



PROCEEDINGS OF EXTENSION SCHOOL
IN
SOIL SCIENCE

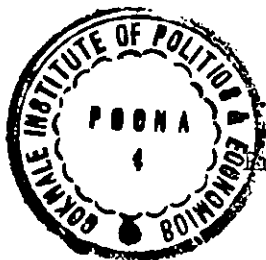
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INTRODUCTION

These proceedings comprise all the papers given at a residential extension school in Soil Science held at the University of New England, February 10-14, 1958. The 90 odd men and women, from areas as far apart as southern Queensland and the Riverina, who attended this school are indicative of the interest being shown in the extension services provided by the University. It has been our policy not only to hold annual residential schools of this kind but to arrange two and three day extension schools in various centres on the Tableland, the Namoi and the North Coast. The excellent support for these activities shows that the man on the land is becoming increasingly aware of the value of the scientific knowledge which is available to him from such institutions as Universities, C.S.I.R.O. and State Departments. It is obvious that these agencies must have the facilities to undertake fundamental research, but it is necessary, too, that the results of this research are put in a form that the man on the land can readily understand. In arranging these schools we are endeavouring to play our part in this regard.

Important as it is to record in a more permanent way the lectures given at our annual residential schools, it would be a mistake to think that they constituted the whole content of each school. Some of the most significant work was done in the question and discussion period which followed each lecture, and in the Open Forum where all lecturers had difficult and searching questions put to them. Then again there were those rewarding informal discussions with lecturers or fellow students which are common to most residential schools.

In its Agricultural extension work the University of New England is fortunate in having the highly trained staff of the Rural Science Faculty to call on. And there is, too, our new faculty of Agricultural Economics which is certain to play an increasingly important role in our extension work. It is of interest to note that when asked what they would like to study in 1959, a large majority of students at the Soil Science School opted for Agricultural Economics and Farm Management. So this will be the subject of our residential school running from February 8-13, 1959.

My special thanks are due to Professor McClymont, Dean of the Faculty of Rural Science, and Professor Lewis, Dean of the Faculty of Agricultural Economics, for the splendid cooperation they have given in planning and carrying through our extension programmes. But these activities would not have been possible without the help of a great many others - staff members of the University of New England; staff members of the Schools of Agriculture in the Universities

of Sydney and Queensland; members of the C.S.I.R.O. and the State Department of Agriculture. To all I give my grateful thanks.

A.J.A. Nelson
Director
Adult Education Department
University of New England

MINERALS AND SOILS

A. H. Voisey, D.Sc. (Syd.),
Professor of Geology,
University of New England.

(1) INTRODUCTION:

In arid and frigid areas, where vegetation is absent or sparse, broken down rock material, of various kinds and sizes, litters the surface. Beneath the waters of lakes and the sea are accumulations of similar particles with the frequent addition of skeletons of fresh water or marine organisms. Fortunately for human beings and other land animals in wetter and warmer regions there are large stretches of the Earth's surface where rocks break down into what we call soil. This consists of varying mixtures of clay, silt, sand, gravel and organic matter.

All these surface deposits overlie more solid aggregations of mineral matter which form the solid rock. Some of the looser accumulations such as sand and gravel are also called "rocks" by most geologists and it is hard to find a basis for separation on the degree of compaction or cementation of these substances.

The subject of geology deals broadly with two sort of things. Firstly, the minerals and rocks of which the earth's crust is composed. Secondly, it tries to interpret the history of the earth and to trace the development of those of its past inhabitants whose remains have become preserved in the rocks. Because of the wide field with which it deals geology as a subject has been subdivided into a number of special branches. For example, Mineralogy deals with minerals; their origin, occurrence, physical properties and chemical constitution; Petrology deals with rocks; Palaeontology with fossils; Stratigraphy with the order in which rock strata were laid down and with the properties of each; and Economic Geology deals with the applications of the subject to industrial and commercial purposes.

Where to begin is a problem with most subjects. In geology it is not unusual to start with the study of minerals. But other aspects could be considered first. For instance, one might consider the processes which led to the formation and distribution of rocks and minerals on the earth's surface and in its crust, or one might commence with a consideration of chemical substances and the constitution of minerals. Because the study of geology is not always preceded by a course in chemistry it is proposed to start here with the examination and description of mineral matter occurring on the earth's surface and then to consider how rocks and soils are formed. With this background it is possible for the student to

proceed, through the study of stratigraphy, to an interpretation of the history of the earth's surface.

(2) EXAMINATION OF THE CRUSTAL MATERIALS

If you take a sample of surface soil and examine it, you may find it possible to separate out the obvious organic matter derived from plants. The mineral particles may then, depending on the kind of soil, be separated into very fine, medium, coarse fractions which we know as clay, silt, sand and gravel respectively. Some soils may consist very largely of the clay fraction, others may be sandy, but all possible mixtures are known.

Weir, W. W. (Soil Science - its Principles and Practices, Lippincott Coy., Chicago, 1936, p. 28) states that the following sizes of particles have been recognised by international agreement.

Above 2 millimetres	diameter	stones.
From 2.0 to 0.2 millimetres	"	coarse sand.
From 0.2 to 0.02 "	"	fine sand.
From 0.02 to 0.002 "	"	silt.
Below 0.002 millimetres	"	clay.

An agreement of this kind has the obvious advantage of giving these words a precision which they do not have in ordinary speech.

As soils are derived largely from rocks it is apparent that these particles have been formed from the parent rock by means of disintegration and decomposition. The larger stones may be recognised as being particular kinds of rock, the coarse sand may be identified as consisting of one or more of the rock-forming minerals such as quartz or felspar, the fine sand can only be identified by examination under the microscope but it is frequently the mineral quartz. The clay particles have originated from the chemical decomposition of rock minerals and are very difficult to study.

It is important that the geology student recognises that the process of rock decomposition produces a comparatively small number of recognisable products. Thus a large number of different rocks yield on decomposition very similar soils. Even in the early stages of formation these are found to differ only in the relative proportions of sand and clay. As they get older these differences become even less pronounced and the effects of climatic zones become more important than the parent rock in determining the character of the soil.

(3) THE ROCK FORMING MINERALS

An examination of rocks reveals the fact that they are

made up of a small number of common rock-forming minerals. Although within the crust over 1500 actual minerals have been identified, the great bulk of the rocks are made up of combinations of only eight of them. They are quartz, orthoclase felspar, plagioclase felspar, biotite mica, hornblende, augite, olivine and calcite.

A typical granite has a composition approximating to:

quartz	20%
orthoclase	50%
plagioclase	20%
biotite	7%
hornblende	3%

A basalt might have a composition approximating to:

plagioclase	50%
augite	37%
olivine	4%
"ores"	9%

Sandstone varies considerably but may consist of as much as 95% quartz grains. Limestone is mainly calcite with varying proportions of other minerals. Shale is very largely composed of the product of decomposed feldspars or clay as it is commonly called.

Before proceeding further it is necessary to recognise the various rock-forming minerals. On the principle that man "observes what he is taught to observe" a number of headings are set out which help us to distinguish between the various minerals.

(4) EXAMINATION OF THE ROCK-FORMING MINERALS

Minerals are usually described with reference to the following headings - words in common use being indicated:-

(I) Form: A crystal - if bounded by plane faces.

A grain - if part of a crystal but not bounded by plane faces.

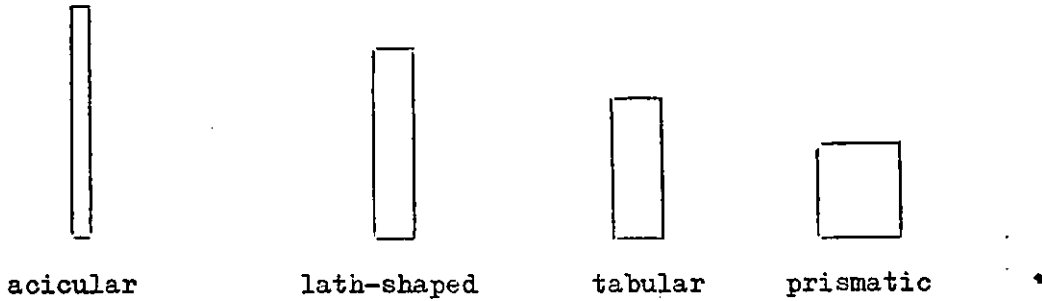
Massive - if made up of a number of small grains similarly oriented in all directions.

(CAUTION: Do not mistake cleavage-planes for crystal-faces, e.g., in calcite.)

Many other terms such as concretionary, fibrous, dendritic, foliated and so on may be used but not when the mineral forms part of a rock.

(II) Habit: This term refers to the way the crystal of a mineral has grown, i.e. it may be long and needle-shaped or acicular; lath shaped (with proportions

like palings); tabular or oblong; prismatic or relatively stumpy.



The same mineral may occur with different habits in different rocks depending on conditions or growth.

Note later that the important attribute of crystals is that the corresponding angles between the faces are constant for each mineral species - the lengths of the sides being variable. Hence, the different habits which any one mineral may assume, do not cause us to place it in a different crystal group in each case.

(III) Colour: This is often the most noticeable feature of minerals but it is not always a true guide as the same mineral may sometimes have different colours, e.g. quartz is commonly colourless or white but it may be pink, green, brown, amethystine or black.

(IV) Lustre: Expresses the quantity and quality of light reflected from a surface, e.g.
Vitreous - like powdered glass
Sub-vitreous - not so glassy
Metallic - ordinary lustre of metals
Resinous - like resin
Pearly - like a pearl
Silky - like silk
Dull - no reflection.

(V) Streak: This is the colour of the powdered mineral and is constant however much the variation in the colour of the hand-specimen.

(VI) Cleavage: This is the tendency to split along one or more directions producing smooth surfaces. For each mineral the number of directions of cleavage should be recorded and also the angle between the planes. The degree of perfection is also noted, e.g. biotite has perfect cleavage in one direction, orthoclase has cleavage in two directions at right angles, one of these being

"perfect" and the other "good".

(VII) Fracture: This is the manner in which a mineral breaks other than along a cleavage plane. Usual types are:- Uneven, even, conchoidal (curved, concave or convex surfaces often showing concentric undulations); hackly - with sharp and jagged elevations as in a broken piece of cast iron.

(VIII) Tenacity: Brittle, sectile (cut by knife); malleable (flattened under a hammer); flexible (will bend); elastic (will bend and then spring back to former position when pressure removed); tough (difficult to crack and break up).

(IX) Hardness: This is a very useful property and Mohs' Scale is usually used. It is based on a standard set of minerals each one of which can be scratched by the mineral below it on the scale. As a set of minerals is not always available comparable hardnesses are indicated with respect to common objects.

MOHS' SCALE

Hardness of Standard Mineral

1. Talc: Easily scratched by fingernail which is usually about 2 to $2\frac{1}{2}$ on the scale.
2. Gypsum: Just scratched by fingernail.
3. Calcite: Just scratched by bronze coin, e.g. - penny hardness just over 3.
4. Fluospar: Scratched by cast iron ($4\frac{1}{2}$).
5. Apatite: Scratched by window glass or ordinary pen-knife ($5\frac{1}{2}$).
6. Orthoclase: Scratched by hardened steel knife.
7. Quartz:)
8. Topaz:) Not scratched by common materials -
9. Sapphire:) hence certain varieties used as gem-
10. Diamond:) stones.

(X) Twinning: An internal structure, developed during the growth of the mineral and displayed by differences in the degree of lustre of alternate strips or lamellae. Orthoclase may show simple twinning and Plagioclase may show multiple twinning.

(XI) Decomposition: May produce opacity, softening, change in colour.

(XII) Other properties to be recorded if necessary are:

Specific gravity: not important with regard to rock-forming minerals which do not vary notably from each other but often diagnostic for the ore minerals, e.g. cassiterite, barite.

Magnetism:

Feel - Smooth; greasy; or harsh.

Odour - Argillaceous (like clay); sulphurous, foetid.

Taste - Only useful in case of soluble minerals, e.g. halite. (N.B. Test with discretion - you may get some arsenic oxides!)

(5) EXAMINATION OF ROCKS IN HAND-SPECIMENS

Quite a considerable amount of information can be gained by the examination of hand-specimens of rocks especially when a pocket lens is used. For more precise naming a thin section of the rock is cut and examined under a microscope. In the field, however, it is necessary to name rocks when only hand specimens, often weathered, are available.

It must be realized that it is often hard to distinguish between orthoclase and plagioclase if no twinning is visible or impossible to differentiate augite and hornblende or again the constituents of the rock may be too small for accurate determination.

(6) CLASSIFICATION OF ROCKS

Rocks may be placed in one of three broad groups:-

I. Igneous rocks which have been crystallised from a molten state.

According to their mode of occurrence they are classified as:-

- (a) Plutonic: when they have been formed well below the surface. They are usually recognised by their coarse crystalline texture which arose as a consequence of slow cooling at depth.
- (b) Hypabyssal: when they have solidified in small intrusions near the surface. They are fine grained but generally are porphyritic because some larger crystals were brought up from the depths with the surrounding molten material.
- (c) Volcanic: when they have been poured out over the surface through volcanic vents and fissures. These rocks are usually fine in grain and may even be glassy if solidification has been rapid. They are frequently pre-

phyritic. Names given to igneous rocks depend partly on mineralogical composition and partly on mode of occurrence as indicated by the following tables.

	Acid	Intermediate	Basic	Ultra-basic
Plutonic	Granite Granodiorite	Syenite Diorite	Gabbro	Picrite Peridotite
Hypabyssal	Granite porphyry Quartz porphyry	Orthoclase porphyry Porphyrite	Dolerite	Limburgite
Volcanic	Rhyolite Obsidian	Trachyte Andesite	Basalt	Limburgite
Minerals in this diagram are the common constituents of the rocks listed in the vertical columns above	Quartz Orthoclase Biotite	Plagioclase Hornblende	Augite	Olivine

The convention of calling rocks "acid" arises from the fact that quartz or silica which is a major constituent is an acidic oxide. Rocks are not acid or basic in the chemical sense.

II. Sedimentary rocks which are made up of fragments of other rocks. They may be recognised by possessing one or more of the following features:-

- (i) Stratification or bedding and the sorting of the grains into layers according to size.
- (ii) Structures such as graded bedding, false-bedding, ripple-marks, mud-cracks and concretions.
- (iii) The presence of fossils.
- (iv) Presence of minerals of chemical or organic origin such as halite, gypsum, glauconite or calcite.
- (v) Absence of easily weathered minerals such as biotite and augite.

They may be divided into a number of groups and sub-groups:-

A. Mechanically-formed.

- (i) Pyroclastic where the material has been derived from volcanic action. e.g. volcanic breccia.
- (ii) Aqueous or sorted by water. e.g. sandstone.
- (iii) Glacial or Fluvio-glacial where transportation has been due to the action of ice. e.g. tillite.
- (iv) Aeolian where wind has been the chief transporting agent. e.g. desert sandstone.

B. Chemically-formed. When chemical processes - usually deposition from solution - give rise to the rock. e.g. laterite, siliceous sinter.

C. Organically-formed. When biological processes are primarily responsible for the formation of the rock. They are usually subdivided on a chemical basis.

- (i) Calcareous e.g. limestone.
- (ii) Siliceous e.g. diatomaceous earth.
- (iii) Ferruginous e.g. some ironstones.
- (iv) Phosphatic e.g. phosphate rock.
- (v) Carbonaceous e.g. coal, torbanite.

III. Metamorphic rocks which have suffered alteration other than that caused by surface or solar forces such as rain-fall and ground-water - these effects being spoken of as "weathering".

When hot igneous rocks accompanied by hot solutions come into contact with other rocks they may "bake" or otherwise alter them. Granites are often surrounded by an aureole of rock so affected. The process is spoken of as Contact-Metamorphism.

Typical contact-metamorphic rocks are those called horn-felses.

Great forces and high temperatures reside in the earth's crust so that rocks deeply buried may be compressed and re-constituted structurally and mineralogically. Such regionally metamorphosed rocks may be banded or foliated. e.g. gneiss and schist. So great may be the changes in the rocks that it becomes a matter of great difficulty to determine what the original material used to be.

(7) WEATHERING OF ROCKS

The petrologist always attempts to collect fresh rock for examination but in many cases this is difficult because rocks are subject to mechanical and chemical processes at or near the earth's

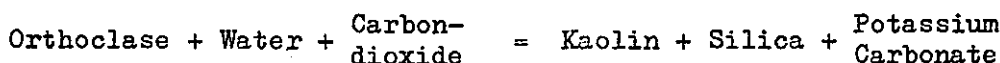
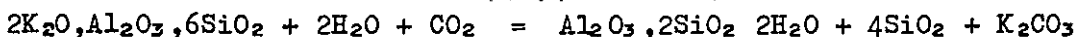
surface. The breakdown of rocks by the action of the weather or by water soaking through the ground is called weathering.

Weather changes involve changes in temperature, rainfall and wind. Exposed rock subjected to changes in temperature tends to be broken up. Firstly, because individual minerals expand different amounts for the same rise in temperature; secondly, because rocks are poor conductors of heat, and while the surfaces expand, the interiors do not. As a result of the first process the surfaces of rocks such as granite tend to crumble and by means of the second homogeneous rocks tend to flake or exfoliate.

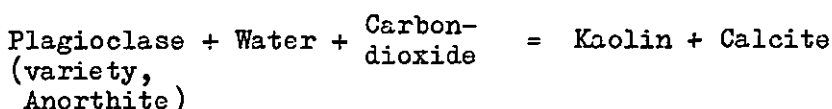
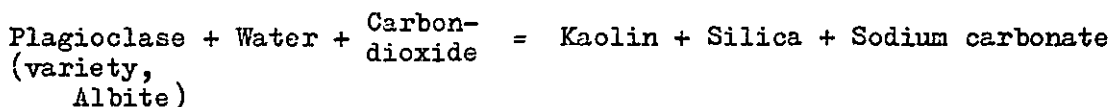
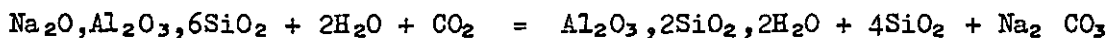
Obviously these processes are more effective in desert areas where large daily variations in temperature take place. In the case of granitic rocks which give rise to the best examples of this kind of weathering the resulting product is a loose mass of quartz, felspar and biotite grains. The exfoliation is apparent around the typical granite boulders or "tors" as they are called. Water soaking into cracks in the rocks may freeze in cold climates and as it expands on solidification causes the wedging apart of the rocks and assists in breaking them up into smaller pieces.

The decomposition of the various minerals is a chemical action which depends on a number of factors. Some minerals such as quartz are stable under most natural conditions so survive unchanged through the whole process of breakdown of the rock and remain in the resultant soil. Others such as orthoclase are relatively weak chemically and break down to form more stable substances. Orthoclase, a potassium aluminium silicate breaks down (when attacked by water which has dissolved carbon dioxide) into clay (the type known as kaolin), quartz and potassium carbonate which goes away in solution.

The decomposition process may be represented by the following formulae:



Plagioclase felspar breaks down in a similar way.



Biotite breaks down to a soft green mineral called chlorite and ultimately to iron oxides, carbonates and quartz. Hornblende similarly may change to chlorite and then to carbonate, iron oxides and quartz.

Thus the products of decomposition of a granite are quartz, clay and iron oxides, the carbonates being removed in solution. Granite soils are usually porous because of the large proportion of quartz grains. As the iron bearing minerals, biotite and hornblende are not abundant, iron oxides are minor in quantity, thus the soil is usually light yellow.

Basalt with its feldspars, augite and olivine gives quite a different soil because of the different proportions of the quartz, clay and iron oxides. Augite like hornblende breaks down to carbonates and iron oxides with a little quartz. Olivine commonly changes to the mineral serpentine but eventually gives rise to quartz, iron oxides and carbonates of calcium and magnesium. Thus a basalt soil is low in quartz grains but rich in clay and iron oxide. It is thus heavy and inclined to be red in colour.

Sedimentary rocks have generally been formed from the breakdown products of rocks, so that a sandstone gives a sandy soil; a shale, a clayey one. There are, of course as many varieties as there are differences between the sedimentary rocks.

Metamorphic rocks such as quartzites and cherts are often very resistant to chemical decomposition so break down mechanically to rock fragments and a very thin poor soil. Gneisses, however, may decompose to give a soil somewhat similar to that derived from granite but generally with more mica flakes in it.

C L I M A T E A N D S O I L T Y P E S

L.J.H. Teakle, B.Sc.Agric., M.Sc., Ph.D., A.R.A.C.I.,
Professor of Agriculture, University of Queensland.

Last October I spent three weeks in Madagascar, that large island of mystery 250 miles off the east coast of Africa. It is sometimes known as the Red Island on account of the colour of the prevailing soil. The soil scientists there consider that the climate is the reason for the general occurrence of red soil which is similar to our Red Leams or Krasnozems. The climate is tropical, the latitude resembling that of the east coast of Queensland from about Maryborough almost to Cape York Peninsula.

No matter the nature of the rock, no matter the present vegetation, so long as the country is well drained and the surface old, the soil is red, like that at Toowoomba. There is a wide range of rocks, from the basic basalts to the acidic granites and mica schists. The vegetation ranges from tropical forest to grass. Apparently, in all cases, the rocks have weathered similarly to yield the sesquioxides, aluminium oxide and iron oxide, and clay minerals, of the kaolinite type. As far as I could gather, there were no soils with the tight clay subsoil so common in Australia and which we call Solodic or Podzolic soils, and no Black Earths.

It was such an observation as this, but extending over the whole climatic range of continental Russia, which gave Dokuchaev, a young Russian geologist, the idea that soil was distributed in zones which coincided with climatic zones. He also noted that the kind of soil, characteristic of the zones, could be identified by the nature of the profile - the profile being the succession of layers, or horizons as they are called, which you see in a pit or in a cutting.

These observations of Dokuchaev laid the foundation for modern soil science, or Pedology as it is called. It took over 20 years for the new Russian ideas on soils to get to the rest of Europe and to America, but, when they did, it was established that the same zonation of soils could be observed. Forty years later, Professor Prescott applied the same principles to a study of Australian soils and published his findings in the famous C.S.I.R. Bulletin 52 which came off the press in 1931. Its title was "The Soils of Australia in Relation to Vegetation and Climate".

The kinds of soil representing the zones were given names. A few examples are -

1. Podzols - soils with a litter of pine needles, etc. on a white subsurface, below which is a subsoil containing humus and iron oxides

with or without clay accumulation. These soils formed in the cool temperate zones, usually under a coniferous forest.

2. Chernozems - deep, black soils, of intermediate rainfall, usually under a grassland.
3. Chestnut soils - shallower, dark brown soils under lower rainfall.
4. Sierozems - grey soils of semi-desert areas.
5. Laterite soils and Krasnozems - Red soils of the humid and semi-humid tropics, usually under forest.

OTHER FACTORS IN SOIL FORMATION

It was recognised that climate was not the only factor which operated in the formation of the soil profile. Briefly, the chief ones are -

1. Parent material, or nature of the rock

The parent material provides the raw material for soil formation. Some people say that the rock is "mother of the soil". When you come to think of it, the term "mother of the soil" is a very unfortunate metaphor, because we expect mothers to produce offspring which will resemble themselves, and nothing could be farther from this in soils. The soil is different in minerals, in form and in structure.

However, it is from the rock that the soil gets its calcium, phosphorus and so on, and the elements to form the clay and other soil minerals. The importance of the nature of the rock in determining the kind of soil formed is particularly evident in Australia where, for instance, in the same area, basalts will form Black Earths, while granites or sandstones, greyish soils with clay subsoils which we call Podzolics or Solodics.

2. Vegetation and other organisms

The hen and the egg controversy arises here because it can be argued whether the soil determines the type of vegetation, or whether the vegetation determines the type of soil. However you answer the question, it is a fact that the vegetation, earthworms and so on, promote the circulation of substances within the soil. For instance, substances gathered in the subsoil by the roots collect in the leaves and later are deposited on the surface; substances dissolved from the leaves promote the leaching of materials such as iron; earthworms and termites churn up the soil; even man affects the course of soil formation by operations such as adding lime, exposing the surface to erosion and filling in areas with new soil.

Vegetation and other organisms, besides circulating and transforming materials, add nitrogen fixed from the air and organic matter formed by photosynthesis.

3. Drainage

It can be readily appreciated that drainage will play a part in soil formation. Where drainage is very free, the products of rock weathering are quickly removed and we can expect a soil such as the red types, which we call Red Loams or Krasnozems. These are largely aluminium and iron oxides and the kaolin clay minerals. If drainage is slow, whether because of low rainfall or slow permeability of the soil, weathering products will accumulate and the result may be clays of the "black" type known as montmorillonite, an accumulation in the subsoil of calcium carbonate, and so on.

Then, in some places, drainage is so restricted that a water table develops. If the water table is above the surface for at least much of the year, peat soils form; if below the surface, grey and blue colours, often flecked with rusty mottlings, commonly occur. They are called gley soils.

4. Time

It is obvious that the processes involved in changing rock and organic matter into a soil takes time - and often a great deal of time. Jenny records the formation of a foot of black soil in about 230 years on the limestone walls of an abandoned castle in southern Russia; on the other hand, volcanic ash may advance sufficiently in soil formation to support a crop in as little as 15 years. Some highly developed soils such as the Red Loams have probably been forming for hundreds of thousands of years.

Time, in years, means little in soil formation - it depends on the rate of weathering of the parent material and the rate at which the other factors - climate, vegetation, drainage, etc. - act on the weathered material. In the course of time, the soil reaches a kind of equilibrium with the environment and the profile attains a stable form - such a soil may be considered mature, irrespective of the number of years taken.

AUSTRALIAN VARIANTS

In Australia, the soils are not neatly laid out in consistent zones as they appear to be in Europe or North America. Of course, zonation is detectable, in fact, is quite obvious in places, but there are many aberrations.

1. Influence of earlier climates

One reason for these aberrations is the widespread occurrence of laterite, a hardened, ferruginous product which we think formed in early Pliocene times - about 12 or 14 million years ago. Soils associated with laterite retain certain characteristics irrespective of the present climate - whether the rainfall is now 10 inches or 50 inches per annum. Where laterite is widespread, the relationship between the kind of soil and the present climate is obscured and we have to think of climates of bygone ages; the climates that occurred during the long period of formation. In fact, I believe that it is of vital importance just what climate occurs when the soil starts to form - as with children, the early environment may affect the whole of its life. This certainly seems the case with our laterite soils. Also, some of the red soil - black soil patterns which we see in north-eastern New South Wales and in many parts of Queensland may also be due to different climates in different ages. The red soils on the higher parts may have had their origin in some earlier climate favourable to red soil formation. Subsequently, the climate became drier, erosion and dissection occurred, removing the red soil in parts. The parent rocks, exposed to a drier climate, formed black soils. Of course, there are other explanations too. In some cases, there may be a difference in parent material. For instance, there may be in some places a layer of volcanic ash, which weathers more readily to a red soil, and the normal hard basalt elsewhere - which favours a black soil.

2. Influence of atmospheric, or cyclic salt

Australia seems unique in the widespread occurrence of soils which bear unmistakable evidence of the effect of salt. There is more than the normal amount of exchangeable sodium in the subsoils, magnesium is also high and calcium low. Furthermore, the content of sodium chloride is abnormally high where the rainfall is low or moderate. A feature of the textural profile in the somewhat sandy types is a dense clay subsoil, sharply differentiated from the sandy surface soil, and often showing columnar structure. Furthermore, the lower part of the surface soil, the A₂ horizon as we call it, is light in colour, often whitish.

It has been possible to relate these soils to accession of salt brought in by the rainfall and deposited in the soil. In fact, I calculated that the rainfall brought in salt at the rate of 15 to 30 lb. per acre per annum in the drier parts of the Western Australian wheat belt. At this rate, it would take about 700 years of rain to account for the salt in each foot of soil.

The result of this is that these soils showing the effect of salt, solonised soils we call them, may be found in at least one quarter of the area of Australia - in a belt of country of variable width around the coast from at least Cairns in Queensland to Northampton in Western Australia.

THE INTEGRATION OF SOIL-FORMING FACTORS

It is evident that a number of external factors act on the parent material, changing it and developing a completely new body which is the soil profile. Many soil scientists have expressed the belief that if you have precise information about all of these factors you would be able to define the soil profile. They even express this idea in the form of a mathematical equation such as:

$$S = \int (P, C, O, D, T)$$

where S = the soil
P = parent material
C = climate
O = vegetation and other organisms
D = drainage
T = time

Personally, I think this is an unattainable ideal. It suggests that, by measuring the easily accessible external factors, the complex internal soil mechanisms can be deduced. I think we would do better to make a more thorough examination of the soil itself rather than of the external factors.

THE CLIMATE AND SOIL TYPES

But I have been asked to talk about climate and soil types. There are two main elements of the climate which are of great importance, the Temperature and the Rainfall. Innumerable soil scientists have endeavoured to correlate functions of temperature and rainfall with the nature of the soil and have had quite a deal of success.

The reason for this is that temperature affects the rate of chemical reaction - this means the rate of weathering of rock minerals, growth of plants and decomposition of organic matter. Generally, for every 18°F increase in temperature these rates are about doubled. It is probably due to the temperature factor that Red Loams do not generally form on granites in Victoria, but only on rocks like basalt. In northern Queensland, Red Loams form on granites and basalts alike.

Also, the rainfall supplies the water to promote rock weathering, plant growth and decay. Furthermore, the amount of rainfall determines the rate of removal and accumulation of the products. When the rain falls is also important because winter rains are associated with low temperatures and summer rains with high temperatures.

Boundaries of the great soil zones are commonly consistent with some function of Rainfall and Temperature; or with some function of Rainfall and Evaporation - evaporation including dryness of the atmosphere and winds as well as temperature. Thus, Professor Prescott has claimed that, for the following soil boundaries, the ratios of $P/E^{.75}$, known as the Prescott Ratio, are:

Coastal Podzolics and Red Brown Earths	1.70
Red Brown Earths and Grey and Brown Soils of Heavy Texture	0.92
Grey and Brown Soils of Heavy Texture and Desertic Soils	0.47

The leaching capacity of the rainfall is of paramount importance and this is a function of a P/T or P/E ratio, when the medium is of the same permeability. This is probably the reason for the observed correlations between these ratios and the soil boundaries.

In concluding this session, let us consider the operation of leaching - that is, the percolation of water through the soil mass, taking with it the various soluble products of weathering and decomposition.

1. High and medium temperatures and strong leaching

The calcium, potassium, magnesium, silicon and other elements are removed rapidly, leaving a residue of iron and aluminium oxides, and clays such as kaolin and allophane. If the rainfall is intermittent, iron oxides accumulate more rapidly; if continually moist, aluminium oxide and allophane. The soils formed are of the Red Loam or Krasnozem type.

2. Low and medium temperatures and strong leaching

The characteristic soil on siliceous parent material is the Podzol - a light grey A_2 horizon under the organic matter surface and a subsoil containing humus and iron oxides. Where there is a fair amount of lime, or the vegetation gathers lime, a brown soil is formed. Some of the best English agricultural soils are of this type.

These soils are not common in Australia, but are represented very generally by the Red Yellow Podzolics in which there is clay accumulation in the subsoil. The clay varies in colour from red to yellow and grey.

It is of interest that Podzols do occur in coastal Queensland and Red Yellow Podzolics are common - in spite of the high temperature.

3. Medium temperatures and moderate leaching

Where the parent material is not too basic, Red Brown Earth soils form in Australia. The surface is loamy, but the subsoil is rich in clay and characteristically red in colour. Except on poor, acid granites, some calcium carbonate usually accumulates in the subsoil.

On basic parent materials, such as basalts and limestones, Black Earths form. These are clayey throughout the profile and the clay is of a type which expands greatly on wetting. It is known as montmorillonite. There is no evidence of clay accumulation to form a subsoil. Calcium carbonate commonly occurs in the soil and there may be some gypsum in some types.

4. High temperature and moderate leaching

Red Brown Earths occur in Queensland as in southern Australia, but the clay is of the kaolin type as in Red Loams and not illite as in the south.

The Black Earths appear the same.

5. Low leaching

Professor Prescott defined a complex group of soils in the semi-arid parts of Australia and named them Grey and Brown Soils of Heavy Texture. The Queensland representatives are heavy clays and resemble the Black Earths in important respects - but are lighter in colour, lower in organic matter and usually contain gypsum - an indication of the low leaching capacity of the rainfall.

There is also a variety of soils in the central desert areas of Australia. It seems likely that many of these soils owe their characters to previous climatic conditions much different from the present.

The importance of climate in the formation of soil types arises out of the influence of temperature and rainfall on the rate of weathering and decomposition and on the removal or redistribution of these products. If the climate is known and the parent rocks are normal - that is, they are not exceedingly sandy or excessively basic - a good deal can be deduced about the type of soil to be expected.

My concluding remark is: "The only certain way to be sure is to go out and see."

S O I L U S E

L.J.H. Teakle, B.Sc.Agric., M.Sc., Ph.D., A.R.A.C.I.,
Professor of Agriculture, University of Queensland.

This title is very short, but the subject is very long - it is really the history of agriculture since man began to manage the land to get better and more reliable production. It has been practised for thousands of years - except in Australia, where soil use came with Captain Phillip in 1788 because Australian aborigines relied on the chase and what nature provided in the way of vegetable foods. Since then, we have been developing our soil use programme in response to expanding needs - needs for local requirements and needs for the export trade.

Soil use is a complex reaction to a number of factors; to economic factors as well as to the capacity of the soil in its environment, and to new discoveries regarding soil improvement. As these factors change, so does soil use change, and, in a developing country such as Australia, is very fluid.

In view of the breadth and complexity of the subject, I propose to confine attention to the soil itself - its use in agricultural development. Three questions may be asked:

- I. What soil characteristics are important?
- II. How can we modify and improve the soil?
- III. How can we protect the soil from deterioration?

I. WHAT SOIL CHARACTERISTICS ARE IMPORTANT?

The agriculturalist looks at the soil as a medium for growing his crops. To be satisfactory for cropping, the soil must perform several functions which we can mention very briefly.

(a) The soil must be of a depth suited to the crop to be grown and adapted to the nature of the climate. Fruit crops generally do better on deep permeable soils; a grass sward may do well on 4 inches of soil in Wales where it is always moist, while in northern Australia deep-rooted species and deep soils are necessary.

Then the soil must be suitable for the cultivating implements to be used; slope and stoniness must be considered.

(b) The soil must supply adequate air to roots. Generally, the soil mass may be considered to be made up of 50% solid matter, 25% water and 25% air. Compaction, and water-logging reduce the air supply and may seriously interfere with crop growth owing to shortage of oxygen. Reduced air supply will interfere with the

supply of nitrate and may cause harmful substances to develop.

(c) Soil temperature may be a factor. In cold countries planting must be delayed until the soil reaches a suitable temperature. In Australia summer-planted seeds may be cooked in bare soil if too near the surface.

(d) The drought year of 1957 makes us very conscious of the moisture factor - and the capacity of soils to store available water for the crop during dry periods. The Black Earths have a very high capacity to store water - one we tested on the Darling Downs supplied over 10 inches to a wheat crop. But permeability is slow when the soil is moist, so the problem is getting the water into the subsoil. Sandy soils have a low storage capacity and the quick changes in moisture content are unfavourable for plants. However, what the lighter textured soils lack in storage capacity they may make up in ready penetration - depth may be a compensation.

(e) Supply of essential nutrients in a suitable balance is probably the most keenly appreciated character of soils - probably because so many are lacking in one or more elements and fertilizers give spectacular responses. The subject of plant nutrition will be discussed on Wednesday by Professor Beadle, so I need do no more than remind you that about 13 essential elements are absorbed from the soil. They are calcium (Ca), magnesium (Mg), potassium (K), nitrogen (N), phosphorus (P), sulphur (S), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), molybdenum (Mo) and chlorine (Cl). A number of others are absorbed, although it is not certain just what function they may play in the plant. Examples are sodium (Na), aluminium (Al) and silicon (Si). A certain rough balance is required - for instance, too much Ca will interfere with the utilization of K; too much Mn interferes with Fe utilization. The great fertilizer industry - nearly 2,000,000 tons per annum in Australia and over 50,000,000 throughout the world - is based on observations that one or more nutrients are in short supply and prevent the crop from yielding to the limit set by such things as water supply, and the capacity of the crop itself. Even the most richly supplied soils develop a need for some fertilizer after long use.

(f) Sometimes substances are present which are harmful to the crop. Perhaps the best known is salt, which threatens a million acres of wheat lands in Western Australia and has damaged much of our irrigated land; there is soil acidity, troublesome under high rainfall in some places; excess manganese affects pineapples and beans in parts of Queensland; too much copper is associated with toxæmic jaundice in sheep in parts of New South Wales.

It is obvious that the soil is a very complicated organisation and many things must be in adjustment for it to be productive.

II. HOW DO WE MODIFY AND IMPROVE SOIL CHARACTERISTICS FOR PLANT GROWTH?

To grow our crops and to establish and maintain improved pastures the soil has to be treated in a number of ways.

(a) Preparation of a seed bed -

From the primitive pointed stick, a wide range of cultivating implements has been developed - mouldboard ploughs, disc ploughs, scarifiers, chisel ploughs and rotary hoes. There are harrows and rollers, cultipackers and so on, all used to prepare the land for the crop.

To establish grass and clover on virgin country, sowing on the burn is often satisfactory - and economical.

(b) Fertilizers are used to improve the nutrient status and grow bigger crops. Superphosphate, supplying P, S, and Ca, is the chief fertilizer in Australia and the micronutrients Cu, Zn, Mo and Mn are beneficial on wide areas of country. Organic manures are not greatly used on account of inadequate supply and high cost.

By the use of fertilizers, many millions of acres grow better crops; on many millions of acres no crops at all could be grown without the appropriate fertilizer.

Fertilizers are the life blood of Australian agriculture.

(c) Rotation of crops is very important in most forms of soil use. While cultivating implements improve the soil for the immediate crop, continued cultivation changes the soil and often causes deterioration. Rate of water absorption is decreased, organic matter and nitrogen content are lowered, and the soil becomes more susceptible to erosion. For most cultivated crops, a form of rotation will prevent deterioration. The alternation of cultivated crops with pastures is very effective. Cultivation enables the best crops to be grown, while the pastures restore the soil structure, rebuild the organic matter and nitrogen and generally recuperate the soil. This is called ley farming. I understand that the Inveroll Soil Conservation officers recommend a rotation of 7 years' pasture and 3 years' under crop. This is an example of the principle of ley farming.

(d) Drainage is necessary on some land - particularly land under irrigation. Excess water is just as harmful as too little and must be removed by drainage. There are various types: Tile drains, mole drains, surface drains. In Australia drains are used

mainly in orchard crops and to reclaim swamp land.

(e) Irrigation is another important means of improving soil use. Production from irrigated land is often 5 to 7 times as much as from dry-farmed land. Often irrigation makes possible the use of fertile soil otherwise almost valueless on account of inadequate rainfall.

There are many ways of improving the soil to make it more useful. All of these involve capital, skill and the backing of science. Australia's record in this field is second to none in the world and we look forward with optimism to increasing very greatly our agricultural production by this combination of science, skill and capital.

III. HOW CAN WE PROTECT THE SOIL FROM DETERIORATION?

All farming systems which have achieved permanence are designed to maintain soil fertility - to protect it from deterioration. These systems are many and varied - from the closed cycle system of the Chinese peasant to the "shifting cultivation" system of some countries such as Java and Africa. Systems which have failed to preserve the soil have disappeared as in North Africa, once the granary of Rome. Evident damage to soil, indicated by erosion, has given rise to soil conservation services in many parts of the world - particularly newly-developed countries such as America, South Africa and Australia.

Three practices are necessary to protect the soil from deterioration.

1. Return of nutrients to replenish reserves depleted by cropping and stocking. In the Chinese system this is accomplished by return of all wastes gathered from the farm and whence the food is consumed. The farmer is the sewerage engineer. Legumes are grown to add nitrogen. Commercial farming as we practise it relies on fertilizers and legumes. Both are successful, but commercial farming is capable of higher production.

2. Maintenance of good soil structure. Good soil structure means a condition of aggregation so that there is an abundance of large pores - non-capillary pores we call them - which allow air circulation, water penetration and root ramification. Cultivation breaks down this structure and the only practical method known for restoring it on broad acres is the use of a grass pasture while avoiding cultivation. Krilium was once thought to be the answer - but the cost is prohibitive. For intensive farming, farmyard manure, compost and green manure are used - all costly operations.

Maintaining good soil structure is a very important part of a soil use programme.

3. Protecting the surface soil from erosion is the third practice I wish to mention. No doubt this will be discussed by Mr. Thorpe on Friday. The principles are simple:

(a) the surface must be covered by some form of vegetation as long as possible - and particularly during periods of heavy storms or high winds.

(b) water and wind movement across the soil surface must be controlled to limit erosive effects.

(c) the soil must be kept in good physical condition to absorb water rapidly and resist erosion.

In conclusion, soil use must be adapted to suit the local conditions so that -

(a) fertility is preserved or improved;

(b) profitable agriculture may be practiced to serve the internal needs of the country and to attract and hold overseas markets.

S O I L A S A M E D I U M F O R P L A N T G R O W T H

K. Spencer, B.Sc. Agr., M.S.,
Senior Research Officer, C.S.I.R.O.,
Armidale.

(1) PHYSICAL ASPECTS

A. Make-up of Soil. Soil, the mixture of mineral and organic material at the land surface of the earth which is capable of sustaining life, is made up in this way -

		<u>Volume basis</u>	<u>Weight basis</u>
Solids	{ Mineral matter	45%	77 lb./c.ft
	{ Organic matter	5	3 lb.
Non-Solids	{ Water	25	16 lb.
	{ Air	25	$\frac{1}{4}$ oz.

a) Solids - Mineral portion consists of particles of a range of sizes, arbitrarily grouped into sand, silt and clay (stones and gravel are excluded).

Sand particles extend from approximately 1/10 inch to 1/1000 inch and comprise that portion of the soil which can be seen by the naked eye. They are relatively inert.

Silt particles tend to aggregate, and are between 1/1000 and 1/10,000 inch in size.

Clay particles are very small and most of the physical and chemical properties of a soil depend on their kind and amount.

Organic matter consists of material at all stages of decomposition between recent litter and 'humus'. The physical and chemical properties of a soil are considerably modified by the amount of organic matter present. Aggregation, and therefore air and water relations, are particularly affected.

b) Non-solids - The amount of air in the pores varies inversely with the amount of water. About 50-50 is considered ideal. Air must supply oxygen for respiration of roots, microorganisms and insect life. Poor aeration, i.e. a low capacity for gaseous exchange with the atmosphere results in a build-up of carbon dioxide. Water is generally scarce rather than in excess, and storage capacity can be improved mainly by improving rate of intake.

B. Texture. This is the term by which the proportions of sand, silt and clay are described. It can be done in the field by rubbing between the fingers at the "sticky point". Alternatively, a mechanical analysis can be made in the laboratory and

the decision made free from personal bias. It is a property which cannot be altered.

- C. Colour. Depends on the amounts and forms of iron oxides and organic matter present. Colour throws some light on the air-water relationships.
- D. Structure. By this is meant the arrangement of the individual particles into aggregates. Size and stability vary between soils and both characteristics are influenced by amendments or mechanical manipulation.
- E. Soil Temperature. The soil is heated by radiation from the sun, and the surface layers during a 24 hour period are at one time hotter and another time cooler than the air adjacent. The maximum, which may exceed 150° F, is usually reached about 3 p.m. Waves of heat pass down into the soil but daily fluctuations fade at about 2 ft. while seasonal fluctuations depend on the latitude.

Soil temperature depends on altitude, latitude, aspect, colour, water content, texture, etc.

- F. Soil Water. There are four recognised types: chemically-bound (in crystals, etc.), hygroscopic (tightly held on surfaces and between particles), film and gravitational. The last two are available to plants, but film moisture is the principal source.

When a soil is wetted, moisture content always rises to a point known as field capacity providing there is free drainage. Moisture content below field capacity is found only when the soil is in the process of drying. Available moisture is that between field capacity and wilting percentage, although growth is affected before wilting percentage is reached.

- G. Soil Air. The composition of soil air is similar to the atmosphere except that oxygen is lower and carbon dioxide higher. If diffusion and exchange with the atmosphere is impeded, the carbon dioxide content of the soil air may build up to harmful concentrations.

(2) CHEMICAL ASPECTS

- A. Introduction. It is a little over 100 years since superphosphate was first manufactured and expensive field experimentation provided the first quantitative data on the fertilizer requirements of crops. Of course, natural fertilizers, such as guano and saltpetre, were used long before then, even as early as 1669. But the investigator of those days was very much in

the dark about what actually constituted the food of plants, and various theories held sway through the 17th and 18th centuries. Water, saltpetre, fine soil particles and humus were successively proposed. Justus von Liebig (about 1840) finally debunked the various hypotheses and gave agricultural chemistry a sound basis on which to build.

- B. Elements of Interest. Most of the known 98 elements occur in soil but we are only concerned with the 16 essential for plant growth, or those affecting the availability of the essential elements to plants, e.g. aluminium and silicon.

In the weathering of rocks to form soil, there is a relative loss of bases, especially calcium, magnesium and sodium; and a gain of aluminium, iron and silicon. The degree of weathering and subsequent leaching determines to a large extent the fertility of a soil.

- C. Large Particles. When the cementing agents and forces are removed, soil breaks up into particles with a range of sizes from gravel down to microscopic specks. The large particles are gravel, grit, sand of various sizes, and silt. They form the relatively inert skeleton, providing an anchorage for plants and a storehouse for air and water. Their composition is very variable, but not very important for present considerations, except that on further weathering they provide more plant foods and finer material.

- D. Small Particles. Clay and organic matter. This is the highly reactive portion of the soil. On and within these particles are held most of the nutrients. We are dependent on their property of adsorption for the soil retaining added fertilizers as well as the native mineral salts.

- E. Soil Solution. Some plant foods, e.g. nitrate, are not held by the small particles but move freely in the soil water. In acid soils, hydrogen is high in the soil solution. Plant foods are mostly absorbed from the soil solution, although there is evidence that roots can take up nutrients by contact with undissolved materials.

- F. Forms of Nutrients Held by Soils. Soils are called upon to supply to plants all 16 essential elements except carbon and some oxygen. Legumes can, of course, derive their nitrogen (via nodule bacteria) from the soil air. Of the total amount of each plant food present in the soil, only a small proportion is at any one time available. We can distinguish readily-available, difficultly-available and unavailable forms of most elements.

Except for potassium, those plant foods required in the largest amounts, nitrogen, phosphorous and sulphur, occur both as inorganic salts and as organic matter. Only the former are available to plants, but microorganisms work towards the mineralization of nitrogen, phosphorous and sulphur, so releasing them from their "reserve" forms.

- G. Soil Acidity. The solubility of most elements in the soil solution depends greatly on the acidity of the solution. Most are more available in acid soils (molybdenum is an exception) but the acidity may be sufficiently great to release sufficiently large amounts of a nutrient for it to reach toxic levels, e.g. manganese and aluminium. Lime or dolomite are used to correct acidity. Flowers of sulphur will increase acidity. Some plants are more tolerant of acidity than others.
- H. Soil Alkalinity and Salinity. Alkaline soils frequently occur in arid and semi-arid regions. The alkalinity may be sufficient to render some of the minor elements insoluble and therefore unavailable to plants. Saline soils contain high sodium and show poor physical characteristics. 'Rise of salt' is often caused by disturbance of balance of nature by man. Reclamation is generally a slow or expensive process.
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SOIL ORGANIC MATTER

J.M. Vincent, D.Sc.Agr., Dip.Bact., Associate Professor of Microbiology, School of Agriculture, University of Sydney.

It is possible to raise healthy plants in the complete absence of organic matter but as a matter of fact this will seldom be the situation. A fertile soil could well contain 10% organic matter, but this will vary between such extremes as a poor sandy soil with less than 1% to peat where the organic matter may be as much as 95%.

The soil's organic matter is continually changing. Plant remains (leaves, fruits, roots), microscopic green plants such as the soil algae, animal remains, faeces and urine all add to it.

On the other hand organic matter is decomposed by soil microbes and, particularly when temperature is high, by chemical oxidation. However, this loss of organic matter is essential for its constituents to become available again to plants.

To understand the changes that take place and their importance in soil fertility, it will be necessary to look a little more closely at the nature of the organic materials that the soil receives. These in fact will be as varied as living matter itself, but to avoid getting bogged down in too much detail we shall have to content ourselves with examples.

Proteins come from both plants and animals. They are the principal supplier of nitrogen to the soil organic matter. They also contain the elements Carbon, Hydrogen, Oxygen, Sulphur and Phosphorus as their chief constituents.

Cellulosic substances are characteristically a plant contribution, as are also the lignins. The former are complex carbohydrates made up of Carbon, Hydrogen and Oxygen; the latter are even more complex molecular arrangements of the same elements. These are abundant because they are the chief skeletal materials of the plant. Older woody tissues and the straw of mature cereals and grasses are much more lignified than younger plant tissues.

The animal's contribution includes the nitrogen rich urine (urea and ammonia) and manure. The composition of the latter will to some degree reflect the foodstuff the animal will have received, but is considerably modified by the animal's own digestive process and the action of the micro-organisms of its gut. It will also contain a large amount of microbial substance, that will have grown there.

The decomposition of a mixture like this is one of the

principal roles of the soil life. Soil inhabiting animals such as worms, and ants help the process considerably by finely macerating the coarser organic matter and distributing it throughout the soil.

~~The chief operators will, however, be fungi and bacteria.~~ Different parts of the soil organic matter will be tackled by different groups. The more generally available materials such as proteins, starches and sugars can be broken down by many different sorts of micro-organisms but others such as the celluloses and lignins require the attention of specialists. Cellulose will be chiefly decomposed by the smaller fungi or by special groups of bacteria, according to the operation of such factors as soil acidity and aeration. Lignins on the other hand are almost the sole preserve of the fungi. In fact the lignins of wood require the prolonged action of larger fungi of the toadstool type.

An important feature is that the breakdown of organic matter can be a cooperative affair. In fact this cooperation can begin at the level of the animal. The sheep's rumen, for example, can be regarded as a magnificently constructed constant temperature incubator and mixer for the housing and growth of a vast population of micro-organisms. Many of these are able to decompose relatively resistant materials such as cellulose and make the products available to the animal.

But the cooperation in decomposition also takes place in the soil itself either by the concerted action of different kinds of organisms or by their successive attack, e.g. fungi followed by bacteria, one providing a substrate for the other.

At the same time as micro-organisms decompose the organic matter they themselves increase greatly in number. This means that the original constituents of the materials received by the soil are partitioned between new microbial substance and the soil or its atmosphere.

To take more specific examples. A large part of organic carbon will be liberated as CO_2 . It has in fact been calculated that a recently manured area producing food enough for one man might well be dissipating enough energy for 6 men. Alternatively we can note the figure of 7 tons of carbon dioxide likely to be lost from an acre of fertile soil in a year.

In the longer term view, of course, this dissipation as carbon dioxide is not waste. It is in fact the major means by which Carbon becomes available for re-circulation via the photosynthesising green plant. The amount of carbon dioxide in the atmosphere at any one time is only enough for 20 years' steady use. Moreover the local

increase of carbon dioxide due to vigorous decomposition in the soil can lead to greater availability of other nutrients.

The case of nitrogen illustrates specially well and in a clearly practical way, the importance relative liberation of nitrogen in a form the plant can use and its uptake in providing microbial growth: These are the chief points:

- (i) Organic matter of any kind is likely to stimulate the growth of micro-organisms.
- (ii) This causes evolution of carbon dioxide.
- (iii) It also demands extra nitrogen for the new cell substance.
- (iv) If the organic matter is sufficiently rich in Nitrogen, this demand can be met and some liberated as ammonia. This then becomes available to the plant.
- (v) If the organic matter contains insufficient nitrogen there will be none left over for the green plant. In fact the microbes whose growth has been stimulated by the addition of the organic matter can then remove sufficient "mineral" nitrogen from the soil, to cause nitrogen deficiency symptoms in the plant.

Let us translate this into more practical terms. A green manure crop of a legume, such as clover or cowpeas will generally have sufficient nitrogenous material in itself to meet the demand created by the extra bacterial growth. It will also increase the level of nitrogen available to other plants. A clear benefit will therefore generally be seen to green manuring with such a crop.

On the other hand cereal straw has plenty of decomposable carbonaceous material, but very little nitrogenous material to go with it. Its addition to the soil is likely to lead to an increase in bacterial numbers that will demand more nitrogen than is available from the organic matter itself. An associated or following non-leguminous plant will, under these circumstances, show marked deficiency in nitrogen.

This effect is seen most readily and commonly with Nitrogen but can operate similarly for elements like Phosphorus and Sulphur.

Micro-organisms may affect the availability of nutrient elements in other ways. This can be well illustrated in the case of Manganese. Certain pairs of oxidising bacteria are able to convert the reduced form of this element, which is the form available to the plant, to the unavailable fully oxidised form. On the other hand a liberal addition of organic matter can set up reducing con-

ditions that make for manganese availability.

So far in this talk I have kept away from the term humus, which broadly speaking can be taken as the name given to the more stabilised organic matter of the soil. Whereas when we refer to organic matter we include any of the carbon-containing material to be found in the soil even if it is the most recently fallen leaf or the most recently deposited dung pat. When this material has been thoroughly worked over by micro-organisms and had incorporated in it the newly grown organisms that have developed from its own decomposition, we have what we loosely call 'humus'.

Humus is likely to consist of those parts of the soil organic matter that are relatively resistant to decomposition, and the gummy and entangling cells of associated micro-organisms. Various artificially defined fractions are known to the soil chemist but humus is an everchanging component of the soil. It is added to and diminished as the processes of decomposition and accretion proceed.

The important thing for us to note at present is that it is a factor having some effect on such physical properties of the soil as determine the formation of crumb structure, aeration, water penetration and resistance to erosion. Humus is not the only factor, and need not even be the most important factor, in affecting these properties but it may well be a material contributor to such effects.

A Note on the relative merits of composting and green manuring:

Composting may be more convenient in that the decomposition largely takes place out of the soil, its addition to the soil increases water retention and it appears to reduce porosity. Green manuring provides for little water retention but is more likely to open up the texture and improve drainage. The further decomposition of compost in the soil will be slow whereas the addition of green manure will initiate a vigorous fermentation and evolution of large amounts of carbon dioxide. Compost will yield less nutrients and humus than will green manuring but will have the advantage of greater freedom, from weeds and parasites, especially if high temperatures have been allowed to develop in the compost heap. There is nothing to show that compost cultures have any beneficial effect.

LEGUME SEED INOCULATION

J.M. Vincent, D.Sc.Agr., Dip.Bact., Associate Professor of Microbiology, School of Agriculture, University of Sydney.

1. THE AVAILABILITY AND IMPORTANCE OF SOIL NITROGEN

Nitrogen and phosphorus are the two elements most commonly deficient in Australian soils. To make good the latter we have no option but to use fertilizer. With nitrogen, however, the use of fertilizer is generally too expensive compared with making use of the nitrogen-capturing ability of the nodulated legume.

This brings us to the question: why should nitrogen be so short in the soil, when four-fifths of the earth's atmosphere is made up of this element? The fact is that the nitrogen of the atmosphere is chemically inactive and as such is unavailable for direct use by the plant. The nitrogen needs to be supplied to the plant as ammonia or nitrate. Because of this the compounds nitrate and ammonia are basic to plant life and, through plants, to the animal.

When we were considering the soil's organic matter in the earlier lecture we paid rather particular attention to the liberation of its nitrogen into the form the plant can use. The nitrogen of the original organic matter is too firmly bound in a form the plant cannot utilise. It has to be released and simplified, that is "mineralised" to the form of ammonia or nitrate. This is one of the several parts of this story where soil microbes play a vital part. It is their job to break down this wide range of complicated substances so as to release nitrogen in a useful form.

However, the breakdown of organic nitrogen can sometimes go as far as the liberation of molecular nitrogen, another form which is no use to the green plant. Excess organic matter added to a soil can under certain conditions lead to such a production of volatile ammonia that the loss to the soil may be considerable.

More generally serious is the loss of nitrogen by leaching and by soil erosion. Crops sold off the farm can cause a particularly heavy drain on soil nitrogen. Direct loss of nitrogen under grazing conditions will not be as serious as under a cropping system, but we would also have to take account of erosion losses from the soil consequent on clearing and grazing. More significant to the grazier is the fact that in many parts of Australia, production is seriously limited by the low level of available nitrogen. This is reflected in poor grass growth and a low plane of nutrition.

Nitrogenous fertilizers and the feeding of concentrates bought off the farm are ways in which nitrogen losses can be offset. In some systems of agriculture they are economically desirable, but this is more often not the case in Australia. A hundred weight of sulphate of ammonia at about £2 will give at the best a temporary response.

Perhaps we can expect up to about 4 lbs. of combined nitrogen in some years, as a gift from heaven following a thunderstorm when electrical discharges can cause the formation of nitrogen oxides. Such conditions might, however, cause as much loss by erosion or leaching.

Much more positive gains than this are needed. Those that are really significant will be due to the beneficial action of soil micro-organisms. This is because there are several kinds that are able to make use of the inactive atmospheric nitrogen. They build it into their own bodies whence later it becomes available to plants.

2. NITROGEN-CAPTURING BACTERIA: THE ROLE OF THE NODULATED LEGUME

The microbes that can capture nitrogen from the air are of two kinds. There are those that lead an independent existence in the soil and, under certain rather special conditions, add to the supply of soil nitrogen. In practice however, this group can be credited with only small gains that would not add more than a few pounds of nitrogen per acre.

On the other hand, when we come to the other group, those that work in partnership with legumes, we find them able to make a major contribution that is really basic to the maintenance and upgrading of soil fertility. A recent estimate credits legumes with supplying three times as much nitrogen to the soils of the United States as that purchased as fertilizers. In this country the difference would be very much greater. Figures obtained in rotation experiments in Victoria show an annual gain of 30-90 lbs. nitrogen per acre due to legume pasture.

The legumes are a family of plants recognised botanically by the way they carry the seed in a pod. This might be straight in the form we are familiar with in peas and french beans, or curved in a spiral as in lucerne and the common burr medic. In this family there are a great many plants, both native and introduced. The former include our wattles, the latter a great many plants of considerable economic value as crops and in pasture (lucerne, clover, vetches, cowpea and so on).

The legumes are rich in proteins, as well as certain minerals, and in some cases provide valuable vegetable oils (soybean, peanut). But for the present we are more concerned with the part the legumes play in obtaining nitrogen for themselves, and ultimately the soil by tapping the huge reservoir of otherwise inactive atmospheric nitrogen.

Historically there have been two forms of agriculture:

Conservational, characterised by the wise use of legumes in systems of rotation and land economy;

Exploitative, "land-mining", a form of get-rich-quick agriculture neglecting the proper use of the legume and leaving a wasted heritage of erosion and reduced agricultural potential. Pasture improvement, with the introduction of a legume component, provides a means by which we in Australia can progress from the latter to the former.

3. FACTS ABOUT THE NODULATED LEGUME

Against the scale of historical time, during which legumes have had their place in sound agricultural practices, it was only towards the end of last century that scientists began to see the reason why they were so valuable. It was then that the German investigators, Helwegel and Wilfarth, recognised that the 'solution lay in the fact that whenever the legume was independent of soil nitrogen it had lumps (nodules) on its roots and that these were filled with bacteria'. It is the association between these bacteria and the legume host that is so important.

This can be shown quite easily. Grow the legume from sterilised seed in a germ-free, nitrogen-free environment and it will show nitrogen deficiency symptoms like any other plant. But to the same combination add a culture of the specific root-nodule bacteria and then you will find that as the roots develop nodules, so will the plant show a healthy appearance.

I think you will agree that this is truly a fascinating example of a biological partnership. That the diseased condition can be caused by micro-organisms is well enough known but this living together and mutual benefit between bacteria and plant is less usual and very finely balanced. If the partnership is to be established and maintained to the satisfaction of each party, then each must be acceptable to the other, each must do its share, each must have certain requirements satisfied.

A knowledge of the conditions that have to be satisfied is of theoretical and practical interest:

(a) The invisible bacteria must be already present in the soil or

added with the seed as "inoculum".

There is a marked degree of specificity in this. It will, for example, require the clover bacteria to invade that host. Lucerne will need another group; vetch another, and so on.

- (b) The nodule partnership must be able to fix nitrogen. This is not inevitable. Not all partnerships are equally beneficial to the plant. A bacterium able to produce good nitrogen-capturing nodules with white clover might produce useless nodules in subterranean clover.
- (c) Conditions in the vicinity of the seedling must be such that the bacteria will survive and multiply. Note that acidity of soil and fertilizer can operate against this.
- (d) Nutrient and other conditions must permit the nodulated plant to fix nitrogen effectively. The role of molybdenum and the results of its deficiency illustrate this. In Australia there are numerous examples of nodulation difficulty due to one or more of these factors.

4. SEED INOCULATION

There is a widespread need for seed inoculation in this country. This fact combined with the relatively low cost of inoculum compared with other establishment costs, justifies the general recommendation to inoculate all sown legumes, unless there is very good evidence to the contrary.

Commercial inoculants are now available for the treatment of the legumes most commonly used by the farmer. There are generally supplied in the form of a fine black powder. It comes in a plastic lined box or envelope to keep it moderately moist. Although the powder can be dusted on to the seed, it is better to make it up into a slurry with water, milk or a sugar syrup for use as directed. Some agar cultures are still sold. In these the bacteria are growing on the jelly-like agar and it is the surface slime which is taken up into liquid and used to inoculate the seed. Both types of culture can give good results.

However, if the inoculant is to do its job certain conditions have to be met. These relate first to the quality of the inoculum itself and secondly to the way it is used.

A satisfactory inoculant will be one that contains the right kind of root-nodule bacteria and enough of them to provide for nodule formation under field conditions. The right kind of bacteria will both invade and secure atmospheric nitrogen for the

legume host. It is generally conceded that there should be at least 100 living root-nodule bacteria put on each seed, although relatively favourable conditions around the germinating seedling might permit us to get away with smaller numbers than this.

Manufacturers of commercial inoculants have on occasions had difficulty in meeting these requirements. In some instances the culture that was distributed was inferior as a nodule producer, in others it was ineffective in nitrogen-fixation. At other times too there were insufficient living root-nodule bacteria in the culture. The latter could arise from two causes: either to a failure of the manufacturer to provide them in the first instance or to too rapid death in the culture after manufacture. Whatever the reason, faulty cultures can cause farmers financial loss far in excess of the purchase price of the inoculant itself.

The Microbiology Laboratory of the Sydney University School of Agriculture has combined with the New South Wales Department of Agriculture to provide a service designed to help the manufacturer consistently produce high quality inoculants. This service which is called U-DALS (i.e. University - Department of Agriculture Laboratory Service), is partly financed by contributions from all Australian inoculant manufacturers but remains an independent body, that regards the interests of the farmer as its prime concern.

Specifically U-DALS does these things:

- (a) Regularly tests strains of root-nodule bacteria in the Laboratory, glasshouse and in the field and collates the results of other workers.
- (b) Maintains a large collection of tested cultures and provides pure "mother" cultures to manufacturers at monthly intervals.
- (c) Tests all batches of manufactured culture before sale and according to its quality recommends its rejection or acceptance.
- (d) Tests cultures at the point of supply to farmers.
- (e) Carries on investigations designed to enable the manufacturer to put more root-nodule bacteria into the packets and to reduce loss of viability of the inoculum between the time of manufacture and use.

In the current season all cultures marketed by Australian manufacturers should be traceable to batches that were tested and found satisfactory at the time of production. Our own field tests of commercial inoculants in the Autumn of 1958 indicate that their quality has improved considerably over previous years.

There remain, however, other possible causes of failure. Poor storage of cultures, particularly at too high a temperature can lead to serious loss of viability. This could be a very important factor between the time of manufacture and use. Sowing the inoculated seed into acid soil or in contact with acid superphosphate can also be responsible for excessive death of the bacteria. Lack of moisture in the soil is, of course, another hazard which is difficult always to avoid. Wherever possible inoculated seed should be sown into a moist seed bed. Superphosphate should be at least partially neutralised with lime or lime-pelleted seed used to provide a more favourable region in the vicinity of the young seedling.

P L A N T N U T R I T I O N

N.C.W. Beadle, D.Sc.(Syd.), Professor
of Botany, The University of New
England.

(1) MINERAL REQUIREMENTS

Green plants take in inorganic materials which are built up by the plant into organic molecules.

15 elements are essential for healthy plant growth and reproduction, namely:

carbon,	hydrogen,	nitrogen,	sulphur,
calcium,	iron,	magnesium,	copper,
zinc,	boron,	manganese,	molybdenum.

The last 5 are referred to as the micro-nutrients or "trace" elements, because they are required in only minute quantities.

(2) SOURCES OF THE ELEMENTS

Carbon, hydrogen and oxygen (C, H, O) are obtained from the carbon dioxide (CO_2) in the air and from water (H_2O) in the soil (a little may also be absorbed through aerial parts of the plant). Carbon dioxide enters through the stomates in the leaves; water enters osmotically through the root hairs, and is carried to all parts of the plants, chiefly through the xylem (wood, veins of leaves).

All the other elements enter through the root hairs. They enter as ions, which are absorbed individually and independently of the water which is taken in, i.e. if a plant is supplied with potassium nitrate (KNO_3) the potassium is absorbed at a different rate from the nitrate.

(3) ABSORPTION OF NON-ESSENTIAL ELEMENTS

Chemical analyses of plants reveal that many non-essential elements are absorbed. Of these the following may be mentioned:

aluminium, sodium, chlorine.

Even heavy metals may be taken in, such as lead and silver, merely because these occur in the soil and some plants have no mechanism for excluding them. Noteworthy accumulations are aluminium in many of our rainforest plants, and sodium and chlorine in saltbushes.

It may be added here that chlorine is now thought to be essential for some plants.

(4) NO SUBSTITUTION

Plants require all of the elements listed above as essential, though the requirements of different plants vary considerably, e.g. some plants have a higher phosphate requirement than others, or a higher calcium requirement, etc.

One element cannot replace another which is deficient, i.e. if phosphate is deficient, this deficiency cannot be made up by nitrate or magnesium, etc. When an element is deficient growth decreases or ceases and a deficiency "disease" may develop.

(5) FUNCTIONS OF THE ELEMENTS

Carbon, hydrogen, oxygen, are the basic elements for the formation of all organic compounds, such as sugars, starches, proteins, etc.

- Nitrogen - for proteins.
- Phosphorus - for proteins, particularly those in the nuclei of cells.
- Magnesium - occurs in chlorophyll molecules.
- Iron - essential for the formation of chlorophyll.
- Potassium - function not clear. Possibly associated with carbohydrate metabolism and cell division.
- Calcium - a constituent of cell walls and may have other functions.
- Sulphur - a constituent of some proteins.

The functions of all the micronutrients have not yet been discovered. Some are known to be concerned with enzymes or hormones. Possibly all of them are.

(6) OCCURRENCE OF THE NUTRIENTS

Carbon dioxide and water occur in the air and soil respectively. The supply of carbon dioxide in the air is constantly being replenished by the decay of organic matter on or in the soil, and by combustion.

With the exception of nitrogen, the remaining elements occur in the soil parent material (rock, alluvium, etc.). Though nitrogen occurs in the atmosphere (4/5ths by volume), this gaseous nitrogen cannot be used by most green plants. Certain bacteria and a few algae are capable of combining gaseous nitrogen (the process is called fixation) with hydrogen or oxygen, whereby the nitrogen becomes available to plants. The organisms concerned are either

free-living in the soil (e.g. Azotobacter) or they live symbiotically in association with legumes (Rhizobia). The nitrogen-fixing algae are free-living and green and very important in some localities, e.g. rice fields.

Also, nitrogen is fixed during thunderstorms by lightning - the nitrogen combines with oxygen or water vapour to form nitrate and/or ammonia which are brought to earth in the rain.

The amount of nitrogen fixed by bacteria is determined by many factors, including the supply of the other nutrients (bacteria have mineral requirements similar to those of green plants). For example, a soil which is low in phosphate, a common condition in Australia, could be expected to be low in nitrogen also.

The remaining nutrients, derived from the parent material, occur partly in the soil solution (which is usually very dilute) or adsorbed on to colloidal particles (clay and organic matter). Certain ions, e.g. nitrate and chloride, are never adsorbed. Nitrate may occur, as such, in the soil solution or it is produced by bacterial action on organic matter (nitrification). Phosphate may likewise occur in the solution but usually it is found in combination, e.g. with clay. In some cases it is "fixed" and rendered unavailable to plants (see below).

The calcium, magnesium, potassium (and also sodium) ions are adsorbed on to colloidal particles. If ions are removed from such particles and taken in by roots they are replaced by hydrogen ions which leave the colloidal particles of the root hair. (It is for this reason that water cultures become acid.) Insoluble or sparingly soluble salts of calcium and magnesium may occur in soils and the ions are slowly available to plants.

MINERAL DEFICIENCIES

A deficiency of any one element causes a retardation or cessation of growth. Deficiency symptoms for any one element may or may not be the same for all plants. The following are some generalisations:

- I. Deficiency of nitrogen:
Stunting; yellow colour develops in leaves.
- II. Deficiency of phosphorus:
Stunting; a blue or purple colour often develops in the young stems and leaves.
- III. Deficiency of magnesium:
Chlorophyll cannot be formed - stunting and yellowing.

IV. Deficiency of iron:

Chlorophyll fails to develop - yellowing, but with little or no stunting.

V. Deficiency of potassium:

Development of yellow patches or of yellowish-grey leaf tips, or margins.

VI. Deficiency of calcium:

Retardation of growth, distortion of young leaves, leaf-margins become yellowish.

VII. Deficiency of boron:

Various symptoms:

Development of dark patches (e.g. internal cork-brown patches in apples); browning of cauliflower; splitting of stems.

VIII. Deficiency of zinc:

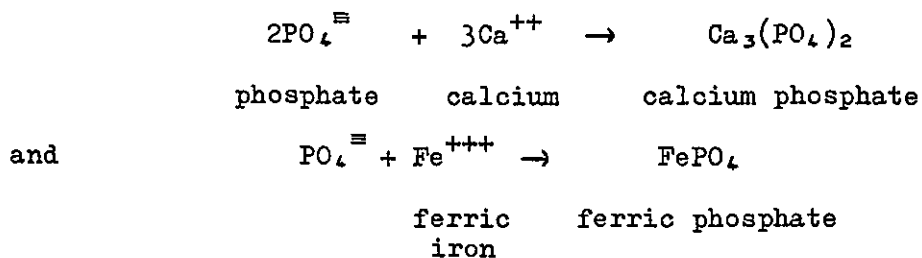
Causes "little leaf" in deciduous trees and mottling of leaves.

IX. Deficiency of manganese:

Causes chlorosis (yellowing), which is mottled (cf. iron).

(7) INTERACTION OF IONS

As far as fixation by precipitation is concerned, one of the best understood examples is the precipitation of phosphate ions by either calcium or iron, especially in alkaline or neutral solution. Thus the phosphate ion (bearing three negative charges) can be removed from the soil solution by calcium ions (bearing two positive charges) or iron (ferric) ions bearing three positive charges. The simplified reaction can be represented in chemical terms by:



Calcium and ferric phosphates are relatively insoluble and the component ions cannot be obtained by the plant.

F E R T I L I Z E R U S E

K. Spencer, B.Sc. Agr., M.S.,
Senior Research Officer, C.S.I.R.O.,
Armidale.

(1) SOME PRELIMINARY CONSIDERATIONS IN THE ADOPTION OF A FERTILIZER PROGRAMME

- (a) First, ensure that any physical properties of the soil which may be restricting plant growth, are improved as far as possible. For example, the land may require draining, or the addition of lime to reduce acidity. The more favourable the soil can be made as a physical medium for growth, the greater the benefits from fertilizer application.
- (b) A good result depends on the identification of those nutrients in short supply. This task is not too difficult as there are only 16 essential elements, and experience, experiment and analysis will tell us those nutrients most seriously lacking. Supply of the most deficient element or elements will produce the largest effects.
- (c) Certain elements may substitute to some extent for another, e.g. sodium for potassium, tungsten for molybdenum.
- (d) A certain balance between elements is desirable. An excess of one may cause direct damage or may restrict the uptake or activity of another.
- (e) There is an upper limit in the application rate. Beyond this, the economic return becomes less and further application will eventually become unprofitable.

(2) WHICH FERTILIZER?

In determining which fertilizer these considerations must be borne in mind -

- (a) It must contain the element which is in short supply.
- (b) It should have a desirable physical condition for even application.
- (c) Conditions may require a slowly soluble or a readily-soluble form.
- (d) It should not have an unfavourable effect on the physical condition of the soil, e.g. on the aggregation or on the acidity.
- (e) One of the alternative forms may be more suitable to the

particular stage of growth.

- (f) The fertilizer with the lowest cost per unit, other things being equal.

(3) HOW MUCH?

- (a) The requirements of species of plants differ; some will grow well at relatively low levels of supply, and show little response to applications of certain nutrients. Well-nodulated legumes, for example, are independent of nitrogen supply.
- (b) Depends on the frequency of application.
- (c) Depends on the order of losses anticipated. The soil may be able to fix a high proportion of that added and hold it in forms unavailable to plants, or rains may leach an appreciable amount from the root zone.
- (d) The optimum rate of application is found by experimentation. Every pound of fertilizer should be expected to pay for itself, other growing conditions being normal.
- (e) The analysis of the fertilizer.
- (f) Excess may induce deficiencies of other elements.

(4) WHEN?

- (a) This depends on the nutrient concerned. Some are more important early in growth, rather than later, e.g. phosphorous for establishment.
- (b) It also depends on the species concerned. Whether it is a leafy plant for instance. Fertilizer should be applied just prior to a period of active growth.
- (c) Soil moisture should be adequate. Rain will be necessary if the fertilizer cannot be buried.
- (d) The frequency of application will depend on the residual value of past dressings.

(5) HOW?

- (a) Methods will depend on the type of country and the machinery available.
 - (b) Drilling in bands makes the best use of small amounts of fertilizer.
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FERTILIZERS AND PASTURE MANAGEMENT

E. J. Hilder, B.Sc.(Agric.),
Senior Research Officer, C.S.I.R.O.,
Armidale.

(1) INTRODUCTION

Pastures differ considerably in different areas, both in type and in productivity. To manage these pastures effectively to get the best in animal nutrients and yet build up soil fertility efficiently usually requires some special care in fertilizing practice.

(2) DIFFERING REQUIREMENTS OF PASTURES AND CROPS

One generally associates a particular soil with various deficiencies, e.g. one soil may be deficient in phosphorous, another in sulphur or copper, etc. Deficiency may also be related to the type of plant we wish to grow. For some plants the soil may not supply enough of a certain element and yet for others it may be quite complete. This difference often occurs between crops and pastures and it results from such factors as cultivation for sowing, return of nutrients (dung and urine) through the animal, etc. Long term pastures may need more nitrogen and sulphur while crops may require more phosphorous.

(3) NUTRIENT REQUIREMENT OF PASTURES

Like other plants, the pasture plant requires various nutrient elements from the soil. Unlike a crop, however, a pasture is a mixture of species needing different proportions of these elements, e.g. grasses must have plenty of nitrogen from the soil, while legumes fix their own. Therefore pastures should be fertilized so that -

- (a) there are sufficient nutrients to provide for the bulk of material (forage) desired.
- (b) the correct botanical composition is maintained, i.e. a mixture of grasses and legumes, with weeds excluded.

(4) MAIN NUTRIENT REQUIREMENTS

Because nitrogen is required in large amounts by plant material, it is often likely to be deficient, and while crop and first year pasture requirements are met by the release of this element through cultivation, older pastures are dependent on the total soil store of it and the rate of its break down from organic matter. As the rate of breakdown cannot be accelerated to any great extent

(except by lime on very acid soils) we must increase the total supply of nitrogen by the use of legumes. Initially our fertilizer and management practices on young pastures are dominated by the need to grow a large bulk of legume material for which sulphur, phosphorus and sometimes molybdenum are required in large amounts.

Fertilizer needs of pastures will largely depend on climate as well as the soil. With good growing conditions and adequate water large fertilizer applications as well as being profitable are usually necessary to meet the growth potential of the pasture. Under drier conditions water may set the limits of growth, not other nutrients.

Management itself has an important part to play as the nutrient needs of a well managed pasture are often higher than poorly managed ones, simply because production is much greater, e.g. overgrazed and undergrazed pastures are much less productive and hence require less nutrient. The same is not true when mismanagement gives poor control over dung and urine distribution.

(5) THE EFFECTS OF RETURN OF NUTRIENTS TO PASTURE

On continuously stocked areas there is a constant stream of nutrients returning to it via the animal's dung and urine. Large quantities per animal are involved, and these are in a form that are mostly quickly available to the plant and so can be put to use again. In particular, nitrogen, phosphorus and potassium are involved, with some of them concentrated in the dung and some in the urine. Care and thought in management is often required to ensure even distribution of these highly important nutrients.

Under pasture conditions a great deal of the elements taken up by the plant is returned direct to the soil whence it originally came. However, maldistribution can occur, often with serious consequences, because the system of animal husbandry results in their over-concentration at certain points. Especially under dairying, there is a drain of nutrients away from the far paddocks towards the homestead through animal transfer and production of conserved fodder. Deficiencies of potash have occurred in this way, rather more perhaps than through the loss in the animal products themselves.

(6) ASSESSING THE NEEDS OF THE PASTURE

For most grass-legume pastures the main requirement is for superphosphate to supply the needed phosphorus and sulphur, leaving the legume to take care of the nitrogen. As a result of heavy applications, extreme clover dominance may occur in the early

years, but this will settle back more quickly to a good balance of grass and clover.

While rate of application can sometimes be judged from local experience, the only sure way of knowing is to carry out one's own trials. Leaving a strip unfertilized on each major soil type and double dressing another are rough means of assessing needs. In some areas superphosphate has good residual effects, in others it has to be applied at least annually for a number of years.

(7) METHODS OF APPLICATION

Methods of application are important in order to get full productivity from each pound of fertilizer applied. All too frequently the fertilizer is simply thrown out as quickly as possible with resulting uneven distribution. Bearing in mind a sort of "Law of Diminishing Returns", highest productivity is not obtained by uneven distribution, and this is especially true with the heavier applications.

(8) CORRECTION OF ACIDITY

In many older countries and in New Zealand heavy applications of lime are given to correct over-acidity and to increase production. Recent research has shown that some of the beneficial effects could be achieved more easily and cheaply with molybdenum application.

On the wetter soils, where clovers grow well, long periods under pasture may slightly increase the acidity, which is due to an increase in the total organic matter content.

THE USE OF NITROGENOUS FERTILISERS

E. J. Waring, B.Sc.Agr., Senior Lecturer in Agronomy, University of New England.

The prices received by Australian farmers for wool, meat and dairy products (i.e. those products other than whole milk) is not sufficient to justify provision of the bulk of the nitrogen in their foodstuffs from fertiliser.

Generally the maximum recovery of applied fertiliser nitrogen from a crop such as grass will not exceed 70-75% and may be much less.

There are certain circumstances such that the cost of fertiliser nitrogen can be recovered manyfold by "strategic" application. Indirectly, by such means as stimulating young clover growth or modifying plant associations at some time of the year; directly, by growing a crop "programmed" to fill some definite gap in the fodder supply.

The partnership between clover and bacteria is for their benefit only and need not necessarily produce forage when we want it, or the maximum amount of which the land is capable. Thus, by the use of nitrogen fertiliser a young legume pasture has been made to produce 25% more forage in spring (when needed) and return eight or tenfold the expense of $\frac{1}{2}$ cwt. sulphate of ammonia.

The balance between competing plants may be favourably affected by small applications of fertiliser. Special fodder crops (including grass) may be produced using nitrogenous fertiliser for "strategic" feeding.

The nitrogen fertilising of high cost winter fodder or irrigated crops may be at least as profitable as their cultivation under normal conditions.

Sometimes deficiencies of other elements such as Potash are revealed after nitrogen fertilising.

THE ECONOMICS OF FERTILISER USE

J. N. Lewis, B.Ec.(Syd.), M.Admin.(Harv.),
Professor of Agricultural Economics,
University of New England.

1. BASIC ECONOMIC PRINCIPLES

There are a number of economic principles especially important in deciding whether to use fertiliser and which and how much fertiliser to use. Like most of the other basic principles in economics these merely summarize common sense and observation. They are, however, easier to state than to apply.

- (a) Law of Diminishing Returns - Beyond a certain point successive increments of fertiliser to land add less to yield.
- (b) The Added Costs - Added Returns Principle (the economic corollary of diminishing returns) - Applications of fertiliser will be profitable as long as the added return is greater than the additional costs.
- (c) Opportunity Costs - Many men on the land, however, do not have unlimited capital and it will not be economic for them to use fertiliser up to this point. Where capital is short the guiding principle is to fertilise so long as a £ spent on fertiliser returns more than a £ spent elsewhere.
- (d) The Substitution Principle - Costs can be lowered by substituting one fertiliser for another (or fertiliser for some other input) while the ratio

$$\frac{\text{price of the new fertiliser}}{\text{price of the fertiliser (input) replaced}}$$

is less than the ratio

$$\frac{\text{quantity of the fertiliser replaced}}{\text{quantity of the new fertiliser required}}$$

As an example, let us ignore any special advantage of different fertilisers in particular circumstances (e.g. effects on soil acidity) and consider only the nitrogen content. Nitrate of soda has a content of only 16% and ammonia sulphate 21%. It will pay to replace nitrate of soda with sulphate of ammonia whenever the price of the latter is less than 21/16 of the price of nitrate of soda. Or it will pay to substitute urea (N content 46%) for sulphate of ammonia if a ton of urea costs less than 46/21 of the price per ton of sulphate of ammonia.

2. ECONOMIZING PRINCIPLES IN PRACTICE

- (i) Assessing Costs - In computing the costs of fertiliser applications it will be necessary to provide for machinery and fuel expenses incurred in spreading it. Even for very light applications the machinery has to cover the ground, hence the cost of applying the second 20 lbs. may be less than the cost of the first 20 lbs. of fertiliser. Labour costs represent a special category. In valuing family labour the appropriate value to be imputed is not necessarily the going wage but should be related to the opportunity cost, that is to say the value of the labour employed in alternative tasks.
- (ii) Assessing Returns - One source of information is experimental data. Careful interpretation is needed because of differences in results with differences in soils, in other environmental factors and in other farm practices. Moreover assessment is complicated by the following factors:-
 - (a) effects of risk and uncertainty - Yield responses to fertilisers are considerably influenced by seasonal conditions. Producers may wish to work on a lower yield than might be expected in a normal year to avoid loss of working capital in the event of a poor season or a decline in prices received.
 - (b) residual returns - Responses in the form of higher yields do not absorb the whole of the essential elements added to the soil in fertilisers. Especially with superphosphate there will usually be a considerable residual effect on later crops and on the nutrient status of the soil. If this is not taken into account less than optimum rates of fertiliser may be applied. For the same reason optimum rates for sharefarmers or tenant farmers may differ from that for owner operators.
 - (c) experimental data often available for a limited range of inputs - Often yield responses are only measured for a few rates of application and interpolation may be necessary to assess the return from other rates of usage.
- (iii) When to Apply Fertiliser - The same principles guide decisions on time of application of fertiliser, whether to apply a heavy dressing at sowing or a lighter initial rate plus one or more supplementary applications. The risk

factor, distribution costs, leaching or fixation and seasonal commitments for other work are relevant considerations. Also important, of course, is the possibility of influencing seasonal growth pattern of plants or composition of pastures by use of fertilisers at the right time.

- (iv) Economies in Freight and Distribution Costs - Freight and cartage, storage and handling costs amount to a substantial proportion of total fertiliser costs. Simple economies such as direct transfer of fertiliser from railway siding to the land are not always practicable, however, in view of difficulties of securing supplies just when required.

In the U.S.A. the desire to avoid paying heavy freights on a high proportion of relatively inert material has given impetus to the development of concentrated commercial fertilisers such as triple superphosphate. There may in the future be some benefit in a similar trend in Australia, particularly with the development of aerial topdressing techniques.

- (v) Substitution between Fertilisers - About half of superphosphate is gypsum. Some years of superphosphate applications may build up phosphorus content of soil to the point where response obtained is due mainly to the sulphur content. If this stage is reached, it will pay to apply sulphur in the cheaper form of gypsum.
- (vi) Standard Recommended Rates of Fertiliser Usage - An important conclusion emerging from the above principles is that the most profitable rate of usage depends on prices of fertiliser and of the commodities produced. If wool or wheat prices are high it will pay to use more fertiliser on pastures or on the wheat crop. Standard recommended rates of application, e.g. 1 cwt. to the acre, will be correct only for one particular set of price relationships.

3. FERTILISERS AND AGRICULTURAL POLICY

Fertiliser subsidies are used in many countries and have a useful role in encouraging agricultural development. They can make a positive contribution to the efficiency of resource use from the national point of view, if they overcome tendencies to use too little fertiliser resulting from effects of risk and uncertainty, or if they promote more rapid adoption of a new technique such as

pasture improvement. The superphosphate subsidy was discontinued in Australia. This made sense in a period when supplies were short. However, there are now several factors supporting re-establishment of the subsidy:-

- (a) Evidence of under usage to which credit restrictions may have contributed.
 - (b) Should primary producers have to bear the costs of government policy of encouraging the use of indigenous sulphur-bearing materials in sulphuric acid manufacture?
 - (c) The possible contribution to achieving equilibrium in the balance of payments.
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EROSION AND CONSERVATION

E. W. R. Thorpe, B.Sc.,
Senior Lecturer in Geography,
University of New England.

Hordes of gullies now remind us,
We should build our lands to stay;
And departing leave behind us,
Fields that have not washed away.
Then when our boys assume the mortgage
On the land that's had our toil,
They'll not have to ask the question,
"Here's the farm, but where's the soil?"

Anonymous

1. THE EROSION POSITION IN NEW SOUTH WALES

The erosion survey of coastal, tableland, slopes and nearer plains areas of New South Wales discloses that, after little over 100 years of occupation, the soils of nearly half of the area had been affected to greater or lesser degree by accelerating erosion. This is even more important when we consider that these regions support virtually the whole of the State's agricultural and 90% of the livestock activities. Just over 1700 square miles was found to be suffering from such severe gully or wind erosion as to be labelled 'beyond economic reclamation'.

For comparative purposes the number of acres treated by mechanical means in the last 15-20 years could be given, but this is a relatively poor measure of soil conservation progress. Mechanically developed structures usually tackle one soil conservation problem, namely the preservation of the physical soil mass. In the total assessment, soil conservation problems seldom occur singly and the problem of retaining the soil mass is usually inter-related with problems of soil improvement, soil reclamation and land use practices.

2. HOW RAINFALL AND RUN OFF WORK IN EROSION

Three processes summarise the action of rainfall and run off in eroding the soil:

- (a) The role of the first process in raindrop action in preparing the soil particles for transportation is often underestimated. Raindrop action plays its part in a number of ways. Firstly, splash action during a rainstorm can be likened to the dropping of hundreds of thousands of tiny bombs, each acting to shatter clods, lift particles and drop them back again, and create turbulence in water

covering the surface. Secondly, rain acts to detach and disperse soil particles - the extent, depending on the force of the rain, the cohesion of the soil and the amount of protective covering provided. Thirdly, the impact of raindrops produces puddling and sealing of the surface soil. This reduces the amount of water infiltrating into the soil and in turn increases the amount available for run off.

Raindrop action, in initiating erosion, can be reduced only by providing a protective cover to the soil to intercept the drops and absorb their energy before they hit the soil. In this regard, the amount of cover is more important than the kind of cover.

- (b) The second process, transportation of soil particles, is limited by the energy available and the amount of soil in a transportable condition. The process commences when the rate of rainfall exceeds the intake capacities of the soils, and for each storm there is a set duration which will produce maximum run off. The calculation of this time interval is important in the design of terrace banks. Two broad forms of run off are evident; sheet flow in shallow layers of water and flow in channels of varying sizes and state of definition. The erosive capacity of running water is affected by a number of items including slope, soil type and structure, vegetation cover.

In summary, rainfall is most important in detaching soil and run off in transporting soil. They can play their parts in erosion separately but produce maximum erosion where they work together.

- (c) In erosion the third process, deposition, is the result of the second and when such deposition occurs on unwanted places and on unwanted soil materials it represents a major erosion damage. It is important to evaluate these two sides to destructive erosion - damage at the point of removal and at the point of deposition. Even with mechanical control structures, some run off and deposition occurs.

3. PROTECTION FROM EROSION

Protection involves breaking down the foregoing forces by natural or mechanical means. The design of a sound conservation policy proceeds in three stages:

- (a) diagnosis of the problem by survey and research in the area
- (b) curative measures
- (c) preventative measures

Survey for soil conservation is much more than the mapping of kinds, severity and the distribution of erosion; in addition, studies of climate, hydrology and nature of soils must be made.

The soil erosion map indicates conditions at the particular time, and as such has no permanent value; the hydrological studies suggest a break up of the area into suitable units for control, while the climatic and land use studies provide additional information.

The survey states the problem and the next steps are the reclamation of damaged land and the prevention of further damage. Engineering structures are most important in the first of these stages, but more and more the prevention of further erosion is realised as a function of land use practices within the local catchment area.
