, (1) Sind American cotton (2) Sind hybrids (3) Imported Egyptian and Sea Island cotton (4) Imported American cottons. Sufficient information has been obtained and observations recorded on the various forms existing in these classes of cottons, and work on isolation of unit species in the more promising types or varieties, study of hereditary characters and the reaction of the plant to diseases, pests and environmental conditions has been carried out. As a result of these observations it has been possible to eliminate certain types and varieties which were found to be susceptible to these troubles and at the same time discarded certain progeny lines (families) which showed greater susceptibility than others. In the plant breeding work at the Agricultural Research Station, Sakrand, a few plants are selected in all the strains every year which conform to the type and are free from disease. The selfed seed of the selected plants is grown in line cultures in the following year. The best line culture is retained for further testing next year. This continuous maintenance of single plant tradition both in the selected strains and

hybrids has greatly contributed to the production of improved strains suited to the local conditions. Among each of the first three main classes the Botanical section has evolved improved strains which, on account of better yield, higher ginning outturn, or superior quality are suitable for extension in general cultivation in the different cotton growing tracts of the Barrage areas. As already stated one of the most important characteristics for which the improved strains have been bred is vigour or hardiness which will enable them to withstand the rigours of the variable Sind climate and in case of Sind American and hybrid cottons to resist jassid attack as far as possible. The other characteristics to which special attention has been given are the improvement of yield of *kapas* per acre and the maintenance of definite standards of staple length and ginning percentage. It has been found that in general the finer cottons are more susceptible to variations in climate and soil and to attack by various diseases such as red leaf, jassids, etc., than the hardier and less superior types. However the botanical work has progressed so far that it has been found possible to combine a high yield with a staple of $1\frac{1}{8}$ " and ginning outturn of 30-34% in certain improved strains.

Improved Sind American cottons.—*Sind 4F-98.*—This strain has been derived from the old strain 4F-18 described in the preceding paragraph. It arose as a natural hybrid and is very hardy and well suited to all classes of soils. It has been found to resist jassid attack and the so-called red leaf disease better than any other cotton so far tried and evolved. The plant is bushy, the vegetative branches spreading more or less horizontally. It is extremely hairy, hairs being found thickly on the main stem, vegetative and fruiting branches, and leaves including the petiole of the leaf. This hairy condition causes slight deposits of dust on the leaves giving a general dusty green appearance. The leaves are medium in size, soft textured, high green in colour, rather broad lobed, with dim pulvinus spot. The bolls are medium in size and conical in shape. The seeds are small, have white and green fuzz. It has a staple of $7/8$ " to $15/16$ " and spins 34's. It has a ginning percentage of 34 and gives high yield. The improved strain has been found to be most suitable type for cultivation in the new cotton growing tracts being established on the Right Bank of the Indus.

Sind Sudhar 288F-1.—This improved strain of Sind American cotton has been derived from the original 289F cotton imported from the Punjab in the year 1923-24 by selection. It is an established strain and has been found to withstand red leaf and jassid attack to much greater extent than other Punjab American cottons grown in Sind. The plant is tall and bushy, vegetative branches long and well developed, ascending upwards and reaching height of the main stem giving a dome shaped appearance to the plant. The plant is not studded with hairs as in Sind 4F-98. Only the young leaves at the top of the plant show some hairiness. The leaves are large, deep green in colour, thick and coarse in texture with a prominent deep red pulvinus spot. The leaf has broad lobes, the basal lobes tend to curl

upwards giving more or less a cup shaped appearance to the leaves. The leaves have prominent honey glands. The bolls are medium in size, round or globose in shape and abruptly pointed. The bolls open wide and hold the ripe cotton from falling on the ground for a long time. The seeds are large and fuzzy, fuzz being white tinged with slight greenish colour. This improved strain has a staple of full inch to $1\frac{1}{8}$ " and spins 40's. It has a ginning percentage of 30 and in normal years is a very high yielder. It is a cotton well adapted to resist jassid attack and red leaf and to withstand seasonal variations of climate, etc. This improved strain has been found to be most suitable for cultivation in the Left Bank areas of Sind.

These two strains of improved Sind American cotton, *viz.*, Sind 4F-98 and Sind *Sudhar*, are the 'bread and butter' of the American cotton growers in the Barrage areas.

Sind Hybrids.—A brief history of the experimental work on field trial of various classes of cottons and their varieties has been described in the previous pages. A careful perusal of this record will show that sufficient evidence had been collected to lead to the conclusion arrived at in the year 1921-22 and recorded by Mr. Main, then in charge of the Agricultural Department in Sind, that the future Sind American cotton for post-Barrage conditions would have to be built on the Punjab American cottons either by selection or hybridisation. Both these lines of work were taken in hand and the improved strains evolved by the first process, *i.e.*, selection, have already been described. Crosses were made in the year 1927-28 at Sakrand between Sind 4F-18 and Meade Upland cottons. The former had proved to be very high yielding and resistant to red leaf disease and to withstand adverse conditions of soil, climate and irrigation. It has a high ginning outturn 34% but the staple was short ($6/8$ "). The other cotton, *viz.*, Meade Upland, was selected as a parent on account of its very long and silky fibre ($1\frac{1}{2}$ ") the other character being defective. This cotton does not thrive in Sind and is affected by red leaf disease and has very poor ginning outturn (20%). The following four hybrids have now been established :—

(1) *Hybrid 101.*—This hybrid is most early maturing. It takes about 60 days to start flowering after sowing. When sown in April-May, the first picking becomes ready in the end of September and the crop is over by the end of October. This improved hybrid strain owing to its early maturing character produces most of its crop of bolls before the red leaf disease makes its appearance on the plant and consequently yield is not so much affected. The plant in the initial stage of growth is tall and erect growing with very few vegetative branches which bend and droop in the later stage on account of heavy bearing of fruit like the Meade parent. The plant is practically glabrous. Fruiting branches are extremely short and short noded and ascend at a very acute angle. The leaves are large in size, glabrous,

thick textured and broad lobed with basal lobes over-lapping each other. The bolls are big in size and rather spherical in shape. The bursting of bolls is good and it facilitates quick and clean picking of seed cotton. The seed is medium and whitish fuzzy. The improved Hybrid strain has a staple length of full one inch and spins 40s. It has a high ginning outturn of 32%. It is slightly rough in feel. It has good yielding capacity and is being multiplied and tested on field scale. On account of its early maturity, this improved Hybrid cotton is likely to be suitable for non-Barrage tracts where water supply is short.

(2) *Hybrid 94*.—This improved hybrid strain is also very early maturing. It takes about 70 days from date of sowing to come in flower. When sown in April-May, the first picking becomes ready by the end of September and the crop is over in November. It resists red leaf disease well. The plant is tall, fairly bushy, with long and erect growing vegetative branches which sometimes bend and droop on account of heavy bearing of fruit at the top of the plant. The fruiting branches are short to medium in size and short noded. The leaves and the stem are hairy. The leaf is rather small to medium in size, hairy, dark green in colour and fairly thick textured resembling 4F-18 parent in shape and lobing. Its pulvinus spot is dim. The bolls are medium in size, conical and pointed. The bursting of bolls is good. The seed is medium in size and greenish fuzzy. This improved strain has a staple of full one inch and spins 44's. It gives 31-32 % ginning outturn but like hybrid strain 101, it is slightly rough in feel. It has got good yielding capacity and is being multiplied and tested on a field scale in different sowing dates in comparison with the standard Sind *Sudhar* cotton. On account of its early maturity, this improved hybrid strain also is likely to be suitable for non-Barrage tracts where water supply is short.

(3) *Hybrid 27*.—This improved hybrid strain is intermediate in maturity when compared to other hybrid cottons. It takes 85 to 90 days after sowing to come in flowering and the crop becomes over along with Sind *Sudhar* improved Sind American cotton in the end of December. It resists red leaf disease to a great extent. The plant is bushy with thick monopodial branches. It is slightly hairy. The leaf is large, hairy, rather dark green in colour and broad lobed with prominent pulvinus spot and basal lobes over-lapping in several leaves. The flowering branches are medium to rather long in size. The bolls are medium to big in size and conical and slightly elongated in shape. The bursting of bolls is good. The seed is medium in size and white fuzzy. This improved strain has the longest staple, $1\frac{1}{10}$ " and has a high ginning outturn of 32%. It has however spun only 35's. It has a fairly high yielding capacity and is being multiplied and tested on a field scale in different sowing dates in comparison to improved Sind American Sind *Sudhar* cotton.

(4) *Hybrid 97*.—This improved hybrid strain is late flowering. It takes about 97 days after sowing to come in flowering but the crop becomes over by the end of

December along with Sind *Sudhar* cotton. It resists red leaf disease well and remains in green condition and holds its leaves right up to the end. The plant is very monopodial and bushy and is very slightly hairy. The flowering branches are medium. The leaf is medium in size, very slightly hairy with rather prominent pulvinus spot. The bolls are medium in size and conical in shape. The bursting of bolls is good. The seed is medium in size and whitish fuzzy. This improved hybrid strain has a long staple length of $1\frac{1}{8}$ inch and gives the best spinning performance, spinning up to 47's. It has been valued at a higher price than Sind *Sudhar* cotton. It has a high yielding capacity and is being multiplied and tested on a large field scale in different sowing dates in comparison to the standard Sind American cotton.

Improved Sind Egyptian and Sea Island Cottons.—Early attempts to introduce Egyptian and Sea Island long-stapled cottons in Sind have already been described. A fresh consignment of seeds of several varieties was obtained from Egypt and these were tested in the year 1927-28. Most of the varieties, *e.g.*, Sakel, Pima Yuma, Marad and Sudan cottons, were found either very late maturing or suffered greatly from 'Leaf Crinkle' disease. The only varieties which were found to be less affected and promising were:—(1) Ashmouni, (2) Zagora Melaky, and (3) Sea Island. In these three promising varieties work of unit selection for high yield and resistance to 'leaf crinkle' disease and adverse soil and weather conditions was done, and as a result of the work of this selection and acclimatisation, the following two improved strains have been produced which can be grown successfully in Lower Sind:

(1) *Improved Sind Egyptian Boss III—16.*—This is the best improved strain of Sind Egyptian cotton in point of quality produced as a unit plant selection from Zagora Melaky, imported Egyptian cotton. It is late maturing when compared to all other improved cottons and requires to be sown early in March-April. The crop is over by middle of January and consequently last picking is liable to damage by frosts and low temperatures. The plant is tall, erect and bushy having several monopodial branches which are rather crowded at the base. The stem and the vegetative branches, on account of heavy bearing of fruit at the top of the plant, sometimes bend and droop in the later stages of the crop. The plant is completely glabrous. The fruiting branches are long, stout and many noded. The leaves are very large and broad, thick textured, dark green in colour and glabrous with no

red pulvinus spot. They have big and prominent nectories on the under surface. The lobes of leaves are very broad, oblong and pointed with narrow sinus. The bolls are mostly three locked, medium in size, long and pointed and shining dark green in colour. They have a rough surface due to numerous deep seated and prominent oil glands. Bursting of bolls is fairly good. The seed is medium in size, heavy in weight, dark naked but generally partially fuzzy, the fuzz being dull white coloured spread over half the seed at the base. This improved Sind Egyptian strain has a very long staple length of $1\frac{1}{4}$ inches to $1\frac{1}{2}$ inches and is very fine and silky in feel. It spins 80's and gives 32% ginning outturn. This cotton is suitable for cultivation in East Sind where the crop matures early and gives fairly good yield.

(2) *Improved Sind Sea Island Cotton*.—This is the best of all the high quality cottons in points of staple length and fineness. It is a unit plant selection from material originally imported from America. It is also a late maturing type like Sind Egyptian Boss III-16 cotton and as such requires to be sown earlier than both Sind American and Sind *desi* cottons. It holds its leaves for a fairly long time. The plant is tall, erect and bushy having several monopodial branches which are crowded at the base. The plant has a tendency to bend and droop in the later stages of the crop on account of heavy bearing of fruit at the top. It is completely glabrous. The fruiting branches are long and many noded. The leaf is large and broad lobed, thick textured and dark green in colour. The lobes of the leaves are broad, slightly deep cut, long and pointed. The bolls are similar to those of improved Sind Egyptian Boss III-16 cotton. The seed is medium in size, heavy and naked black in colour having very slight greenish fuzz at the tip. This improved Sind Sea Island cotton has a very long staple length of $1\frac{1}{2}$ "— $1\frac{5}{8}$ ". It is extremely fine and silky in feel. It spins 70—80's and gives 30% ginning outturn. This cotton is suitable for cultivation in East Sind where the crop is over early and gives fairly good yield. Both the improved Sind-Egyptian and Sea Island cottons are, however, slightly susceptible to seasonal and climatic variations and adverse soil conditions, and white ant attack on virgin lands, and consequently give lower yields than improved Sind American cotton. They require to be sown early and on good soil with good cultivation.

Study of hereditary characters.—A number of hereditary characters have been studied in all pure lines of established strains, new selections, parents and hybrids

and their average performance in normal years from the year 1928—1935 is summarised in the following table :—

Variety.	No. of Monopodia per plant.	Ar. Node of 1st fruiting branch.	Ar. No. of days taken to come to flowering.	Average staple length in mms.	Average Ginning %	Single plant yield in gms.	No. of bolls per plant.	Weight of Kapas per boll in gms.	Weight of 100seeds in gms.	Weight of lint per seed in milli-gms. (Calculated value).
I. Improved Sind Desi										
1. Sind N. R. ..	7.2	17.8	..	..	39.05	114.1	54.6	2.09	5.36	34.2
II. Improved Sind American										
2. Sind 4F-98 ..	4.2	8.2	80.5	24.8	33.0	123.8	37.3	3.32	8.3	40.8
3. Sind Sudhar	3.9	11.5	83.7	26.8	29.0	118.2	36.8	3.21	8.6	35.1
III. Sind Egyptian & Sea Island cotton										
4. Boss III-16 ..	7.3	23.6	96.6	34.2	31.8	103.2	51.0	2.02	10.12	47.1
5. Sea Island 2.4	8.6	21.9	95.0	38.1	29.7	100.0	47.0	2.13	9.85	41.6
IV. Parents										
6. 4F-18 ..	8.2	12.3	79.0	20.1	33.0	96.2	38.6	2.49	7.5	36.9
7. Meade ..	4.4	7.7	70.1	39.0	23.1	83.6	27.9	3.00	11.65	35.0
V. 4F-18 × Meade Hybrid.										
8. Hybrid 101 ..	3.2	6.9	74.3	28.8	32.6	90.9	27.8	3.26	9.94	48.0
9. Hybrid 94 ..	3.8	7.9	75.2	29.0	31.2	104.0	38.9	2.67	8.6	39.0
10. Hybrid 27 ..	3.9	8.3	90.6	29.3	31.9	138.5	46.5	2.97	9.3	43.6
11. Hybrid 97 ..	5.1	8.87	97.8	29.7	29.8	84.3	28.8	2.93	9.2	39.0

Maintenance of pure seed and seed multiplication scheme.—The scheme for the maintenance of purity and the systematic multiplication of pure seed of improved varieties of cotton is based on a 'unit' system, each unit representing a final area of 25,000 acres in the final state under one improved variety. The programme of seed multiplication of one such unit consists of five progressive stages as shown in the following table :—

Stage.	Area in acres.	Location.
(a) Seed Patch (from produce of Selfed plants).	2½	Agricultural Research Station, Sakrand.
(b) Increase block	25	Government Farm.
(c) Field Scale planting	250	'A' class registered growers.
(d) Village groups	2500	'B' class registered growers & co-operative organizations, etc.
(e) District groups	25000	General cultivation.

Each stage is fed from the preceding one. The first three stages are under direct departmental supervision. The crop is thoroughly examined and all off type plants removed. The produce of all the stages of the seed multiplication scheme is ginned under the strict supervision of Agricultural Department. The scheme has now reached its final stage. At the present time, eleven such 'units' of multiplication are being supervised by the Department and these are being distributed among the different varieties of improved cottons as under :

7 'units'— Sind American Cottons, *i.e.*, Sind *Sudhar* and Sind 4F-93.

3 'units'— Sind N. R. (*Desi.*)

1 'unit'— 'Quality' cottons, *i.e.*, Sind Sea Island and Boss III-16.

As a result of the past year's experience in the working of this organization it was found that on account of the tremendous increase in cotton cultivation, the number of 'units' being dealt with is insufficient to meet the demand for pure

seed of improved cottons after the 3rd stage of multiplication. It has therefore been proposed to increase the 'units' of multiplication from 11 to 24 distributed as under :

I. Improved Sind American Cottons		18 'units'
(a) Sind <i>Sudhar</i>	11½ 'units'	
(b) Sind 4F-98	6½ 'units'	
	Total	18 'units'
II. Sind N. R. (<i>Desi.</i>)		5 'units'
III. Quality Cottons (Sea Island & Boss III-16)		1 'unit'
	Total	24 'units'

Thus the total areas required each year for the development of 24 'units' of seed multiplication will be as under :

1st year (Seed patch)	..	..	..	60 acres
2nd year (Increase block)	..	..	..	600 acres.
3rd year (Field scale planting)	..	..	..	6000 acres.
4th year (Village groups)	..	..	..	60000 acres.
5th year (General cultivation)	..	..	..	600000 acres.

PLANT BREEDING

Paper No. 6.

SOME EFFECTS OF X-RAYS ON UPPAM AND KARUNGANNI COTTONS

BY

V. RAMANATHA AYYAR AND R. BALASUBRAMANIA AYYAR,
COTTON BREEDING STATION, COIMBATORE.

It is often claimed that progressive mutants in plants can be produced artificially by means of irradiation and that the breeder can take advantage of this technique for the improvement of crops. The Indian Central Cotton Committee, Bombay, is subsidising a breeding scheme in the Madras Presidency for the improvement of the coarse and short stapled variety of *G. herbaceum* locally called 'Uppam.' It was programmed to employ in this scheme the new method alongside the time honoured methods of selection and hybridisation. The present paper records the results obtained so far in that direction. X-rays were used in these trials for exposing either the pollen or the seed.

POLLEN TREATMENT.

Pollen grains of two strains (2405 and 2919) of Uppam (*G. herbaceum*) were collected in gelatin capsules at about 9 a.m. on the day of flower opening and exposed to X-rays for 5, 10, 15 and 20 minutes at a target distance of 15 cm. using a current of 3 m.a. and 75 K.V. and aluminium filter of 1 mm. thickness. The treated pollen grains were immediately dusted on to the emasculated stigmas of the same strains. Boll setting and seed development were found to be normal. When these seeds were sown next year the germination capacity was noticed to decrease with the increase in the time of exposure (*Vide* Table I).

TABLE I.

Nature of treatment		Strain 2405		Strain 2919	
		Number of seeds sown	Percentage germination.	Number of seeds sown	Percentage germination.
Untreated		103	81	106	91
Treated	5'	79	73	71	70
	10'	172	70	111	71
	15'	116	50	64	54
	20'	117	52	66	53

Subsequent growth was quite good and no morphological differences were apparent among the plants. Finally, however, the average production of *kapas* per plant was distinctly higher in the treated series (Table II). It was of particular interest to note that the plants from 2919 responded more to the treatment than those from 2405.

TABLE II.

Nature of treatment.		Average yield of kapas in grams per plant.	
		Strain 2405	Strain 2919
Untreated		7.7	5.1
Treated.	5'	11.6	15.2
	10'	8.1	13.2
	15'	11.4	12.6
	20'	9.4	8.3

The produce of each plant was then sown in separate rows with controls intervening after every two rows. No phenotypic differences were observed even in this generation, but wide variations in the productivity were again manifested in the progenies of 2919. The cultures derived from strain 2405 on the other hand were poorer in performance than the control and were not studied further.

A good number of plants was selected from the better rows of 2919 and picked separately. 52 of these were sown next season in three row plots with the control repeated after every two cultures. Thirty were found to surpass the neighbouring controls in yield. In addition to these, 12 sibs from each of two high yielding cultures were found pure when tested for purity in seed and lint weights. In a third trial, two mixtures were made up, one with the produce of all rows that gave yields ranging from 1 to 10% over control, and the other with those yielding 100% and over. These were sown along with untreated 2919 as control in replicated plots for comparison of yields. Hardly any difference either in growth or yield was noticeable in both mixtures.

In the next year 37 single plants selected from the best of the 30 higher yielders and 20 plants from the reserved material of the previous season were compared in replicated rows. None of them was found to be better than the control. The two cultures declared pure during the last season also proved disappointing when tested for yield in replicated rows. Further trials with these types were therefore given up.

SEED TREATMENT.

Dry seeds of the above mentioned two *herbaceum* strains together with those of a Karunganni strain 546 (*G. indicum*) were exposed for 2, 5, 10, 15 and 20 minutes at a target distance of 15 cm. employing a current of 10 m.a. and 50 K.V. with no filter. When these seeds were sown, their germination was found to fall with the increase in the time of exposure (Table III).

TABLE III.

Nature of treatment	Name of Strain.					
	2405		2919		546	
	Number of seeds.	Percentage germination.	Number of seeds.	Percentage germination.	Number of seeds.	Percentage germination.
Untreated	164	91	164	93	164	87
Treated 2'	60	45	77	78	36	64
5'	119	55	178	74	77	68
10'	73	66	114	58	52	73
15'	138	52	145	75	114	55
20'	70	42	115	54	78	53

An aberrant plant (Plate I) with a peculiar type of leaves was soon spotted in a plot raised from treated seeds of strain 2919. It was poor in growth and died within three months after producing a few flower buds with deformed thread-like stigmas and sterile pollen. Other plots did not show any change in vigour or morphological characters.

All the plants were picked individually and sown during the next year. It was of extreme interest to note in three of the plots, segregations for chlorophyll deficiency in cotyledons and for meristic variation in floral parts.

The chlorophyll deficient types occurred in two plots, one from the *herbaceum* and the other from *indicum* species. They differed in their phenotypic expression. Those derived from the *herbaceum* plot had very pale and yellowish cotyledons with no chlorophyll grains and died within four days after germination. Their mode of segregation in the second and third generations are given in Table IV.

TABLE IV.

Parent type.	Generation.	Number of families.	Total plants.	Number of plants with		Value of P. for 3 : 1 ratio.
				Green cotyledons	Deficient cotyledons	
2405	X. 2	1	97	84	13	<0.01
	X. 3	43	3117	3117	..	
		22	1234	962	272	>0.01

It will be noticed that the fit for a monogenic ratio is poor in both generations. When the total number of families raised in the third generation is examined from another standpoint, *viz.*, the proportion of segregating families to those breeding true to green cotyledons, only 22 are found heterozygous against 43 homozygous families. The excess in the number of homozygous green families leads one to think that the chlorophyll deficient type met with here does not appear to be a simple Mendelian recessive. Further work is in progress.

The chlorophyll deficient types occurring in the *indicum* showed a different behaviour both in appearance and in the nature of their segregation. They had pale green cotyledons corresponding to patterns 4 to 6 of Harland (1932). Their sections contained a few disintegrated chlorophyll grains. Although most of

Plate No. 1.

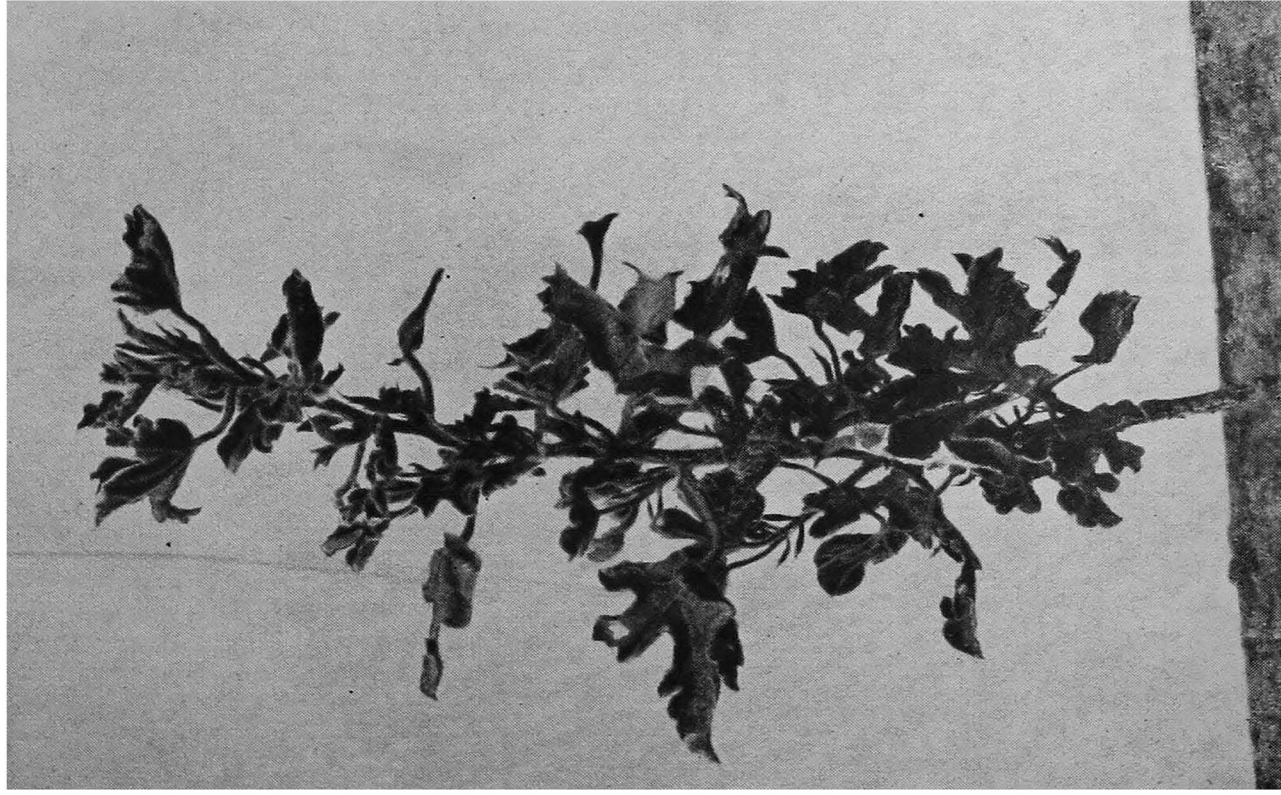


Plate No. 2.



these also died within a few days after germination, a few (3.9%) managed to turn green and survive. It behaved genetically as a simple recessive in the second and third generations (*Vide* Table V).

TABLE V.

Parent type.	Generation.	Number of families.	Total plants.	Number of plants with		Value of P. for 3:1 ratio.
				Green cotyledons	Deficient cotyledons	
546	X. 2	1	55	42	13	>0.90
	X. 3	9	640	640	..	
		23	1627	1241	386	>0.30

It would be noticed that unlike in the previous chlorophyll type a good fit was obtained in the proportion of heterozygous and homozygous families in the third generation; nine families out of thirty-two bred true to green.

It was interesting to note that the meristic mutants also behaved as simple recessive in the second generation and in the back crosses (Table VI).

TABLE VI.

Nature of cross	Generation	Number of families	Total plants	Number of plants like		Value of P. for 3:1 ratio
				Normal type	Meristic type	
546 X mutant (S x 439)	Back cross		26	15	11	>0.30
	F. 2	1	68	45	23	>0.10

These were quite normal in appearance except in the floral parts. They had generally four or more bracts, five to eight petals, four to seven loculi per boll. Very often extra carpellary structures with many ovules and occasionally with a well developed seed were found developing inside the central axis of the boll. In a few cases a single seed developed in the centre of the placental axis without any carpellary structure (Plate II.) No marked differences were noticed in the productive-

ness of these plants. The total number of seeds per boll was about the same as in normals although the average number per lock was distinctly lower.

DISCUSSION.

It is seen from the foregoing results that higher dosages tend to lower the germination capacity in the case of both pollen and seed treatments. It cannot be said that such a behaviour is a common feature in all cases of X-ray treatment of plant material. That viability of seed is lowered with higher dosages has been reported by Asabekoma on peas (1936). Yefeikin and Valiyev on wheat (1936), and Malhotra on maize (1932). Moore and Haskins (1933) have found that higher doses caused marked injury and stunted habit in cotton. Horlacher and Killough (1931) report on the other hand that the germination percentage was not affected appreciably when dry seeds of cotton were exposed. Further Mackay and Goodspeed (1930) have found that when treated pollen grains were used for pollination, seed setting was reduced in higher dosages. This experience is not in accord with what has been obtained in the present studies.

Of particular interest is the differential behaviour observed between pollen and seed treatments. In the former all the resulting plants showed increases in vigour and yield, although such induced vigour lasted only for three to four seasons, while in the case of seed treatments, no stimulation was discernible. Stimulation of growth has been, however, recorded as a result of treating dry seeds with X-ray by various workers on tobacco [Singh and Choudri (1935)], on soya beans [Long and Kersten (1936)], on *Vicia faba* [Patten and Wigoder (1929)], on peas [Atabekowa (1936)], and on cotton [Nehru (1932, 1933)]. In the majority of cases, it was said that weak doses tended to produce transient accelerated growth while strong exposures resulted in injury. Mackay and Goodspeed report however a contrary experience. Treatments of pollen have produced in their case various deformities and mutations. Possibly the fact that they were dealing with American cottons may be responsible for the divergence in the results obtained. It is not uncommon to find that different varieties respond differently to the X-ray treatment. *Durum* wheats were declared to be less liable to change than *vulgare* by Sapehin (1935). Even in the set of experiments dealt with here, it has been noted that strain 2919 was more susceptible to treatments than strain 2405.

When dry seeds are exposed to X-rays, three mutants—2 chlorophyll deficient and one meristic—are found to occur as recessive segregates, in the second generation. Obviously only one gene in one of the homologous chromosomes was affected by the treatment. This observation differs from that of Horlacher and Killough who noticed the occurrence of mutations in the first generation itself. But here again their obser-

vations relate to American cottons and to treatments with longer duration and hence are not comparable.

Another point which is important in the present studies is that all the three mutants secured are of the defective type and hence not of any use for the object in view. It may be added that this is a very common experience in the artificial production of mutations by X-rays. Khlop (1936) while reviewing the work done on this aspect of plant improvement throughout the world concludes that "no artificial mutants of established value agronomically have yet been produced, and the chief method of creating the variability necessary for selection is still hybridisation though the method of artificial mutations may possibly be of importance in the future." The only exception seems to be the appearance of a mutant in wheat, resistant to cold [Sapehin (1936)]. Horlacher and Killough report that progressive mutants were obtained by them in cotton but nothing has been said of their superiority agriculturally.

ACKNOWLEDGMENTS.

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SUMMARY.

1. Pollen grains of 2 strains of *G. herbaceum* and dry seeds of 2 strains of *G. herbaceum* and one strain of *G. indicum* cottons were exposed to X-rays for different periods with the idea of producing progressive mutants useful for breeding.
2. Higher dosages were found to lower the viability of the seeds. Boll setting and seed development were not affected.
3. The response to treatments varied with the strains. Of the two strains tested here, one did not show any appreciable effect.
4. When treated pollen was used, plant growth was found to be stimulated in the succeeding generations. No differences in morphological characters were observed.

5. By exposing dry seeds to X-rays, three new types of mutants—2 chlorophyll deficient and 1 meristic variant—were obtained in the second generation. These were recessive in genetic behaviour. All the three were not of any use economically.

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PLANT BREEDING

Paper No. 7.

COTTON BREEDING IN THE CENTRAL PROVINCES AND BERAR

BY

D. N. MAHTA, ECONOMIC BOTANIST FOR COTTON,
CENTRAL PROVINCES, NAGPUR.

INTRODUCTION.

Cotton breeding is concerned with the improvement of the cotton plant. Its object is the production of better crops, at no additional expense to the grower. Men of all times have attempted to improve the quality and yield of their cultivated plants. But improvement in the past has, for the most part, been haphazard, accidental and slow. Recent advance in Genetics, however, has placed plant breeding on a sound scientific basis and has added considerably to our knowledge of the methods and scope of plant improvement. The plant breeder can now proceed with his task of producing new plants better suited to the many and varied requirements of agriculture and commerce in a systematic and orderly manner. There is little doubt that plant breeding is destined to play a very important role in the agricultural economy of the world.

It is proposed in this paper to trace the development of the cotton plant in the Central Provinces and Berar and to summarize the chief improvements which it has been possible to effect by the application of modern breeding methods. It may perhaps seem purely academic to discuss this subject at a time when the Indian mills are reported to be overstocked with stapled cotton and when, therefore, the grower of the improved types sees but little chance of securing that premium for the superior quality of his lint, on which the extension of area under such cottons must ultimately depend. It must be assumed, however, that conditions will gradually return to normal and that before long there will be within the country a great increase in

the demand for cotton of better staple and quality. In the great central markets of the world, cotton of good grade and staple invariably brings in more than poor, coarse cotton, though the differential is variable. It is therefore not unreasonable to assume that, in the long run, the profitableness of cotton growing in these provinces also will tend to lie in improved cottons of superior quality and staple.

HISTORICAL RETROSPECT.

The cotton produced in the Central Provinces and Berar is commercially known as "Oomras" cotton. The quantity grown annually amounts roughly to one-fifth of India's total production of cotton. How long cotton has been cultivated in these provinces, it is difficult to say with any definiteness. Certain it is, however, that at one time the common cotton of the whole "Oomras" tract, was *Gossypium indicum* or bani which under the name of 'Hinganghat' bani attained the reputation of being the finest Indian cotton. Bani produces far and away the best lint of any truly Indian cotton. Its staple is strong, silky and from 1" to 1½" in length. "Oomras" to the present day owes its value to the percentage of bani that it contains. To-day bani has almost everywhere been supplanted by coarser varieties of the "Neglectum" group. The change was due partly to inherent defects in bani and partly to economic causes. Bani was later ripening than, and not so hardy as, the cottons which threatened to take its place. The bolls on ripening did not open fully at their base and the lint had a tendency to cling to the capsule. It was therefore comparatively difficult to get the whole lock of cotton out of the boll with one pull, with the result, that it took longer to pick than other cottons, while the lint contained small fragments of leaf and septum which increased the blow-room loss. The biggest drawback, however, was its low ginning percentage which in commercial samples rarely exceeded 26. It was in fact, this factor more than any other, which with the prevailing system of disposal of cotton in the "Oomras" tract, proved to be the death-blow for bani. It was Rivett Carnac, in the sixties of the last century, who first drew attention to the fact that 'Jari,' a mixture of cottons of coarse types, supposed to have come from East Khandesh, was ousting bani. He made a serious attempt to check the introduction of this Jari but economic conditions were all against him and the hundreds of tons of pure bani seed which he distributed did but little to stem the tide. The cultivator preferred to grow the coarse variety because it was reared with far more ease, was earlier ripening and gave less trouble in picking. The middleman, too, preferred it, because he saw in its higher ginning percentage an easy source of profit. The authorities were very concerned about the change that was taking place and made one more attempt to check its spread by the introduction of superior cotton seed of exotic types. The Upland Georgian mixture of from 5 to about 20% which is still found in cotton fields all over the cotton tract of the province is a relic of their achievement in that direction.

How far the intermixture of Jari and bani had gone on in the sixties, it is impossible to say, as no classification of our cottons was attempted till 1906, by which year it was found that Jari had replaced bani everywhere except in Chanda District and on the borders of the Nizam's Dominions. In Chanda District, over a few thousand acres, a more or less pure bani is still grown as a *rabi* crop. The classification carried out by the Department of Agriculture in 1906 showed that about 99% of the cotton area in the province as a whole was cropped with Jari. This so-called Jari on being classified was found to consist of no less than six distinct varieties namely *Gossypium neglectum malvense*, *Gossypium neglectum verum*, *Gossypium neglectum roseum*, *Gossypium neglectum cutchicum*, *Gossypium indicum* and Upland Georgian (*Gossypium hirsutum*). Over the greater part of the province, the white flowered *Gossypium neglectum roseum* was found to be dominant. Agricultural study of the constituents of the Jari mixture further showed that of the five indigenous varieties, *Gossypium indicum* with its one inch staple yielded the lowest mount of lint per acre, while *Gossypium neglectum roseum* with its coarse short staple and high ginning percentage gave the highest outturn.

As a result of the gradual ousting of bani by Jari, the quality of the "Oomras" began to deteriorate and vary in proportion of coarse varieties in the mixture. To keep the varieties pure, no real inducement was offered by the trade as a whole, for the buyer paid no attention whatever to staple; what he wanted was clean white bulky cotton. The bani *kapas* raised from the seed given out by the Agriculture Department in these provinces in 1904-05 was reported by the growers to have fetched less in the cotton markets than the Jari mixture. There was indication all over the provinces that Jari, for the time being at least, had come to stay.

The great influence played by high ginning percentage and the fact that the highest ginner of all "Roseum" was the easiest to grow practically decided the next step. It was the separating out, multiplication and distribution of pure roseum seed by the Agricultural Department. In this way the whole of Berar and the Central Provinces to an increasing extent became flooded with this cotton. The natural outcome of all this has been that the bulk of the crop now produced in these provinces is of the shortest and coarsest staple possible—capable of spinning no higher counts than 8's or 10's. There is little doubt that for a time the extension of roseum added largely to the farming profits of the cotton growers.

The growing of a coarse cotton requiring but little cultivation, though a great temptation for the cultivator, cannot, however, be called sound permanent agriculture on any stable economic basis. It is usually accompanied by soil impoverishment and land deterioration is bound to be followed by crop diseases and other inimical economic factors. This is, in fact, what actually did happen in Berar. Tempted by high prices which prevailed during and a few years after the Great War, cotton

and still more cotton was grown on the same land without rotation or other considerations of rational farming. Continuous cropping of the land with cotton led to the incidence of the wilt disease to which the common variety, roseum, proved to be particularly susceptible. The disease began to spread with alarming rapidity and to cause a large loss of revenue to the provinces.

A cotton policy was now more than ever needed. With a watchful eye upon the future, the Agricultural Department was not slow to realize that if cotton growing in Berar was to be made a permanent success, attention must be paid to the finding out of cottons of a superior type. The improvement of the race of plants by breeding methods began thus to be considered of the utmost importance. This was perhaps a more difficult and slow method but it was the best ultimate aim and most permanent improvement in agricultural practice. To achieve this object, the Department in 1922 placed the Government Experimental Farm at Akola under the Economic Botanist in order that the work of evolving improved and resistant varieties, testing multiplication, cultural experiments and other essential investigations might be correlated and carried out under one management. In the same year the Indian Central Cotton Committee was formed and laid substantial funds at the disposal of the Agricultural Department for conducting botanical research and cultural experiments for the improvement of the Central Provinces and Berar cotton crop.

PRESENT POSITION.

The new organisation for research commenced work in 1923. The position at this time was briefly this. More than sixty years of promiscuous growing of varieties differing widely in quality and cropping power had brought about a marked deterioration in the reputation of the "Oomras" cotton. As a result of the intermixture, the quality of the cotton produced varied from *tahsil* to *tahsil* or even from village to village. For the spinner, it was extremely difficult to obtain uniform lots of cotton of known staple. The wilt menace was on the increase and was driving many cotton lands out of cultivation. The immediate need of the moment was a wilt-resistant cotton which at the same time yielded well. If quality of staple could be combined with it, so much the better.

The first few years were of necessity spent in obtaining pure strains of the various types of Indian cotton and in making a systematic botanical survey of the cottons met with in the provinces. The latter revealed that the existing crop consisted of a mixture of types of great variability to almost every visible character, such as length of staple, percentage of lint to seed, uniformity of fibre upon the individual seed, strength of fibre, size of boll, earliness of maturity and resistance to wilt disease, etc. A mixed population of plant showing such wide variations offered great scope

for selection. Desirable combinations might with advantage be sought in the existing crop. While, therefore, hybridisation and acclimatisation were not excluded from the programme of investigations, it was decided to concentrate on the plant-to-row method of cotton breeding for sure and comparatively rapid progress in the obtaining of suitable types.

The work of crop improvement is necessarily slow in the production of results, because of the many years involved in the selection, fixation and testing of suitable or superior new types. Several years of critical tests are required before it can be safely said that a new strain, no matter how promising, is really better than those already grown. But the period from 1923—1936 has been one of uninterrupted progress and marked advance in the matter of production, development and introduction of new, improved and wilt-resistant varieties of medium stapled cotton which admirably meet the present-day requirements of the spinner and are at the same time profitable for the cultivator to grow. It is not claimed that in them a complete solution of the cotton problems of these provinces has been found. But the first step in the right direction has been taken. Further improvement will follow in its train.

It was along the lines indicated above that the work proceeded. The existing crop was classified and unit species separated. Rigid selection and testing followed. Of the common acclimatised "neglectum" types of cotton, it was previously supposed that it was only in certain strains of *G. n. malvense* that any degree of resistance to wilt existed. *G. n. verum*, though the best neglectum type with regard to lint quality, had up to this time been ruled out as a desirable cotton on account of its great liability to wilt disease attack. Careful examination of the neglectum cotton types, however, indicated that the most likely type combining a maximum of desirable characters might possibly be obtained from *G. n. verum*. No work seemed ever to have been done upon the type to try and improve it. Strains were selected and examined but at first they all showed a very high susceptibility to wilt disease. After considerable selection and trial, however, strains of *G. n. verum* were found showing a resistance to wilt. It is interesting to remark that at the same time this resistance to wilt was being found haphazard as it were in certain verums, hybridisation experiments planned originally with no idea at all of wilt resistance gave a clue as to what resistance to wilt in verum cotton and probably in any neglectum cotton was due. The neglectum cottons have for long been suspected to be a group of hybrid origin. Hybridisation experiments conducted here showed that *G. n. verum* could be derived by crossing *G. arboreum* with *G. n. roseum*; *G. arboreum* with *G. indicum* and *G. indicum* with *G. cernuum*. The *G. n. verum* obtained by method 3, although indistinguishable to the ordinary eye from the *G. n. verum* of methods 1 and 2, yet differs from the latter in being considerably resistant to wilt disease. This resistance to Berar wilt disease and its inheritance in neglectum

cottons at all events seems to be always due to the presence of cernuum ancestry. This ancestry can, so far as we have seen, be recognised in narrow cottons by the character of the middle lobe of the leaf. The fact of the two borders to the leaf lobe being slightly doubly convex so that the middle of the lobe expands somewhat instead of the lobe being an isosceles triangle as in other narrow leafed types indicates cernuum blood and wilt resistance. Sometimes the drooping character of the *G. cernuum* branches is to some degree brought over with the other verum characters; this also is an indication of wilt-resistance. By comparing the verum selections with types derived by known methods, it was possible, in some cases, to assign them a certain method of origin.

Attention was now concentrated on the resistant material of *G. n. verum*. By the selection of individual plants possessing desirable characters, the degree in which each was able to transmit its desirable characters was determined. Further testing, while increasing separately the product of the best rows, determined which strain was likely to be of the greatest commercial value. Six years of patient experimentation were necessary before the first variety was thought worthy of general distribution. This was verum 262. Being a pure line selection for wilt resistance, it fulfilled the immediate requirement of the time and was a considerable improvement over roseum. With a ginning percentage of 32 and capacity to spin 20's to 22's highest standard warp counts, it gave lint yield which on wilted land was unquestionably higher than that of roseum. Even on non-wilted land the premium it obtained more than compensated for its slightly lower yield and ginning percentage as compared with Jari. In 1929, it was grown over an area of 5,000 acres; in the following seasons, the acreage was 35,000, 1,50,000, 1,64,800, 83,591, 89,560 and 96,000 acres respectively. Experience, however, proved this cotton to be susceptible to variations in climatic conditions which rendered estimation of its cropping power a difficult matter owing to wide fluctuation in yield from year to year.

Something more was needed. A cotton that would supplement verum 262 in areas of heavier rainfall to the east of Berar and in the Central Provinces where the duration of the monsoon is comparatively long. In the meantime, the work of breeding new strains was being patiently carried forward on a gradually expanding scale. Further search in the original resistant material of *G. n. verum* had provided a wide range of new combinations. While the desirability of finding and perfecting a single all-round type for the entire cotton tract, as being the soundest policy both from the agricultural and commercial points of view was at no time lost sight of, all suitable combinations wherever met were isolated and worked up. One of these, now known as Late verum, answered the immediate requirements, was multiplied and distributed. Superior to verum 262 in quality and capable of spinning 31's highest standard warp counts, it soon became popular in tracts for which it was developed and has been obtaining a premium of Rs. 10/- per *khandi* over verum 262.

Another useful strain, No. 438, a pure line selection from *G. n. verum*, followed in rapid succession and has proved valuable for lighter descriptions of soil. While progress of these strains was carefully watched in the field, investigations were continued for the finding out of a strain of cotton which would serve as a good all round type. By the end of 1932, the fixing of such a type became possible and led to the development and multiplication of V. 434, the chief merit of which lies in its adaptability to varying conditions of soil and climate. It is a strain which possesses, in addition to wilt resistant qualities, drought-resistance, prolific flowering capacity, quickness in forming buds and setting fruit, comparative freedom from shedding and excellent lint characters and good ginning percentage. Its staple is strong, silky and nearly one inch in length. It has been adjudged suitable for spinning 32's to 37's highest standard warp counts—no mean advance over the 8's of roseum and 20's of verum 262. In ginning percentage it rivals with verum 262 and the handsome premium which it commands for the superior quality of its lint, more than compensates for its lower ginning percentage as compared with Jari. The Empress Mills, Nagpur, which tested this cotton along with other growths under identical conditions found that it gave almost the same tension as "Bhensa" cotton, while the blow-room loss was even less. V. 434 is the best all-round type available at present and judging by its rapidly increasing popularity and demand for seed all over the provinces, it should in the course of the next few years have considerable areas under it.

Another aspect of the work has been an examination of the possibilities of buri (acclimatised *G. hirsutum*) cotton in the Central Provinces and Berar. An area of 50,000 acres in and around Burhanpur in the Nimar District appears to be peculiarly suited to this cotton. Buri yields well in years of ample rainfall especially, and does not suffer from wilt disease. In the cultivators' fields, it is generally met with as an admixture in varying proportions and no doubt improves the general quality of the lint. The lint, however, is weak. Systematic work was therefore undertaken to see if it were possible to get a strain that showed any inheritable consistency in its lint strength. Various strains were selected initially with lint strength as one of their desirable characters and they were selfed and thus carried through succeeding generations. As the work progressed it showed conclusively that the variation in lint strength from year to year was caused by varying environmental conditions. No uniform improvement in the lint strength could be obtained with local environment. It was therefore decided to restrict work to the improvement of its staple and yield. Intensive selection by the plant-to-row method of cotton breeding was resorted to and is still being carried on. As a result of this work three improved strains, viz., Buri Ak. Special, B. 107 and B. 84, have been developed, of which the first two have shown excellent performance and have been taken up wherever buri is grown. In years of heavy rainfall, these strains have yielded as much as 1000 lbs. of *kapas* at the Akola Farm. Their ginning percentage is 28 and 29 respectively.

Since the receipt of grants from the Indian Central Cotton Committee, a good deal of hybridisation work has also been carried out. This work was somewhat handicapped at first owing to the lack of pure types. The chief aims in this work have been to investigate the possibility of hybridisation itself producing either as hybrids or mutants—new forms of value and secondly, to study the inheritance of independently behaving characters. This work has largely been of academic interest except the hybrids with *G. indicum* and *G. cernuum*—some fixed strains of which appear promising and are being multiplied up for field-scale tests. An interesting point in connection with this cross is that considerable quantities of it, whole fields and areas of it at times, are to be found growing in the C. P. No. 1 region and that it is prized for its superior lint and wilt resistant properties.

The old bani cotton (*G. indicum*), too, has not been neglected. This has offered a vast scope for improvement in all directions. But the biggest drawback has been its low ginning percentage. Here we have to contend with the fact that with our Indian cottons as ginning percentage increases the staple gets shorter. Nevertheless, two new strains have been developed, viz., bani 306 and E. B. 31, which are capable of spinning up to 50's and yield up to 500 lbs. of seed cotton per acre. Their ginning percentage is about 27. To these have been added two new strains B. 790 and B. 773 which have this year been grown on an acre scale and are a definite improvement on the two previous types. The department will thus be ready with suitable forms when the time comes for the cultivation of bani to be taken up once again. It is realized, however, that until direct contact between the grower and the spinner can be established, until, in fact, the quality of cotton and not the ginning outturn becomes the basis of valuation, there is little chance of extension of area under such superior cottons.

This account will not be complete without a brief reference to the Chanda Jari cotton, a fairly pure cold weather crop of *G. indicum*. At the time of high cotton prices the area under this crop was about 20,000 acres and it was considered by some that there were possibilities of expansion. The crop was therefore examined with a view to improving it. The first thing required was the eradication of a dirty or tinged strain that was found universally in the crop. A study was therefore made to discover the method of inheritance of this dirty character in Chanda jari and at the same time to test the inheritance of *khaki* colour in other cottons. Our experiments have shown that colour from all gradations from merely tinged lint to markedly drab or *khaki* linted forms behaves as a complementary character with whiteness on straightforward Mendelian lines. The tinged or *khaki* form is dominant and the whiteness is recessive. The heterozygous form is intermediate in colour and in the case of a tinged form only (like that of Chanda jari) may be of so slight a nature as easily to pass for white to again throw the fully tinged form next year. A pure white good yielding strain has now been isolated and fixed and is being given out for trial

and multiplication. The possibility of extension of the Chanda jari crop has also been looked into and it is doubtful in the extreme if it be very great. The present yield of Chanda jari is about 2000 bales and there does not seem much likelihood of this crop assuming great importance by itself. All that can be hoped for is the substitution of the tinged lint types by the white-linted strain isolated here.

CONCLUSIONS.

In conclusion it is hardly necessary to emphasize that in no cotton producing area can the crop be improved and that improvement maintained without a widespread recognition of the principles of plant breeding and the practical application of those principles. Plant breeding alone, however, will not solve the entire cotton problem of the province. The progress of our improved strains has been undoubtedly grievously retarded by a pernicious practice of buying cotton as *kapas* and paying attention solely to ginning outturn. Under such a system, no cotton of a superior type is going from birth to stand on its own legs without attention. In other words, improvement in the staple by breeding and selection must go hand in hand with improvement in the conditions under which cotton is marketed. The cultivator, too, must realize that to be successful in cotton growing, he should begin with pure pedigreed seed and should frequently renew it from the breeding source to prevent natural deterioration and accidental mixing. By the production of a quantity of selfed seed at the Akola Farm each year and its planned distribution in the following two years, facilities are provided by the Agriculture Department for renewal of seed. But while much work has been done in recent years on cotton research in these provinces and while many cultivators in Berar do in fact appreciate the superior qualities of the well-bred cottons, there is still a lamentable ignorance on the part of the majority of growers, of many of the essentials underlying the production of cotton of the highest net money value. There will perhaps always be a demand for cotton of any kind but it is now becoming increasingly evident that competition, stimulation to higher prices, will in future lie with cottons of a finer type. There is no good reason why staple cotton cannot be substituted for coarse cotton over the greater part of the cotton growing areas of these provinces. Varieties exist to-day which are as early and nearly as productive as any varieties of short cotton and which are at the same time adapted to every kind of soil and climate existing in the cotton tract. In V. 434, the Agriculture Department has an excellent all round type to offer to the cultivator, while for certain special areas, there are other strains of equal merit to meet those special requirements. The ideal for which the Berar cultivator should strive for cotton production should be a cotton that would spin higher counts than 20's.

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DISCUSSION.

There was no discussion on these papers.

COTTON STATISTICS

Paper No. 1.

THE DELIMITATION OF AREAS FOR STRAINS OF AGRICULTURAL CROPS WITH SPECIAL REFERENCE TO COTTON

BY

V. G. PANSE, STATISTICAL ASSISTANT,
INSTITUTE OF PLANT INDUSTRY, INDORE, C.I.

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I. INTRODUCTION.

The Institute of Plant Industry has undertaken a series of variety trials since 1932 in order to discover whether superior strains of the main agricultural crops could be introduced into Central India and Rajputana. The results obtained so far have been published elsewhere [Hutchinson and Panse (1936)]. The most important conclusion to be drawn from them is that it is never safe to introduce a new variety without thorough trial in the tract in which its distribution is proposed. Another conclusion was that only a strain bred under similar conditions had any chance of being successful and then it was not always suitable for the whole of the tract. For example, Malvi 9 cotton, a strain evolved at the Institute Farm, was found significantly superior to local cotton in yield of *kapas*, ginning outturn and staple in the southern and more typical portion of Malwa with soil and climate

similar to that at Indore ; but in the northern part with somewhat different conditions it did not differ significantly from local cotton in yield and its distribution in that area was justified only on account of the premium obtainable for its superior ginning percentage and quality.

The object of introducing new strains is to secure better returns to the cultivator. It is, however, a well known fact that the premium obtainable for quality is seldom adequate and strains of superior quality are therefore not profitable to the cultivator if their yield is low. It is a safe rule not to recommend any strain unless its yield is about as good as that of the local type. Similarly in India at least, where the cultivator has no reserves, strains that give a high yield in some seasons and a poor yield in others are not desirable. Consistently good yield thus becomes a most essential character in a strain to be recommended and varietal trials conducted at several representative localities in the tract for three or four seasons are the only means of testing it. From the results of such trials alone the agricultural officer can decide whether to undertake the distribution of a strain and to what part of the tract confine it. The plant breeder is also concerned with these trials because he must make sure that his strain is promising over a sufficiently wide area to justify multiplication on a commercial scale. It is possible that a strain may do very well under the special conditions of a breeding station but fail to maintain its superiority over any considerable area outside.

All this indicates field trials on an extensive scale requiring careful planning and organisation and it is proposed to outline in this paper a comprehensive testing scheme based on experience gained at the Institute.

II. THE METHOD.

(a) *The observation plot*—Strains brought from outside and bred under conditions dissimilar from those existing in the tract should first be grown in small single plots by the side of the bulk crop of the local type to study their growth habits, because for successful cultivation a strain must possess certain growth characters determined by the soil and climatic conditions in the tract. For example, where frost is common a strain must mature early to escape it. A strain must also be free from the diseases and pests to which the local type is resistant. Strains that do not possess the necessary characters can be discarded at this stage. It will be found that almost all the foreign types can be disposed of in this way and the labour and expense of trying them in replicated experiments saved. It is hardly necessary to add that yield comparisons from observation plots are not sound and should not be relied on.

(b) *The replicated trial*—Modern ideas on the layout and statistical analysis of replicated trials are now generally known and will not be repeated. Attention will be drawn only to those points which make varietal trials efficient and prevent draw

ing of misleading conclusions. The type of soil on which the trial is laid out should be representative of the area to which its results are required to apply. Cultivation, rotation and manuring of the experimental area should conform to the practice of the local cultivators. Results of variety trials laid out on highly fertile land, well graded and intensively cultivated by improved implements will not, in all probability, be reproduced on the neighbouring cultivators' fields and such results, though spectacular, will be practically useless. All operations on the experimental crop such as spacing, seed-rate, irrigation, interculture, etc., should follow the local practice for that crop and only such variation as would increase uniformity without affecting the essential factors in the local agricultural practice should be allowed. For instance, in sowing a given weight of seed per plot, uniform distribution of seed in the different rows will increase the uniformity of the stand over the trial and reduce experimental errors, but sowing seed at a regular spacing with a mechanical drill will be objectionable. Clean weeding of experimental plots will similarly help to increase uniformity.

Unless there is evidence from previous trials to justify variation, all strains in the trial should be given identical treatment in respect to the various agricultural operations. This is a point which is often overlooked. In some cotton varietal trials recently conducted in the United Provinces some varieties were sown at a wider spacing than others in the same trial and only one variety was topped. It is impossible to interpret results of such trials in terms of varietal differences, for spacing and topping are inseparably confounded with varietal differences. In the above trials, for example, Raya American, an Upland strain, sown at a wider spacing than Cawnpore 520 gave a significantly lower yield than the latter. It remains doubtful, however, whether the lower yield was due to the poor yielding capacity of the American plants or whether it was due to the lower stand of the American strain caused by wider spacing. To answer such questions properly a somewhat different type of trial is necessary. Taking narrow and wide spacing between rows as an example, each strain in the trial should be sown in two plots per block, with narrow spacing in one and with wide spacing in the other, the plots being distributed at random. The statistical analysis of the trial will then show (1) whether strains differ significantly irrespective of the spacing adopted, (2) whether the two spacings give significantly different yields on the average over all strains and (3) whether some of the strains are at a greater advantage than others at a particular spacing. Whether the strains should be sown at different spacings or at the same spacing in varietal trials will depend on whether the conclusion on the third point is positive or negative. Similar questions sometimes arise when alternative practices exist in the same tract in respect to some agricultural operation. Instead of adopting arbitrarily one or the other practice it is preferable to design the trials to provide information on both. For this purpose the split-plot technique is a convenient device. If, for example, thinning of the stand is to be compared with no thinning, only one

plot per variety per block need be sown. It can be divided into two longitudinal sections at the time of thinning, and the crop in one of the sections, selected at random, thinned and that in the other section left unthinned.

On the assumption that the local variety is an inferior mixture it is generally omitted from varietal trials. If from the results of such trials one strain proves superior to the others, the question whether it is superior to the local type still remains unanswered. The latter comparison is really the more important one since the primary object of varietal trials must be to discover whether any or all of the selected strains are really improvements over the local type. Also the adaptability of improved strains is to be tested and the local type is the only criterion of local adaptation.

For statistical efficiency optimum plot size and shape and number of replications should be adopted as far as possible. It has been shown [Hutchinson and Panse (1935)] that for cotton long and narrow plots up to 1/50 acre in size replicated about six times give results with the degree of accuracy desirable in varietal trials. Experience with other crops is similar. Several trials with 1/100 acre plots were carried out by the Institute and it was found that an almost equal degree of accuracy is possible if trials are conducted carefully. While maintaining long and narrow plots the actual shape of the plot should be so selected that the resulting block is nearly square.

For eliminating border effect it is necessary to discard one row on either side of each plot. Extra rows should be sown on both margins of the whole layout to keep down the border effect of the edge rows [Hutchinson and Panse (1935)]. Keeping of open paths within the layout is neither desirable nor ordinarily necessary. Such paths tend to enhance margin effect in adjoining rows and are generally less cultivated than the plots themselves. The whole layout ought to be treated as a single unit for the purpose of agricultural operations and not as a series of independent plots. Where absolutely necessary, paths may be kept between blocks provided an extra row is sown on the margin of each block.

(c) *Multiple trials*—Varietal trials must be conducted in as many localities as is necessary to secure a representative sample of the tract. To do this successfully the programme must be developed gradually through successive stages.

In first stage, trials consist of a comparatively large number of possible varieties and new strains in the process of multiplication. Only at experiment stations are the necessary facilities available for handling the large number of plots involved and maintaining the purity of seed of new strains. The object of these trials should be to eliminate all material inferior to the local type and usually not more than four or five strains should be carried to the next stage.

These strains must then be tried out extensively. For this purpose, the number of experiment stations will be too small and all of them may not be situated in representative localities. Co-operation of the more advanced cultivators therefore becomes necessary. While the main purpose of trials on cultivator's land is to confirm the results obtained at experiment stations, they possess the additional merit that cultivators can observe differences between strains growing under their own conditions and have no hesitation in taking up the cultivation of a strain which has proved promising on their own land. In the beginning there is a natural reluctance on the part of cultivators to spare land for an experiment that they fear may come to nothing; but once a start is made with some successful trials this difficulty disappears. Out of forty-two centres at which varietal trials were carried out under the direction of the Institute of Plant Industry, at thirty-three centres they were laid out in cultivators' fields.

These trials depend on the good will of the cultivator and in order to retain it, it is important that they should be carried out successfully without an undue strain on his resources. Certain precautions are therefore necessary. The number of varieties should be small and any that are likely to disappoint the cultivator should be rigorously excluded; hence the need of first eliminating inferior varieties by trials at experiment stations. The land selected should be free from defects that may depress the growth of the crop or cause damage to the trials. Trials are often ruined by being laid out on land liable to waterlogging or containing weedy patches or in a corner of the field where the crop cannot be protected from animals and human beings. Under such conditions the crop is not normal and the cultivator may plough it up before the trial is complete. Even if it is carried to the end variation between plots is great and high experimental errors result.

Availability of land is an important factor. A trial with five varieties in plots of 1/50 acre size replicated in six blocks will require nearly an acre. A cultivator cannot always spare so much land for an experiment and it is also not necessary that one cultivator should do it. The trial can be split up into sets of blocks and distributed to different cultivators. With six as the minimum number of replications for a complete trial four or five cultivators belonging to the same village or to neighbouring villages can take up a pair of blocks each, making a total of eight or ten blocks. Provision of extra blocks is necessary when the trial is divided because not all replications are always successfully carried to the end. If pairs of blocks are laid out in different villages the data provide additional information regarding the significance of interaction between varieties and places. This interaction as will be shown later is an important item in the analysis of multiple trials. The trial can even be divided into a number of single blocks. The cultivator can manage a single block more easily and appreciate the comparison better. Even the harvesting of plots separately can be entrusted to him with some safety if an emergency arises.

With a larger number of plots this is not possible and good trials are not infrequently ruined by the cultivator harvesting all plots together. Against this must be put the difficulty of close supervision and careful observation in blocks scattered widely and the consequent danger of mistakes being made, in addition to the necessity pointed out above of laying down an extra number of replications. How far a trial can be safely divided will naturally depend on local conditions and facilities for supervision.

Observations called for should be simple, so that a visiting fieldman or agricultural supervisor or where necessary a person without any special training can record them. Quantitative observations should be avoided as far as possible, though in some cases, *e.g.*, in comparing incidence of wilt in different varieties of cotton, a count of plants may be necessary. Recording the yield per plot separately in suitably small units (*e.g.*, seers and chitaks) cannot be over-emphasised.

If from the results of these trials one or more strains are found suitable for distribution, as many single blocks as possible consisting of these strains and the local may be scattered all over the area. These blocks serve the purpose of demonstration on a large scale and being designed according to statistical requirements, the data obtained from them can be analysed and used for confirmation of previous results. Very careful observations are not necessary and attention should be concentrated on securing accurate records of plot yields only. Weights of those parts of the crop, like stalks or straw, which are of relatively small economic importance may be dispensed with.

In varietal trials a carefully assessed *bazaar* opinion of quality of different strains is valuable, specially where the crop is meant for local consumption. Laboratory tests on quality can be made at the central station on bulk samples. Sometimes plot-wise samples are necessary as when the staple length of cotton strains is to be compared [Hutchinson and Panse (1935)]. Careful instructions to persons responsible for collecting samples are needed to secure really representative material without any attempt at selection.

(d) *The efficiency of multiple trials*—Some idea of the statistical efficiency of these trials as judged by their percentage standard errors can be obtained from the table given below. Forty-five cotton varietal trials are classified in the table according to their standard errors and divided into three groups: (1) those conducted at the Institute by the staff, (2) those conducted at State farms by agricultural officers trained in this method of field experiments and (3) those conducted in cultivators' fields under the supervision of agricultural and other State officials. Only trials with 1/100 acre plots and six replications are included to make the data strictly comparable.

TABLE.

Frequency of standard errors per cent in cotton varietal trials 1932-1935.

Location	Standard errors per cent.					Total
	Up to 5	5—10	10—15	15—20	Above 20	
Institute	.. 2	5	1	..	..	8
State Farms	.. 4	8	4	1	1	18
Cultivators' fields	.. 1	9	7	1	1	19

It will be seen that the trials at the Institute were most efficient, trials on State farms came next and those on the cultivators' fields third. The efficiency of the trials, on the whole, was fair, the majority of trials having a standard error of ten per cent or less. Experience with other crops was similar.

III. DISCUSSION.

It has been shown before that the profitableness or otherwise of a strain is determined principally by its yield due to the fact that premium for quality is not adequate. Statistical analysis of yields from multiple trials is fairly straightforward provided the different trials are of uniform design, *i.e.*, with plots and blocks of the same size and shape. In planning trials, therefore, this uniformity should be maintained as far as possible. The randomisation for each trial should, however, be independent, a principle which is not always realised. The arithmetical procedure of analysis has been well illustrated by Paterson (1933) and Immer (1934). The different items in the analysis of variance will be as follows:—

- (1) Varieties
- (2) Places
- (3) Seasons
- (4) Varieties \times places
- (5) Varieties \times seasons
- (6) Places \times seasons
- (7) Varieties \times places \times seasons
- (8) Error.

For making recommendations we are concerned with items 1, 4, 5, and 8. It is not enough that the strain to be recommended should give a better performance than others on the average if it does worse than others at some of the places or in some of the seasons. Average differences between strains are established if the mean square due to varieties is significantly greater than that due to error. If, however, items 4 and 5 are significant indicating a differential response of strains to places and seasons, recommendations cannot be based merely on the existence of average differences. In such a case the varietal mean square must be compared with mean square due to the interactions given in items 4 and 5 and only if it is significant a recommendation can be made for the whole tract with an assurance that the recommended strain will prove superior in future seasons [Fisher (1935), Immer (1934)]. By a further examination of interactions it can be discovered whether any strain is suitable for recommending over a part of the tract. Interactions thus enable a test of the consistency of behaviour of different strains to be made and this test as shown before is most important in varietal trials.

When the variances of individual trials in a set are widely different the above method of analysis is not permissible and a combined comparison of all strains not possible. For dealing with such cases Yates (1934) has suggested two separate tests which have to be carried out on pairs of strains at a time. Uniformity of design in the different trials is not essential. The significance of mean difference between two strains can be examined by a T-test, the variables being single values of difference between two strains, obtained from each trial. In this test the error variance really consists of the interaction between strains and experiments, *i.e.*, places and seasons. Whether this interaction is significant can be tested by a Q-test. Much useful information is obtainable from the application of these tests specially when the number of trials is fairly large.

When statistical analysis of the combined data is not profitable or simple it is still possible to interpret results for making recommendations by an inspection of the statistically reduced data from individual trials. If the mean yield shows satisfactory superiority, the remaining important consideration is that the strain to be recommended for an area should not give a significantly lower yield than the local or any other established strain, in any of the trials in that area.

IV. SUMMARY.

The importance of conducting varietal trials in representative localities before undertaking distribution of a new strain has been shown. A scheme for conducting such trials has been outlined and precautions to be observed have been pointed out.

The statistical aspect of the problem has been discussed.

V. ACKNOWLEDGMENT.

I am indebted to Mr. J. B. Hutchinson, Geneticist and Botanist at the Institute of Plant Industry, for guidance and criticism during the writing up of this paper. The scheme presented here has developed out of varietal trials designed and conducted under his supervision.

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DISCUSSION.

Mr. V. G. Panse said that as yield was the principal factor in determining the paying capacity of a variety it was necessary that adequate yield trials of varieties should be undertaken before they could be recommended to cultivators. Variety trials throughout Central India and Rajputana were conducted by the Institute of Plant Industry, Indore, with Malvi 9, a strain superior in all respects to local cotton in the southern and more typical portion of Malwa, yet in Rajputana and in Nimar this Indore strain was found inferior to the local varieties both in yield and ginning percentage. Further varietal trials in these tracts were in consequence stopped. Even in Malwa itself it was found that in the lower and more representative part of Malwa this Indore Malvi 9 strain did better than the locally grown cotton in yield and ginning percentage but in the northern part it did not do better than the local cotton in yield though it was superior in ginning percentage and spinning quality. Distribution of Malvi 9 has been continued in Malwa and the sub-strains obtained were further being tried. These strains were not being tried in Rajputana as they were found unsuitable. Other varietal trials were being carried out in respect of Malvi 9, 20 and 13 in demonstration plots in Northern Malwa and of Malvi 9, 20 and 17 in Southern Malwa. The reason why the last strain of each set selected was different was because the conditions of growing in North and South Malwa were slightly different; M. 13 was an early maturing strain and M. 17 a later maturing one.

In any scheme involving a large number of varietal trials over an area, the co-operation of the cultivators was necessary because Government farms could never adequately cope with the number of trials required. The paper referred to certain precautions which were very necessary to be taken both for securing the co-operation of cultivators and for retaining it. From a paper presented by 'Student' before the Agricultural and Industrial Section of the Royal Statistical Society on Co-operative Experiments and from the discussion thereon the consensus of opinion seemed to be that the range of adaptation of a new variety was wide and that if varietal trials were conducted in one or two localities it was sufficient and there was no need to attempt them on a wider scale. Experience at Indore was, however, different. It was found that the range of a type was very much limited and this factor emphasised all the more the necessity for conducting as many varietal trials as possible in the area for which strains were to be recommended.

Mr. Koshal said that in the year 1930 Dr. E. J. Maskell read a paper entitled "Field Experiment and the Analysis of yield variation in Cotton" at the Empire Cotton Growing Corporation Conference in which he had outlined the necessary conditions for carrying out a set of variety trials repeated over a range of seasons. In the same paper he had dealt with briefly the various statistical processes applicable to such trials. He (the writer) had discussed the same question in a note submitted to the Crop and Soil Wing of the Board of Agriculture in India in 1935 (and later printed in their first Proceedings, pp. 176-189) in which it was shown that if different sowing dates were combined to form a 'complex experiment', the inter-action between

the sowing dates and the varieties would give some indication of variety and season. If such variety trials be carried out at a number of stations in India, we would be able to get in a few years very useful information about the effect of different kinds of climate and soil on the different varieties of cotton.

Mr. Mohammad Afzal said that he had one Central Breeding Station in the Punjab and he was expected to supply varieties to different ecological regions of the province. As an example he cited a type of sanguineum cotton which was now classified as arboreum which he had in his own pure line plot at Lyallpur. That pure line was very early maturing and apparently possessed very desirable characters. He multiplied it and put it in variety test. In the very first year it behaved so very badly that it was discarded but fortunately the pure line was retained. The pure line was sent to Multan and it did so very well there that he was tempted to multiply it and in the year just closed he put it under varietal trial. This kind of behaviour may occur in other parts of India. A variety which might not do well in one place might be quite good in another. He therefore wanted to know the best way of starting this work. As selection had to be made from several varieties, one would like to know which of those varieties were likely to be most suitable to the different tracts. He wanted information as to what was the minimum number of trials that should be put down in the different ecological regions and the minimum number of years for which the experiment should be carried out so that one could be reasonably certain that a variety was really good and that this was not due to environment only.

Mr. Hutchinson said that as some important fundamental points had been raised he would like to give his own views on the subject. It was Dr. Maskell's paper referred to by Mr. Koshal that led to the trials in Central India and Rajputana being systematized and some data on this point had been collected. Dr. Maskell possibly also suggested the adjustment of sowing dates, and during earlier discussions on another paper it was stated that by sowing date adjustments the effect of slightly different environment on the strain could be determined. There was one very important agricultural consideration involved which affected all the raingrown cotton areas of India and that was that if the sowing date was missed by even a few days the crop was lost. The effect of sowing date was very violent under monsoon conditions and in their experiments at Indore they had tried to bring this factor into consideration. In Central India the rainfall and climatic conditions varied more from place to place than in the Punjab and the strains were more closely adapted to local conditions. Malwa was always regarded as fairly uniform but actually it was divided into two sub-tracts as far as crop varieties were concerned. The main object of the paper was to bring out the necessity for systematising variety trials in such a way as to delimit the number of areas. He thought that part of the solution of Mr. Mohammad Afzal's problem lay in delimiting the number of his areas with a sub-station in each. It was a case of a central station versus a number of sub-stations and the specifications of conditions. It was not known previously that North Malwa was different from South Malwa any more than Mr. Mohammad Afzal realised that there was a difference between Multan

and Lyallpur. He thought that the solution of the problem lay in the delimitation of areas and then only could it be said whether or not cottons for particular areas could be bred. It was only in sub-stations that a very large range of suitable material could be bred which otherwise would be discarded in a central station.

Mr. Koshal observed that it was only in rain fed tracts that any serious difficulty might arise by including sowing dates along with the varietal trials. Irrigated areas would be free from that difficulty.

Mr. Hutchinson said that his remarks applied only to dry areas.

Rao Bahadur Vaidyanathan said that the question was whether it was practicable to conduct experiments in various tracts and at the same time combine the dates. He thought this might be possible with regard to selected tracts though it might not be possible to conduct a series of experiments in the farm itself. The Imperial Council of Agricultural Research recommended the conduct of experiments in the same experimental farms for three or four years and only after this had been done did they try to reach the cultivator. The practical advantage in the latter arrangement was that the results could be judged on the farm itself.

Mr. Wad said that the sowing dates could be changed but the delimitation of tracts was a much shorter way of arriving at one's objective.

Mr. Mohammad Afzal said that he himself was doubtful regarding the inclusion of sowing dates in his experiments and he thought it would be better to leave sowing dates alone and try to delimit areas by straight trials. He wanted, however, to know what number of experiments should be tried in each area and the number of places in which they should be carried out. Fortunately in the Punjab there were certain big grantee estates which were willing to co-operate with him in his trials. He had started replicated trials of the most important varieties in about 15 places and from these he made an analysis of variation taking varieties on the one side and places on the other.

Mr. Panse, in summing up, said that the question of sowing dates had been answered by Mr. Hutchinson. When carrying out varietal trials the only consideration to be borne in mind was that of giving the cultivator a better money return simply by change of seed and nothing else. This was the policy followed at the Indore Institute in carrying out varietal trials, agricultural conditions being strictly the same. Improved implements also were not advocated. Normal operations were carried out in the several tracts under experimentation and only the seed was different for the different tracts. As regards Mr. Mohammad Afzal's difficulties he could not say whether he was in a position to tell him in which localities he should try his experiments in the Punjab. Experience at Indore had shown that experiments should be conducted in as many localities as possible without limitation. At Indore all variety trials were conducted for three seasons before any recommendations were made. He could not say whether there were any statistical reasons for this except the fact that there was generally a great hurry to push a new variety into cultivation as early as possible. He thought that this period was the necessary minimum. As regards Rao Bahadur

Vaidyanathan's point about the practicability of conducting experiments on cultivators' fields he could not quite follow what the difficulty was. The Indore scheme was based on experiments conducted in cultivators' fields and in a large number of localities. Regarding seasonal variation he took it that Rao Bahadur Vaidyanathan meant that if experiments were conducted at the same farm for two or three seasons, the seasonal variation could be studied. He thought that what was really wanted was a study of the seasonal variation and the locality complex together. By seasonal variation he meant the season pertaining to the particular locality as the two together would probably vary from tract to tract. It was therefore better to carry out varietal trials in different localities. About the statistical analysis of trials he thought that such points as variances were likely to differ from trial to trial and it was not possible to pool together the data of several trials into one combined analysis. Some alternative method of combining these data together in order to obtain the best information possible had to be worked out.

Mr. Mohammad Afzal requested that he might be supplied with this information without waiting for it to be published.

COTTON STATISTICS

Paper No. 2.

DISCUSSION OF SAMPLING METHODS IN DEVELOPMENTAL STUDIES ON COTTON AND THE STATISTICAL TREATMENT OF RESULTS

BY

RAO BAHADUR M. VAIDYANATHAN,

STATISTICIAN,

IMPERIAL COUNCIL OF AGRICULTURAL RESEARCH.

INTRODUCTION.

The principles of 'sampling technique' applied to developmental studies on experimental crops have been discussed in a general way by Wishart in his 'Principles and Practice of Field Experimentation, pages 85-95 (Empire Cotton Growing Corporation-1935). He has shown that to make an efficient sampling, a sufficient number of sampling units should be located independently and at random representing the plot fairly accurately, and that the *size of the unit* taken is an important consideration for reducing the sampling error. An optimum size for the sampling unit, combined with a sufficient number of such sampling units well distributed over the plot, should be the main consideration for reducing the 'sampling error'. Further, it is needless to point out the need for a correct sampling technique to be applied to experimental crops, as periodical studies of developmental phases of a crop which can be done only by proper *sampling*, can alone elucidate the effects of *weather*, and those of insect-pests spoiling the crop at certain stages of the crop growth, and besides offer a partial explanation to the physiological processes operating upon different varieties or treatments under trial. It may further be emphasised that any particular sampling technique to be adopted depends upon the particular crop and the phase of the developmental study under consideration; thus the method of sampling for a study of tillering of *wheat* cannot be applied to *boll-count* in cotton. In fact, the sampling methods to be employed for *cotton* and for different types of

developmental study on *cotton* are entirely different from those ordinarily adopted in the case of *cereals*. But in common with other crops, a broad differentiation should be made between the technique to be adopted between experiments where plants have to be removed *periodically* as for example to ascertain *weights of plants*, and those experiments where characters like height, number of nodes, etc. (which do not necessitate the removal of the plant) have to be judged. In the former case the plot may be sub-divided so that one sub-division is allotted to the cutting of plants and others for ascertaining final yields alone; sufficient borders are however necessary in such cases between the several sub-divisions to minimise the effects due to the cutting of plants. In the latter case where height, number of nodes, etc., have to be ascertained, the whole plot can be set apart for sampling, but to minimise the damage that will be caused by a frequent handling of plants a fresh set of plants can be taken at each count. But if successive stages of the plant-growth should be correlated it seems necessary to observe the same set of plants at all the stages, and we may then use 'the method of covariance' for studying the effects of weather, insect attack, etc., from stage to stage, so far as they are correlated to final yields.

PRINCIPLES OF SAMPLING TECHNIQUE.

The terms commonly occurring in a sampling study are *sampling unit*, *sample*, and *sampling error*.

'Sampling units' are those parts of a sample which are located independently and at random within the area to be 'sampled'; and the 'sample' refers to the 'aggregate of sampling units' taken from the area. A valid estimate of error is possible only if each sample consists of at least two sampling units. Assuming that there are p plots and q sampling units in each plot, the plot error is based on $(p-1)$ degrees of freedom and sampling error on $p(q-1)$ degrees of freedom. The calculation of sampling error per sampling unit is then worked out by the usual analysis of variance, and the sampling error per plot (and hence sampling error as percentage of the mean) is then easily evaluated. To make the sample of the plot adequately dispersed over the plot, a further sub-division of each plot into sections may be carried out and from each section a definite number of sampling units* is taken at random. The chief consideration should be that a sufficient number of units is taken over the whole plot. The points to be settled in a sampling study are therefore the *magnitude of a sampling unit*, the *number of sampling units* in a plot or a section of a plot, and the *location of the sampling unit*. The number of sampling units to be taken will depend on the number of plots, as the sampling error is to be calculated from 'within plots' with a sufficient number of degrees of freedom.

*It has been suggested that a 5% Sampling is considered efficient in the case of wheat from experience at Rothamsted.

The loss of accuracy in sampling and efficiency of sampling shall be estimated in each case before a satisfactory method is evolved. The following statistical constants will be of help :—

- (1) The size of the sample as a percentage of the plot.
- (2) Degrees of freedom in the calculation of sampling error.
- (3) Sampling error per sampling unit as percentage of plot mean and sampling error per plot deduced therefrom.
- (4) Ratio of sampling error per plot to observed plot error per cent.
- (5) Estimated true plot error per cent.

The loss of accuracy in sampling may be judged from (3) and (4), and also from a comparison of the observed and true plot error per cent after allowing for sampling. *The efficiency of a particular sampling method* is the ratio of the error-variance when *sampled*, to that when the whole plot is *harvested* by taking all possible sampling units. Thus different methods could be compared on the basis of their error variances for judging their relative efficiencies. In Appendix A is given an example for the calculation of *sampling error*.

* METHODS OF ASCERTAINING THE DEGREE OF EFFICIENCY OF A SAMPLING METHOD.

The main test for judging the efficiency of any sampling method is to know whether the *sampling error* is low as compared to other errors (primarily experimental errors) obtained from the experiment. The degree of efficiency will thus chiefly depend upon the variance between the sampling units in a plot. The *efficiency of sampling* will however be the ratio of the *experimental error*, when the *whole plot is harvested*, to the *experimental error* when only a *portion of a plot* is cut as the result of sampling. But the difficulty in ascertaining the *efficiency of sampling* is to estimate what would be the error when the entire plot is harvested (on the basis of the sampling fraction), which any sampling procedure wishes to avoid; but where the entire plot can be harvested—which seems necessary before a proper sampling technique can be deduced—it is easy to strike the ratio of the error variances in both the cases (*i.e.*, full harvesting, and sample harvesting) to obtain the degree of efficiency.

The actual fraction of the plot harvested will be another important consideration in deciding upon the degree of efficiency. A simple formula for *efficiency of sampling* may, however, be deduced as follows :—

* Ideas in this para are developed from 'estimation of the efficiency of sampling' by Yates and Zaccopany (Jour. Agr. Sci. XXV. p. 547).

Let A and B be the variances due respectively to (1) between plots and (2) within plots, obtained by analysis of variance from the particular sampling method adopted; and let x be the fraction of the plot sampled. Then the amount of information that is lost by sampling may be estimated from the expression $(1-x) B/A$, and hence a formula for the *efficiency of sampling* E, will be:—

$$E=1-(1-x) B/A=1-(1-x) y \text{ (say)}$$

$$E=1-y+xy.$$

which is of the second degree in x and y . A graph is given in Appendix B showing the relation between x and y , for different efficiency percentages. The following table gives the *efficiency* for 5% and 10% sampling:—

VALUES OF E.		
B/A	5% sampling.	10% sampling.
1/2	21/40	11/20
1/3	41/60	21/30
1/4	61/80	31/40
1/5	81/100	41/50
1/6	101/120	51/60
1/8	141/160	71/80
1/10	181/200	91/100

The table shows that as the ratio of B/A decreases from $\frac{1}{2}$ to $\frac{1}{10}$ with a 5% sampling, nearly 90% efficiency is obtained, and the same even with a 10% sampling, the ratio of B/A is a more important consideration for the value of E. It is thus clear that the smaller the sampling error obtained, the greater is the efficiency.

Where the experimental error, when the whole plot is harvested, can be estimated, the following method may be adopted for calculating efficiency:—

• **EXAMPLE.**

In an experiment with a 1/40 acre plot, the experimental error per foot-length when the whole plot is harvested is observed to be 8%, and the sampling error for

the plot per foot-length (from a sampling area of 1/200 acre per plot) is 1.2%. Calculate the *percentage efficiency*.

In this case $x = 1/5$, and the % variation between sampling

$$\begin{aligned} \text{units} &= 100 \frac{(1.2)^2}{8^2} \\ &= 2.25 \end{aligned}$$

Efficiency in this case is only the reciprocal of

$$1 + (2.25) \times \frac{(1 - 1/5)}{1/5}$$

i.e., the reciprocal of

$$1 + (.0225) \times (4) \text{ or } 1.09$$

This gives efficiency = $1/1.09 = 91.8\%$

Thus it will be possible to examine with regard to a particular type of sampling experiment which of the combination of *the size of sampling unit* and *number of sampling units* per plot, could secure the maximum efficiency under the given conditions.

SIZE OF SAMPLE CONSISTENT WITH AN ASSUMED STANDARD ERROR AND NUMBER OF REPLICATIONS.

Having secured a sampling variance by a particular sampling method, it seems necessary to deduce therefrom the number of sampling units (or ultimate units) per plot which will give a required level of standard error for a given number of replications. The following formula is deduced from Immer ('Sampling technique with sugar beets'—Journal of Agricultural Research, April 1932):—

Let K be the variance of the mean aimed at, N the number of replications, n the required number of sampling units (or ultimate units per plot), and A and B the variance respectively, obtained from the experiment, of 'between plots' and 'within plots' based upon, say, 1 sampling units per plot.

$$\begin{aligned} \text{Then } K &= 1/N \left(\frac{A - B}{1} + \frac{B}{n} \right) \\ &= 1/N \left(1 + \frac{B}{n} \right) \text{ say.} \end{aligned}$$

Here the unknowns are K , N , and n . Given K and N , n the size of the sampling unit is known. The relation between the number of replications and the sample-size is expressed by the equation :—

$$n (KN - 1) = B.$$

Assume $K = .01$ (the standard of variance to be attained),

$A = .02$, and $B = 2$,

then the equation becomes

$$n (.01N - .02) = 2.$$

A graph of this equation and that of the equation when $K = .05$ are given in Appendix C. The following table gives the values of n for $N = 4, 5, \dots, 10$, to attain a standard of a variance of 0.01 (on the basis of experimental data).

TABLE OF N AND n .

N	3	4	5	6	7	8	9	10
n	200	100	67	50	40	34	29	25

This shows that as the number of replications increases, the size of the sample goes down, but as the number of replications cannot be increased beyond a certain limit, the standard of the size of sampling unit is also automatically fixed.

REFERENCES TO PREVIOUS WORK ON SAMPLING.

As examples of methods of sampling adopted in other countries on other crops, the following may be mentioned :—

Clapham (1) has shown the disadvantages of *systematic* sampling (with cereals) as compared to random location of sampling units. He tried three methods of sampling, of which the following method was found to be the best :—

Each plot rectangular in shape was divided transversely into three equal parts and ten metre-lengths were taken from each part. He concluded that with 1/16 acre plots the random sampling method would provide an estimate of yield with a standard error of less than 6%.

Wishart and Clapham (2) in sampling potatoes have used a complex sampling unit with the plant as the ultimate unit. Their technique of sampling is as follows :—

From a note-book containing a list of pairs of numbers chosen at random was taken a pair of numbers which had been assigned to the sub-plot about to be sampled and a white wooden peg was stuck in the ground beside the plant corresponding to the smaller of the two numbers. Similar white pegs marked every twentieth plant from this starting point. The same procedure is followed starting with a black peg stuck besides the plant corresponding to the larger of the two numbers. Thus two complex sampling units are built up.

An analysis is made of the yields of 54 sub-plots each of 1/90 acre (of the Rothamsted Potato Experiment of 1928) both as estimated by the sampling method and as determined by large scale lifting. It is concluded that at Rothamsted 102 and at Woburn 56 plants would have to be lifted to give a sampling error as small as 4% making it profitable to sample experimental plots of 1/20 acre.

Immer (3) working on sugar beet with 4 row plots of different lengths has constructed tables to show the number of beets per plot needed to reduce the standard error of the mean to 0.3, 0.2 and 0.1 per cent sugar, for different replications. His method of sampling is to pick 10 beets, from a row taken at random out of 4 rows. The beets were picked in such a way that the entire length of the row was uniformly sampled.

Kalamkar (4) working with five different types of sampling units on wheat concluded that sampling of four parallel half-metre lengths on adjacent rows appeared to be the most precise. The half-metres within such sampling units appeared to be negatively rather than positively correlated and a significantly lower sampling error is obtained in consequence. Eighteen such complex units amounting to 36 metres of drill from one-fortieth acre would give about 5% sampling error.

Yates and Zecopanay (5) have recently published a comprehensive paper on the 'estimation of efficiency of sampling for yield in cereal experiments'. They have discussed how 'bias' could be avoided by proper randomisation and how the structure and size of sampling units are important in influencing the sampling error. The methods of calculating 'efficiency' and loss of information and also of determining optimal amount of sampling are fully described. It has been shown that it is advantageous to sub-divide the plots for sampling and the method of determining the optimal amount of sampling has been discussed.

COTTON STUDIES.

Suggestions regarding sampling studies with reference to cotton were made by Maskell at the first conference of the Empire Cotton Growing Corporation, and a detailed contribution on the same subject was made by Heath at the second

conference. The Technological Laboratory at Matunga have evolved different methods of sampling for technological work and a paper on 'sampling for staple length' by Hutchinson and Panse (6) has recently been published. There is unfortunately no published record of systematic work in India on other aspects of cotton sampling. The general method that is followed in experimental farms in India is that a few random plants are being taken from each plot for some particular observation, and the data available so far are such that it is not possible in all cases to deduce the sampling error, and the efficiency of the method adopted. But sampling methods adopted for cereals (such, as random metre lengths in sub-dividing plots) cannot be used in the case of cotton as the stand of the crop is not so thick and regular. A certain number of plants chosen at random from each plot seems to be the only feasible method, requiring however a critical examination. In the study of the development of the cotton plant, a number of factors should be considered as the height, number of nodes, number of branches, bolls, leaves, and flowers (besides sampling for chemical analysis). There are also the different characters of the final product, as ginning percentage and lint length. In all methods of sampling, the main idea is that the sample should represent the whole population to a reasonable degree of accuracy. A proper sampling technique should therefore be built up for each type of observation.

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- (3) Immer F. R., J. Agric. Res. XI, p. 633.
- (4) Kalamkar R. J. J. Agric. Sci. XXV, p. 547.
- (5) Yates F. & Zaocopanay L., J. Agric. Sci. XXV, p. 547.
- (6) Hutchinson J. B. & Panse V. G., Ind. J. Agric. Sci. V, p. 545.

APPENDIX A.

(Data from 'sampling for staple length determination in cotton trials' by J. B. Hutchinson and V. G. Panse (6).

Lay-out—6 randomised blocks with 6 varieties; method of sampling—10 seeds per plot at random.

ANALYSIS OF VARIANCE OF HALO-LENGTH MEASUREMENTS.

	D. F.	S. S.	Variance.	Remarks.
Blocks	5	20	4.00	
Varieties	5	486	97.20	
Between plots	25	334	13.36	(Variance for judging varietal differences).

Within plots and between

seeds	324	407	1.26	(Sampling variance).
	<hr/>	<hr/>	<hr/>	

Total 'between seeds'	359	1,249	
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General mean* = 21.5 mm.

Sampling error per seed $= \sqrt{1.26} = 1.12$

or $\frac{100 \times 1.12}{21.5} = 5.2\%$ of the mean.

Sampling error per plot $= \sqrt{1.26/10} = 0.355$

or $\frac{100 \times 0.355}{21.5} = 1.65\%$ of the mean.

Observed plot error $= \sqrt{13.36/10} = 1.156$.

or $\frac{100 \times 1.156}{21.5} = 5.4\%$ of the mean.

Estimated plot error $= \sqrt{(13.36 - 1.26)/10} = 1.10$

or $\frac{100 \times 1.10}{21.5} = 5.1\%$ of the mean.

Estimated per cent of the

observed plot variance

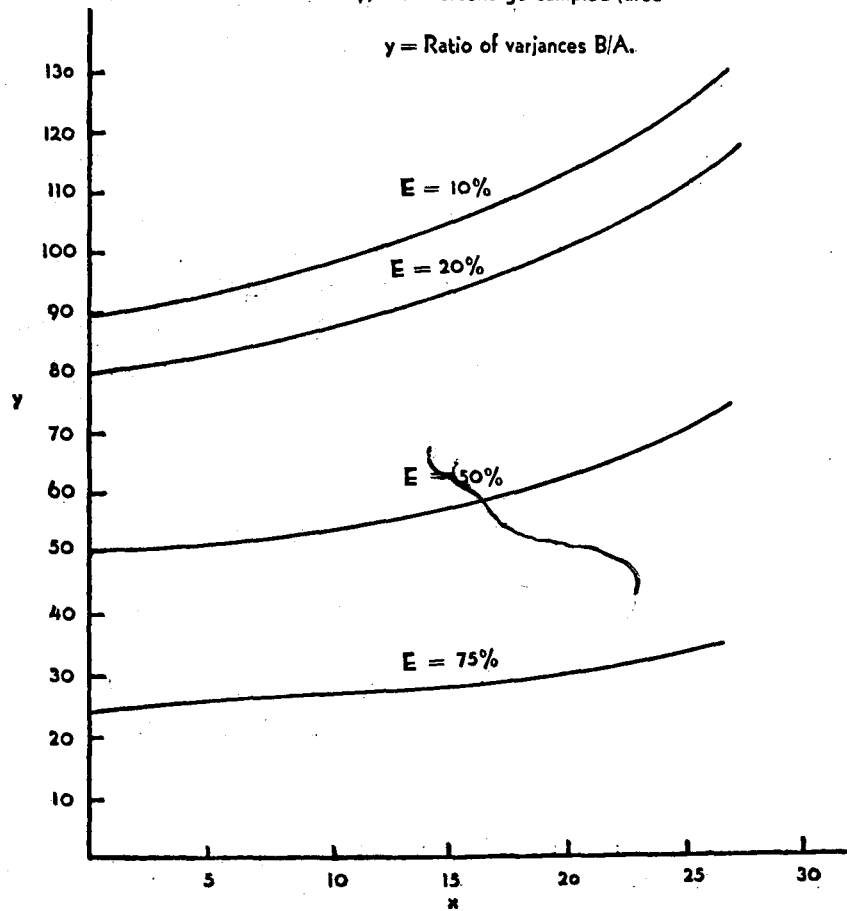
due to sampling $\frac{1.26 \times 100}{13.36} = 9.4$

* Not given in the paper, but kindly communicated to me by Mr. V. G. Panse.

APPENDIX B.

Graph of $E = 1 - y + xy$ for different percentages of E.

E = Efficiency, x = Percentage sampled (area)
y = Ratio of variances B/A.



APPENDIX C.

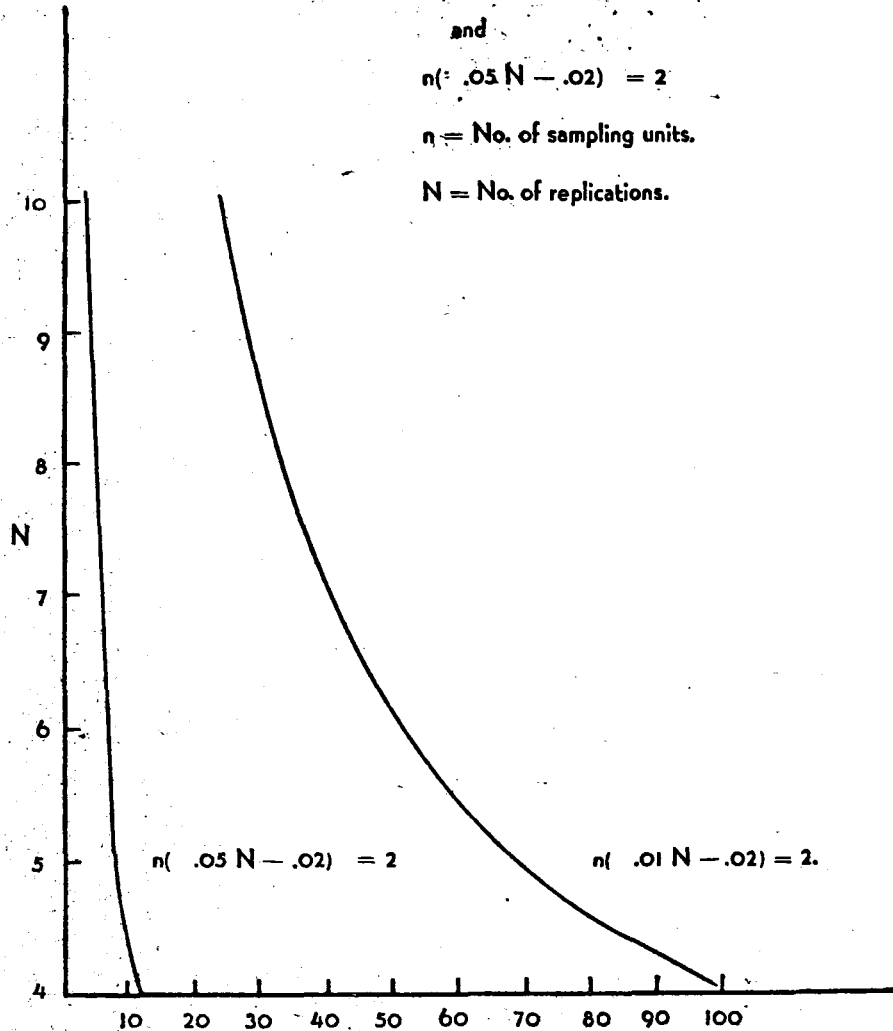
Graph of $n(.01 N - .02) = 2$

and

$n(.05 N - .02) = 2$

$n =$ No. of sampling units.

$N =$ No. of replications.



DISCUSSION.

Rao Bahadur Vaidyanathan said that his paper was intended to call attention to what he felt was a gap in the experimental work in some farms in India, and this was the sampling technique to be employed for studying many important observations on cotton and other crops. The Imperial Council of Agricultural Research had been following certain methods with regard to sampling and had also asked farms to conduct experiments on sampling. So far as cotton was concerned no clear indications of sampling methods adopted in farms were found by him and the object of his paper was primarily to ask the Conference to see whether experiments could not be conducted to evolve a suitable sampling technique for different types of observations on cotton. For this purpose he had indicated some general principles with regard to those methods to be adopted. The various factors that came into play in the main statistical consideration of evolving a satisfactory sampling technique was that the sampling variances should be as low as possible. In replicated experiments the error could easily be found out. If a sufficient number of samples were taken from each plot and the field variance was small as compared with plot variance, then the method adopted might be considered to be satisfactory; the actual mathematical methods to be adopted to find out the efficiency was also indicated in his paper. With regard to the sampling unit itself, the size of the unit, its location and the relation between several units taken from each plot had to be found out. In physiological observations a series of plants at random and another set of 20 plants from the same plot could be taken. These would constitute the different sampling units and the variation between them could be decided by the sampling technique adopted. The ultimate unit was also important. With regard to cotton very few data were available in various farms, and from some of the experiments carried out at Indore it was found that plants taken at random for some observations put up a very low standard error. What he was anxious about was that with regard to particular types of observations conducted, it seemed necessary that particular sampling techniques should be evolved. His paper showed the work done on other crops but with regard to cotton there was no indication of information being available even in other countries. The three mathematical points raised in his paper were intended to judge efficiency; if plot variance and sample variance were known the efficiency formula could easily be found out. Another method which had been used for sampling experiments for other crops was to work out the ratio of the experimental error and to limit it to the sample, leaving out the percentage efficiency. Appendix B and C of his paper explained how to calculate the efficiency. The general indication was that the actual ratio and the sampling ratio varied. A 5% sampling error was satisfactory and could be considered to be a good criterion for judging the efficiency of the sampling method. Another mathematical point was the fixing of the number of samples to be taken from each plot. Once the sampling variance by the usual formula was obtained the standard error could easily be found out. The three methods mentioned by him in his paper were followed with regard to sugar-cane and he wished the Conference to consider whether it would not be possible to conduct experiments even on a small scale regarding particular

methods of observations and the particular methods of sampling which would be best for cotton.

Mr. Koshal said that in one chapter of his paper printed in the Proceedings of the Crop and Soil Wing of the Board of Agriculture and Animal Husbandry in India, 1935, he had outlined a sampling technique for the estimation of yield of cotton. This method is of special importance in physiological experiments where it is not possible to make observations on all the plants in a plot. In the case of cotton individual plants for purposes of estimation of yield might be taken as constituting a sampling unit. According to this technique 5×5 Latin square may be divided into six parts, and from each of these sub-plots the yield of 5 plants taken at random may be determined; 750 yield samples would give 749 degrees of freedom which could be apportioned as follows:—

	D. F.
Treatments	4
Rows	4
Columns	4
Error	12
Difference between sub-plots. }	125
Error due to sampling	600
	<hr/> 749 <hr/>

The other two points raised by Rao Bahadur Vaidyanathan referred to the size of the unit and the location of the unit. For the purpose of estimation of yield if a single plant was taken at random it would be sufficient. As regards location, five plants at random within each sub-plot were sufficient. If there were five rows of cotton, by means of random principles one plant from each row could be selected. With a large number of rows the same method could be employed with suitable modifications.

Mr. Hutchinson remarked that he did not want to raise any statistical point at the moment but that there was one point in sampling which should be remembered carefully and that was that care should be taken not to develop an elaborate method of sampling. Yield was rather a risky thing to sample on because plants were liable to wide variations. In his opinion one of the first things to be done before sampling was to decide as to how much would be gained in comparison with the loss. Sampling estimate of a single character was never as good as an estimate for all characters.

Mr. Dabral concurring in the views expressed by Mr. Hutchinson observed that a single plant might vary in yield from 20 grams to 300 grams. Plants with wider

spacing tended to make up for the loss in the number of plants and when the number of plants were more, the yield was less. Some sampling experiments were tried at Sakrand in respect of soil, space and watering by dividing the plots in the manner suggested by Mr. Koshal and the conclusion arrived at was that the yield per unit area was a better criterion than the others.

Mr. Pansa said that a reconciliation of statistical requirements with ability to manage the experiments was wanted. At Indore data had been accumulating and one method of sampling was found both manageable and fairly accurate. This was the selection of random plants as independent units, without dividing the plot into any sub-section or without having more complex units. In an experiment conducted by him he had 1/100 acre plots and the stand of the plants was about 400 for each plot. In each plot 10 random plants were selected and with these ten random plants standard errors were observed for fruiting nodes, sheds, height, number of monopodia, but nowhere was 10% of error exceeded; if the same method were extended to a larger number of plants say to 15 or 20 the problem of sampling from the agricultural standpoint could be solved.

Mr. Afzal Husain said that this sampling business had come into the entomological work also but unfortunately the problem was very intricate indeed as sometimes a comparison of the population of insects in the crop in one season with another was required. Rao Bahadur Vaidyanathan wished experiments to be conducted on absolutely statistical bases but this was quite impossible. A comparison of the incidence of an insect pest on a whole province would be absolutely impossible particularly when the men who had to collect samples were not highly educated. Rao Bahadur Vaidyanathan had not suggested any workable, or manageable, method of sampling in respect of insect population or insect incidence over an extensive tract.

Mr. Ramantha Ayyar said that he was often faced with the problem of flower counts in cotton plots. He wished to know from Rao Bahadur Vaidyanathan which method would be best to adopt with regard to flower counts in varietal plots. The difficulty in Madras was that in some of the plots irrigation was being done and records were required for these. The officer would have to walk through the furrows every day trampling the plants and this would probably have some effect on the plant yields.

Mr. Koshal in reply to Mr. Hutchinson's remark about elaborate method of sampling observed that for the purpose of the estimation of yield it was not necessary to take 750 plants. The plots could be divided into a smaller number (say 3 or 4) sub-plots and a smaller number of plants may be taken from each sub-plot, thereby reducing the total number of plants for the estimation of yield.

The President enquired why it was necessary to take the sub-plot and not the whole plot.

Mr. Koshal replied that it was necessary to get random as well as representative samples; 50 plants at random might not be representative but 50 plants could be selected from plots in a big area. In order that the sample should be a representative one the field must be split into a number of sub-divisions and out of these sub-divisions the plants should be selected at random if sampling were required. Regarding the question of sampling technique error he said that the usual standard error due to sampling for plots of $1/40$ of an acre is about 5%. The usual standard error per plot is 10% which by using the sampling method becomes 11.2%. Thus the increased inaccuracy introduced by the sampling of technique for any crop is likely to be so small that the method can be used with confidence. Moreover this method is especially useful in physiological experiments where it is not possible to take observations on all the plants. The method could also be employed for the estimation of quality of cottons as judged by the determination of fibre properties with suitable modifications.

Rao Bahadur Vaidyanathan said that the sampling technique adopted should be very simple. For example, even with 700 or 800 plants the variation was very small, viz., 10%. Therefore, the essential point to be noted was the extent of variation in a plot with a particular type of observation and if the variation was very small there was no necessity to take more than 150 measures, the actual number of measures to be taken depending on the variability. The relation between plot variance and the sampling variance was the primary consideration in fixing the sampling technique. In regard to harvesting, if a small plot of $1/50$ of an acre could be managed, there was no need for sampling the border effect of 2 or 3 rows on either side, or the whole plot could be harvested, and the sampling technique adopted would be final. As regards flower counts, the actual number of flowers per plant on 25 plants should be taken at each stage of cultivation.

Subject 3—Supply of samples of Standard Indian Cottons for test at the Technological Laboratory.—Reference from the last meeting of the Agricultural Research Sub-Committee.

Mr. Ramanatha Ayyar stated that samples for spinning tests were usually sent from fields raised under normal conditions and that when he sent the figures for irrigation and other data, the Director, Technological Laboratory, wanted similar information for previous years and he gave him figures from different fields which led to the correspondence on the subject under discussion. It seemed to him that the Director had recommended that the cottons should be grown in the same field year after year and that the field had to be divided into a number of plots some of which were required to be reserved for next year's sowing; the kapas from these reserved plots were to be sent to the Director, Technological Laboratory, every year. This arrangement raised one important point with which he was actually faced. Last year in the Cotton Breeding Station all plots were badly attacked by pink boll-worm with the result that he could not send the Director of the Laboratory kapas grown under normal conditions. He therefore requested the Superintendent of the Central Farm to send the required quantity of 20 lbs. If this action was wrong, he wanted to know how his difficulty could be got over. There was no certainty as to when and where insects would come so that the sending of samples from the same plots could not be ensured. Naturally, if the samples were to be representative it would have to come from cottons raised under normal conditions. The next point raised by him was that if the objects of the spinning tests were to be fulfilled, it was not desirable to send samples from the same strain year after year for a number of years because selections were not being made with regard to the various fibre properties. Attention was being paid only to lint length. If samples were to be sent from the same type of cotton for a number of years, the genic constitution of the sample might not be the same as in the first few years. One of the objects of continuing the spinning tests was to find out the spinning performance of cottons but if the genetic composition was going to be different after some years, no importance could be attached to the studies made from samples sent, say, after ten years. Another point was that samples of kapas produced from the entire pickings were being sent and it was often found that the samples got during the first period of the picking were entirely different from the samples got during the close of the picking; if therefore the fibre properties were to be correlated with the spinning performance it would be desirable that the samples sent should be from the produce obtained from a definite picking period.

The President observed that certain conditions had been requested by the Director, Technological Laboratory, in his letter to the Cotton Specialist at Coimbatore and he wished to know if similar requests had been sent to other cotton botanists.

Dr. Nazir Ahmad said that the Madras case was a special case and it arose out of an unforeseen and unusually strong insect attack. As a result of it Mr. Ramanatha Ayyar could not send sample of the standard cotton from the same field and had to obtain a sample from a neighbouring field for which relative data was not

available. Since the question was important and affected other cotton breeders also, he suggested that it might be considered at the Conference. Regarding the various points raised by Mr. Ramanatha Ayyar, he said that if any valuable conclusions were to be obtained from a statistical analysis of the results, it was necessary to make sure of the purity of the seed and also of the conditions under which the samples were grown in the successive seasons. As regards the seasonal variation referred to by Mr. Ramanatha Ayyar, he did not think the difficulty was serious. In the paper by Mr. Koshal and himself, it had been shown that the effect of a secular change in the season could be eliminated if sufficient data was available. As regards different pickings it would be enough if the sample was taken from the combined produce of all the pickings. He was aware of the fact that the last picking did not come up to the level of the first or second picking in quality, but if he restricted the sample only to second pickings, he would get even better results than at present and would be blamed for getting a wide disparity between the mill and the Laboratory test results. Therefore he thought the best way of dealing with this question was to take a sample from the produce of all the pickings rather than from the cream of the crop.

In this connection he wished to make one request to the cotton breeders. Frequently the cotton breeders evolved strains which were of great interest to themselves, but by the time the fibre characters and the spinning performance of these samples had been found they were no longer available for further work. He, therefore, requested that when cotton breeders came across such samples they should especially draw his attention to them. Since the Laboratory was fully occupied with testing nearly 600 samples per year, it was possible that interesting samples might be overlooked unless attention was specially focussed on them. Furthermore, if 25 or 30 lbs. of lint of such samples could be supplied instead of 12 lbs, there would be some lint left for further work. That morning he had been pressing for uniformity of type as it was very important in the eyes of the trade. But for technological study abnormal samples were equally important, as it was from a study of such samples that valuable information might be gleaned.

As regards the standard cottons, his request was that unless the conditions prevailing in their own fields were abnormal, the samples should be grown on the same field and on the same plot, the plot being divided into four sub-plots one of which should be left fallow, as there would naturally be gradual depletion of the nutrition in a plot under perennial cultivation. He would also like cotton breeders to keep records of rainfall, maximum and minimum daily temperature and soil temperature and, if possible, the hours of sunshine and the atmospheric humidity. If it was not possible to take all these readings, they might take and record as many as possible. He was sometimes unable to find out from the information supplied to him whether any manurial treatment had been adopted; if so, it should be continued in the successive season. In this connection, however, it should be noted that if any manure, either inorganic or organic, was applied year after year, the results for a particular year might be affected not only by the manure applied in that year, but also by the residual effect of

the previous year. In these circumstances he suggested that after every few years a somewhat smaller dose of the manure might be applied to counteract the cumulative effect.

Mr. Mohammad Afzal said that with regard to standard Indian cottons there was some confusion in the Punjab as, probably, the conditions of growing and sending them were not previously definitely specified. There were three standard cottons in the Punjab, viz., Punjab-American 4-F, 289-F and Mollisoni. Punjab-American 4-F was supplied by the British Cotton Growing Association up to 1930-31 and by the Cotton Research Botanist thereafter. Punjab-American 289-F and Mollisoni had been supplied by the British Cotton Growing Association ever since the tests were started. Regarding the 4-F samples supplied by him these were from the middle picking. The British Cotton Growing Association at Kharnawal had no definite routine of rotations as they grew their cotton wherever they found it would be suitable. He was also not sure from what pickings samples were sent though he believed that these were from the mixed lots, but not necessarily of all the pickings. The seriousness of the position lay in the fact that he was not able to say from which pickings samples were being sent. The same was the case with Mollisoni. As regards manure, this was applied in rotation and very rarely to the cotton crop itself. Manure was usually applied to other crops in the rotation and cotton benefited from the residual effect. He, therefore, suggested that the Director, Technological Laboratory, should specify definite conditions for the supply of samples and circulate these to all concerned. This would ensure that the samples sent were according to his requirements. He also suggested that in future samples might be obtained through him instead of through the British Cotton Growing Association.

Mr. Hutchinson observed that it was obvious that there was a fair deviation in the conditions of supplying samples from different places and he suggested that the onus of supplying samples should definitely fall upon the plant breeders after Dr. Ahmad had specified the conditions he would like to be observed. He was of opinion that samples should be taken from the best seed though he did not think it desirable to keep the same seed. It was better to risk a little as a result of improvement than to allow deterioration by mixture. As regards the picking period he suggested that samples should comprise mixed lots from all pickings but separate samples from each picking might be supplied for comparative tests; this would enable Dr. Ahmad to judge if there was any wide difference between the samples. Regarding Mr. Ramanatha Ayyar's point that occasionally the field on which the cotton intended for sample tests was grown may be badly affected by some disease or insect pest he suggested that such material as was available should be sent as also the affected sample from the regular field. Thus Dr. Ahmad would be able to carry out all the fibre tests on the samples of the same fields and he would at the same time be able to compare them.

The President observed that the suggestions made were more or less a definition of certain minimum conditions to be observed by plant breeders and the Conference

had to decide if it agreed to them. As regards seed, the best seed should be used; with regards to packing, samples must be taken from all the pickings and at the same time from samples of the various pickings and, if possible with specification of the percentage in the main sample; and finally with regard to the field, there should not be any violent change of soil conditions. Plant breeders should be responsible for observing the conditions specified by the Director, Technological Laboratory, and supply samples accordingly.

This was agreed to

The President observed that before the Conference dispersed, he would like to thank Dr. Ahmad for his arrangements to show members round the Laboratory on the previous day. From what was seen after a lapse of years it was clear how greatly the Laboratory had developed and the papers before them which were discussed had shown how great a part the technologist played in the development of cotton growing. He also wished to express the thanks of the Conference to the Secretary, Indian Central Cotton Committee, for the good arrangements he had made and to Mr. Parekh, Secretary of the East India Cotton Association, for his courtesy in showing the standards of the Association. Thanks were also due to the Indian Central Cotton Committee for having organised the Conference and for placing its Committee room and other facilities at their disposal and he proposed that the Secretary, Indian Central Cotton Committee, should put this record of thanks on the agenda of the next meeting of the Indian Central Cotton Committee. He also thanked all members for helping him in getting through the business of the Conference quickly. He further added that the Conference could not conclude without recording its thanks to its chief member who was responsible for getting the Conference together, viz., Mr. J. B. Hutchinson, who had been very helpful in organising it. It was unfortunate that Mr. Hutchinson was leaving India. They had had the advantage of his presence for so long and he thought that all had greatly benefited as a result of the help he had given them in their work. He had been on a number of Committees with Mr. Hutchinson and felt inclined to make the remark that on all these he had played the part of Portia. He thought they would all agree in giving Mr. Hutchinson a hearty send off and in wishing him the best of luck in his new work at Trinidad.

Mr. Hutchinson warmly thanked the President and the members of the Conference for the hearty send off given to him. Whilst regretting that he would not see their faces again, he expressed the wish that he would see their signatures. He did not want to feel that he was in any way being cut off from one of the most interesting cotton countries of the world and one of the most interesting crops which had educated him. To be in India for nearly four years and to study India's cotton and other crops had been a tremendous education to him as a botanist, agriculturist and geneticist; and he was very glad to have that opportunity of thanking all for the information, help and collaboration they had given him and the enthusiasm with which they had co-operated with him. He very definitely considered that such success as he had achieved in

India was due rather to the co-operation between cotton workers than to any ability or anything else on his own part, and it was by this co-operation that such things as the distribution and the history of the cottons, breeding methods and a large part of the programme designed at Indore had been worked out in response to the needs expressed by workers in correspondence. He felt that all of them knew a great deal more than they had ever put on paper and he hoped that the knowledge which they might accumulate as plant breeders in the course of their work would find its way into scientific publications, and not only into correspondence files as was being done at present. He was convinced that the tremendous amount of progress which would be made in practical genetics in the next few years would come from plant breeding work and he would be glad to give whatever help he could wherever he might be. He relied upon the workers for the bases of his information in theoretical and genetical matters far more than they thought he did.

Dr. Nazir Ahmad said that on him fell the pleasant duty of proposing a very hearty vote of thanks to the Chair with which he associated Sir Bryce Burt who had presided at the Conference on the first day and Dr. W. Burns who had presided on the last two days. They had extremely interesting and instructive discussions for three days and all had spoken frankly of their difficulties and discussed in a sympathetic and helpful manner. He had attended the Second Empire Cotton Growing Conference in London and it was on his return to India that he had proposed to the Indian Central Cotton Committee that a similar Conference should be convened in India. From the manner in which this first Conference went on it was abundantly clear that they had made a very big advance in the right direction and he was sure that this Conference would become a permanent feature of the activities of the Indian Central Cotton Committee. The experience gained this year would help them to improve matters in the succeeding Conferences which, in course of time, would become a very powerful instrument for the advancement of research on cotton in India and the discussion of problems connected with it. The names of Sir Bryce Burt and Dr. Burns would always be very prominently linked with it as having presided over the first Conference and having guided its deliberations efficiently to a successful end. He proposed a hearty vote of thanks which was carried with acclamation.

P. H. RAMA REDDI.

APPENDIX.

Note by P. N. Krishna Ayyar on Cotton Entomology Paper No. 4.

The observations recorded in the paper are, as clearly defined in the title of the paper and reiterated in the introductory paragraph, essentially preliminary and tentative in nature and the object of the author in presenting the same is merely to invite suggestions and criticisms so that he may alter or modify the methods of tackling an admittedly difficult problem which is probably the first of its kind in India. The writer, therefore, whole-heartedly welcomes any criticisms offered particularly at the hands of the most experienced of Entomologists in India.

The points raised may be brought under the following heads in the order of their importance.

- I. The validity of the statement that 'Pempheris is indigenous'.
- II. If an indigenous pest the question of its biological control might be dropped.
- III. The question of 'transference' from its primitive habitat.

As regards the first point, i. e., the question of its native home, the evidence in support of this conclusion may be summarised as follows:—

(a) *Pempheris affinis* came into prominence with the introduction of an exotic variety of cotton namely Cambodia from Cochin China. It was, therefore, naturally suspected that the insect pest was also unwittingly imported. Special enquiries made in that quarter definitely elicited the reply that this insect does not occur in Cochin China.

(b) By correspondence with Entomologists all over the World and from information supplied by the British Museum and Bureau of Entomology, Washington, it is definitely known that this insect does not occur in any part of the World other than the Indo-Malayan region.

(c) Three species of *Pempheris*, out of five known, are confined to Indo-Burman zone among which two are found in India.

(d) Investigations made by the writer since the inception of the Scheme in selected and typical parts of upper India and in several districts of South India show that the insect is found in virgin plant-associations and in hilly and forest regions in Dehra Dun forests at foot of the Himalayas, in Mudgole forests in Vizag and hill tracts like Manantoddy in the extreme South of the Peninsula.

(e) The insect has been taken in such situations from indigenous plants like Bhandi, *Sida acuta*, *Sida rhombifolia*, *Urena lobata*, *Triumfetta rhomboidea*

Malvastrum many such localities being far removed from and completely cut off from any cultivated areas or cotton cultivation by natural barriers.

(f) A few parasites (undetermined) have also been found in association with the insect in some of these primitive situations which are apparently absent in cultivated cotton areas.

(g) The writer therefore naturally came to the conclusion that the pest is a native of India and its original host is not cotton but some one or other of the plants mentioned above. Any way the insect appears to have had an older and a more primitive association with some of these plants than cotton. Since it has been recovered from Bhindi from such diversified situations from the foot of Himalayas to places very near Cape Comorin it was tentatively suggested that Bhindi might probably have been its original host. The writer will feel grateful for any suggestions regarding fresh avenues of investigation for further elucidating this aspect of the problem namely its original home and habitat.

II. In regard to the second point whether an indigenous pest can be tackled by biological means, let me quote the latest pronouncements of eminent authorities on the question.

Thompson ("Biology" 1935, London) "An increase in the effect of native beneficial insects could conceivably be brought about by adding to the parasite population, using colonies of individuals brought from elsewhere or reared in the laboratory; or by manipulating the general insect fauna and perhaps also the flora, in such a way as to keep the parasite population at a permanently high level." "It is true that most of the work on biological control has been concerned with pests imported from other countries without their natural enemies" but yet "the utility of the method is not, as has been suggested, restricted to isolated areas, but that under favourable conditions, it is a method of world wide application."

Myers (1931 and 1935) F. M. B. 42.1931. Bull. Ent. Res. Vol. 26, 1935. The recognised principles and technique of biological control embrace not only introduced pests but also indigenous ones although greatest successes have been obtained from the former. In the case of the latter "primitive environment of the pest has been regarded not only as the most promising source of efficient parasites but also as the key to its present status and eventual control." In other words the primitive environment of a native insect is as good a source for parasites as the native home of an introduced pest.

Clausen (1936) states, "Even with native insects the natural expansion of their range over continental areas often permits of the utilisation of biological control methods in the new areas of infestation." (Annals Entomological Soc. America, Vol. XXIX, 1936, p. 201.)

III. Regarding the point of 'transference' the writer is of opinion that if the pest is indigenous its primitive host is probably not cotton. The disturbance by the equilibrium in nature has followed the 'transference' of the insect (as suggested by H. S. Smith in one of his papers, 1935) from its native habitat to its new habitat, in cultivated areas when a more favourable and extensively cultivated food plant is introduced. From available evidence it looks quite reasonable to suppose that cotton is not perhaps its original food plant. This, therefore, seems to be a good instance of a plant brought into a new country having acquired a new enemy which has migrated to it from its original native food-plant.