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SOIL EROSION IN SOUTH AFRICA

by

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SOIL EROSION IN SOUTH AFRICA

P.H.Kitto

Introduction

The developement of Soil Science in western Europe, eastern North America, and later in other countries, which in its modern form only started about the beginning of the last century, might be said to mark the first step in the consideration of Soil Erosion from a scientific aspect, although it was some time before scientists began to concentrate on and study the problem as one which demanded a detailed investigation.

Empirically, erosion has been noted and, where the value of the land warranted it, practical methods adopted for its control, in many cases with no small measure of success, for centuries, but the methods adopted were localised to small regions, and the major destruction went on unchecked. The seriousness of this destruction was usually not realised until too late, and striking examples exist of the complete desiccation resulting from this neglect. Those of China, Arabia, Mesopotamia and other countries have often been quoted, and need not be described again here.

One might think that these countries would have been sufficient evidence to make later generations profit by the unfortunate experience of once prosperous nations,

but such is not the case, and even comparatively lately America has undergone, to a lesser degree, many of the processes which tend to make a land uninhabitable. There has always been a very small minority, who, either through being brought into immediate contact with the problem or because they have clearer vision than most, have realised what was happening and tried to make the community as a whole, and the state, take the necessary action, but, notwithstanding the examples already given, their attempts were until recently largely wasted.

For reasons which will be given later it will be seen that, generally speaking, erosion only becomes serious when the population increases above a certain limit depending on the nature of the country and the climatic conditions. With increase of population agriculture must obviously become more intensive, and through ignorance and carelessness erosion then increases also. Eventually the land becomes too poor to support this population, and the numbers must of necessity decline. This is what changed Arabia from a prosperous country into a semi-desert thinly peopled by nomadic tribes, and there is no reason to believe that a similar process might not take place today if conditions were suitable. In fact examples of such a decrease in modern times are to be found in

America and even in South Africa. In the final report of the Drought Investigation Committee (1923) it was concluded that the decline of European population and small stock in more than thirty Midland districts of the Cape Province is directly due to the increased soil erosion. Before proceeding further it would be as well to consider erosion itself in a little more detail. To the geologist the term is very general, including all the process of rock destruction and removal. Of the three major divisions of the rocks forming the earth— igneous, sedimentary and metamorphic — the sedimentary cover by far the largest portion of the earth's surface, and were formed as a result of erosion and subsequent reconsolidation of previous rocks, all of which were originally igneous in character.

We see that the process is quite natural and took place long before the earth was inhabited at all, but in nature an equilibrium exists between climate, topography, flora and fauna, and water supply, and the total effect in many places is such that the material removed by denudation is more or less equalised by that formed by weathering and from vegetation. If man disturbs this normal balance, however, the erosion is liable to become very serious, andthe results are often disastrous. In a fertile country with few inhabitants "shifting cultivation" is very often practised, and the agriculture that takes place

does not upset the equilibrium to any great degree, but with a denser population the area of land under cultivation or used for grazing purposes is proportionally larger, and bad farming may result in very serious damage to the country as a whole.

The usual idea of erosion is that of the visible destruction that takes place when suitable precautions are not taken.

The only two important agents which bring about erosion, as such, are water, in some form or other, and wind, and the work which they perform in nature is profoundly influenced by the diastrophic movements of the earth's crust i.e. the effects they produce will vary in accordance with the elevation, subsidence, or stationary character of the region, elevation favouring denudation and subsidence favouring deposition of transported material.

Water Erosion

Water in the form of rain is the primary agent at work, and the nature of the rainfall — light or heavy — has a most profound effect on the rapidity with which surface material is removed. Its action is both chemical and mechanical, and is greatly influenced by climatic factors.

The damage done by the rivers themselves is not nearly so great as that caused by the immediate run-off from a heavy rain, but is often much more spectacular.

The first effect of denudation on a recently uplifted surface is an increasingly irregular surface; then, as the streams cut deeper and deeper into their channels the slope becomes less steep, and as long as the region is neither uplifted nor depressed vertical erosion takes place at a constantly decreasing rate. Eventually a stage must be reached when the vertical cutting will cease, and the river is said to have reached the base level of erosion. If the country is elevated of course the process starts again and continues until a new base level is reached. After this lateral cutting takes place until a flat gently-rolling surface is produced, the base level of erosion of that region.

Pure water has very little abrasive action on rock, but may remove loose material, and it is this loose material carried by the water which cuts so rapidly into the surface. The capacity of water for abrasion varies in a geometrical ratio with the sediment carried. It is not generally realised what an important effect the nature of the underlying rock has in determining the amount of run-off from a surface and consequently the amount of surface that will be removed. Run-off occurs when the surface soil has become saturated,and apart from the soil itself other factors come into play in determining how

much water is necessary to saturate it. The extreme case is given by limestone regions, which are characterised by the small number of surface streams, most of which disappear underground through channels dissolved out of the limestone.

Dolomite is a relatively porous rock, and in the large dolomite areas of the Transvaal the run-off is small and erosion very slight. Granite on the other hand, is relatively impervious, and the surface soil is inclined to wash off, leaving large areas of bare rock exposed. Examples occur at Paarl in the Cape Province.

The joints and cracks and the angle of dip of the rock strata are also important in determining the amount of water which will be absorbed by the rock. The physical nature of the soil has, of course, the greatest effect on the run-off from a particular rainfall, and this will be considered in more detail later.

Apart from rain and rivers, water in other forms is active in causing erosion, though not to such an extent. Researches during the last 15 - 20 years have accumulated a mass of evidence supporting the view that glaciers, are efficient agents in this respect. Materials carried by the glaciers, which when deposited are known as moraines, as well as the glaciers themselves, have a powerful scouring action. Abundant evidence of this action may be seen in present glacier regions and in

countries such as portions of North America and Europe which were once covered by ice-sheets.

Snow also has an effect as avalanches or from the run-off occurring when it melts, but in the latter case the volume of water is not sufficient to be very serious except in extreme cases.

In countries like South Africa where the snow is limited to comparatively small areas of mountainous country it is only when a dry wind or sudden rise of temperature occurs after a heavy fall of snow and the subsequent run-off flows over land denuded of its vegetation that the result is at all bad. In this respect it might be noted that the dry wind is apt to cause more rapid run-off, because ordinarily the sun is without appreciable effect on the melting snow and ice, and rapid melting only occurs when the rays first impinge on some other substance which warms them up and then by conduction thaws the snow.

The sea is also an erosive agent, as are lakes to some extent, but not of sufficient seriousness to warrant much attention, in South Africa at any rate.

In dealing with water erosion there are two definite stages between which we must differentiate. The first is the removal of material from the surface layer (and perhaps the lower layers) by running wwater, influenced very largely, apart from other major factors, by the

slope of the ground, because the slope of the ground determines its velocity. Some of the material is carried in suspension, while some is merely rolled along the bottom or proceeds by "saltation" i.e. by short skips and leaps. The amount moving in this way is larger than might be expected, because it is very difficult to measure.

The second stage is the deposition or non-deposition of this material when the water reaches more level ground, and its rate of flow diminishes. Naturally the particles rolling alongthe bottom or proceeding by saltation will come to rest, but the important consideration is whether the suspended material will be deposited, either partially or completely. This aspect is very serious, because the portion remaining in suspension will be the finer grained particles and colloidal material containing most of the more fertile portion of the soil. Apart from soluble matter in the water — which is the important controlling factor at this stage — most of the reserve plant food and material keeping the soil in good physical condition is contained in this finer portion, and the problem is one which is of particular importance in this country. It will be considered in more detail when the colloid portion of the soil is discussed.

Wind Erosion

In arid and semi-arid regions this can be very destructive, and as in the case of water it is the material carried which does the damage, the greatest effect being near the ground where the particles are larger. Loess is a soil which has been deposited after being carried by the wind, and the huge loess deposits of China, for example, are supposed to be due mainly to the dust blown from Central Asian deserts. The terrific dust storms that arise periodically in the United States in the Great Plains area, and which have been particularly severe during the past few years, show the enormous damage that can be caused by the action of the wind on unprotected soils. In South Africa transported sands and semi-arid soils cover larger areas than any other types, and the effect of wind on such soils can readily be imagined. A vast area in and around the Kalahari consists of red or greyish transported infertile sands, while the same type occurs in the localities bordering the Karroo. The worst effects are produced on high lands and where vegetation, particularly trees, is scarce, and the amount of erosion depends on the velocity of the wind and the type of soil. The smaller the particle and the more powdery the soil the more easily it will be transported. Hence we

often have a sorting out of material, the coarser the gravel and stones remaining behind as "desert pavement" — and hence also the "growth" of stones in certain sandy areas.

EROSION IN SOUTH AFRICA

Of the two main types of erosion, gully and sheet, the most noticeable effect is produced by the gullies, which may rapidly turn into huge dongas, but the most widespread damage is that caused by sheet erosion. Gully erosion does not affect the same huge areas, and it is probable that the amount of land directly ruined by it is not of such consequence as the lowering of the water table it may cause over larger areas. It is obvious that if this happens large tracts of valuable land may eventually turn into unproductive and barren veld.

Sheet erosion is very often unsuspected even by those farmers directly concerned, because though the surface layer containing nearly all the fertile portion of the soil is gradually being removed the result may only be noticeable in the slow deterioration of the vegetative cover.

In South Africa both these types are extensive, and owing to the nature of the country itself very difficult to combat. Geologically it is a young country, and a long continued uplift has occurred, resulting in a very high mean altitude. Not less than 51 per cent of the Union lies between 3 and 5 thousand feet in height. Consequently we have rapidly

flowing rivers, many of them dry for the major portion of the year and none being navigable, and there are very few alluvial plains of any size.

Unfortunately our climate is such that erosion when started tends, in most regions, to be aggravated. South Africa is situated largely within the dry anticyclonic zone of the earth, and though a strip in the south and west has its rain dominantly in winter the remainder is principally in the summer in the form of thunderstorms. The coastal belt has a far less erratic rainfall than further inland, because the moisture laden winds blowing from the sea strike the mountain belt extending round the coast and most of the moisture is precipitated. In the higher altitude of low humidity and comparatively flat topography beyond the ranges what water vapour does pass over has little tendency to be deposited, and the rain is consequently somewhat spasmodic in its occurrence.

It has been asserted by many people that the rainfall is declining and the country "drying up", but while meteorological records show that there has been a slight though definite decrease in our total rainfall during the past half century, this is almost certainly only a secular variation, and as such will right itself in the course of time. The idea that the distribution and character of the rainfall has in certain areas changed for the worse does not seem to be

supported by the meteorological data so far collected, but that its beneficial effects have in many cases diminished cannot be doubted.

Of that portion of Africa below the 17th parallel, 33% is covered by Kalahari sand, bare mountain ranges cover large portions of Namaqualand, the Southern Cape, and parts of Griqualand West and the Transvaal, while of the remainder much is semi-arid, so that plainly the amount of land available for profitable use is small.

On the whole South African soils are deficient in humus, which has important qualities in binding a soil and increasing its resistance towards erosion. This deficiency is due to the low and unevenly occurring rainfall combined with a high temperature, the scanty vegetation and destruction of this vegetation by fires, andthe excess of substances such as calcium carbonate or iron oxide in the soil.

Conditions being so favourable, it is not surprising that in places where erosion has started it has rapidly assumed alarming proportions.

It is extensive in and around Basutoland, in Northern Natal, the Transkei and parts of the Karroo, between Aberdeen and Kingwilliamstown, many of the river valleys, and at particular localities like Chunespoort, Transvaal.

Advanced erosion has also taken place in portions of Bathurst, Peddie, Albany and the Addo watershed, and the whole of the Fish and Sundays River Watersheds, as well as further north beyond the borders of the Union.

At first sight it would appear that as the land east and south of the mountainous belt is so much steeper the tendency to erode would be very much greater, but a little consideration shows why this is not so. The rainfall nearer the coast, as has been stated, is much more evenly distributed throughout the year and less inclined to be torrential, besides being generally higher, and the result is a very much denser vegetation. As vegetation is the most effective guard against erosion it is only where this has been removed that the position becomes serious. The lime-containing sweet-veld in the regions of high temperature and less even rainfall east of the mountains shows very bad erosion in places like the Mid-Tugela valley or the Fish River, and here conditions are rather like the Karroo. Otherwise the ability of natural vegetation to reestablish itself when once removed is of course much greater in the coastal belt. If erosion once gets the upper hand, however, it spreads very rapidly.

On the high land beyond the ranges the destruction is

much more extensive and difficult to control and as the land is notso valuable farmers are still less inclined to spend money on costly reclamation schemes.

The Effects

So much has been written from time to time about the damage caused by erosion that it will only be necessary to discuss the subject briefly here. Firstly there is the removal of the richest part of the soil, with all its attendant evils. Rainwash removes plant food even if there is no erosion,but this can be restored, if economically possible, in the form of fertilizers, soil-improving crops or similar means. The soil can only be restored, practically speaking, by the exceedingly slow natural processes and with these months or even years might haveto elapse before the material removed in a single heavy rain could be replaced.

Not only does this cause irreparable damage to that particular area but it may also silt over adjoining lands and ruin them, The harm done to public works such as roads or railways may be very considerable. The question of the silting of reservoirs is one which has received a great deal of attention, but there is no satisfactory method, as far as the engineer is concerned, of overcoming the difficulty except the temporary ones of making allowance, where this is possible

for raising the height of the wall when the storage capacity becomes insufficient, or building "trap" dams to catch the silt. The effective lives of many of our largest reservoirs and the irrigation schemes connected with them have been reduced far more than was ever anticipated owing to the increase in the amount of solid material deposited each year. This is definite proof that erosion is on the increase in the catchment areas concerned.

It has already been pointed out that the worst effect of gullies and dongas is the lowering of the water table they produce, whereby the ground water is made less available to plants and the difficulties and expense of obtaining supplies by boring is increased.

The decrease in vegetation which results from erosion of any type means a decrease in the efficiency of the watershed in maintaining a permanent flow of irrigation water, quite apart from the increased silt content of the run-off, because of the effectiveness of a vegetative cover in retaining moisture in the soil and enabling very much larger quantities to be absorbed, besides reducing the velocity of the excess water and retaining silt and suspended matter.

At one time the idea existed amongst certain farmers particularly in America, that by decreasing the density of the

vegetation more water would be made available for irrigation, because the water which is transpired by the plants would be utilised. This is true to the extent that when the rains occur there will be more immediate surface run-off, but less water will be preserved, and later on when the land is seriously in need of moisture there will be a shortage. The water holding capacity of a soil is roughly in proportion to the amount of organic matter it contains, and as it is not generally possible to utilise all the run-off from a heavy rain this will be wasted, and the subsequent period of stream flow shorter.

The Causes.

South Africa, as has been emphasized (vide supra) is climatically and physiographically favourable towards erosion but even here it is only when natural conditions have been disturbed that it has become a serious menace. There are various agencies at work all the time in Nature resulting in the weathering, denudation, transportation and deposition of rock material, this being normally a slow process. The rate, however, may increase or diminish from year to year with climatic variation. Drought, by which we mean a period during which abnormally dry conditions prevail, results in increase in wind erosion, and with the rains, usually more inclined to be torrential following such a period, increased water erosion.

Besides the natural agents previously mentioned, it must be remembered that lightning, which is perhaps more serious in this country than any other, may cause veld fires resulting in depletion of vegetation and consequently increase in erosive tendency.

When we turn to what T.R.Sim (1) calls biotic causes, i.e. "the reactions under the influence of vegetable and animal life, and especially of man", we find that almost without exception they are concerned in some way or other with the removal of vegetation. This acts as a protective covering to the soil, guarding against the detrimental effect of excessive heat, wind or rain. It keeps the ground temperature lower and hence reduces surface evaporation, while it also protects against frost. The humus formed from the decay of this covering, the roots of the plants and their chemical action all help to keep the soil in good condition and a stable state.

An examination of the land available in South Africa for farming purposes shows that this is mainly a pastoral country, and as a result the practice of overstocking, unfortunately so prevalent in many parts, is one of the main causes in the reduction or retrogression of the natural vegetation. Much of the ranching country in the Northern Transvaal, the Rustenberg bushveld, the Waterberg, Springbok Flats and the thornveld of Natal has been materially ruined by overgrazing, while examples areto be found in practically every stock producing region in the Union.

A farm which in a good year can support the stock on it without deterioration must nevertheless be considered as overstocked unless during the bad seasons sufficient additional feed is given such that the veld suffers no harm from the stock it is carrying.

The carrying capacity of many farms which must be considered as overstocked could be maintained at their present level if more use was made of the system of camping or rotational grazing. Grazing at periods of critical growth of the grass or bushveld means that the young plants never reach maturity and consequently never get a chance to seed. If different parts of the farm could be rested to enable the vegetation to spread the veld in many cases would not deteriorate as it now does. It has also been proved by analysis that, contrary to expectation, young grasses. though perhaps more succulent on account of higher water content, have not nearly the food value of the more mature growth.

Accompanying this deterioration there is usually the damage caused by the increase in veld-tramping and the kraaling of stock, often necessary for protective purposes if the farm is insufficiently fenced and especially serious in the former case if the number of drinking places is limited.

An important agent in the destruction of vegetation is veld burning about which a tremendous controversy has been, and still is to a certain extent, raging. There can be no doubt that on some farms it is necessary to do this if the veld is to be maintained in a condition suitable for stock, but from the point of view of the country as a whole it is a bad practice. It should definitely be prohibited as far as possible in catchment or other areas where the welfare of the whole community is concerned. Fortunately the custom is not so prevalent today as it was some years ago and is decreasing yearly, but there are still parts where indiscriminate burning takes place, and here it is to be hoped that measures of control will be adopted. In the Waterberg Mountains, the Eastern Transvaal, the Northern Free State, the Highlands of Natal and the South eastern and South western portions of the Cape veld and mountain burning still continues. To quote an example from America, it has been stated (2) that in California alone fires have completely or partially devastated more than 981,000 acres of forest, bush and grassland, so that the increase in rainfall run-off can be imagined.

Many districts have been completely cleared of valuable indigenous forest growth by excessive bush cutting, and here again the practice still continues, though with some measure

of control. With the scientific exploitation practised by the South African Government an area is closed for 40 years after its mature growth has been removed, but with indigenous species this is too short a time to allow of full recovery. Faster-growing, imported species, however, do not suffer under this treatment.

Agriculture always tends to make land more liable to erode, but it must be remembered that good farming should prevent or lessen soil erosion, not increase it. The abandonment of old lands is causing rapid deterioration of some parts, and in the winter rainfall areas, especially in the wheat lands of Malmesbury and Piquetberg, allowing lands to lie fallow during the rainy season is, according to Dr. Viljoen, the chief cause of the erosion there.

Roads and railways are often responsible for concentrating water in ditches alongside, and eventually this water has to be turned out to one side or the other. Adequate provision for spreading it so that its effect may be beneficial instead of harmful is usually not made, perhaps in most cases through lack of funds, and the adjoining farm lands have to suffer in consequence. In addition, the mere action of clearing the vegetation to make them is sufficient on some slopes to start incipient erosion.

Mining has also caused some damage for the same reason, but as it does not usually occur in an agricultural area the immediate effect is not so serious.

Finally must be mentioned the introduction either intentionally or by accident of plants and animals or insects which have had a deleterious effect on the natural and cultivated species. For example the danger of prickly pear or other undesirable aliens to the soil itself is that on removal they leave portions of land in an unprotected state before natural growth can reestablish itself. Insect pests of course do a lot of damage to crops and so indirectly to the soil, and many of them have been introduced with imported species.

Remedies and Preventive Methods Adopted

The destructive action of soil erosion being a cumulative one, it follows that the sooner remedial measures are applied the more effective and less costly they will be. It is far easier to prevent it by taking reasonable precautions, especially in the case of agriculture, than to stop it when once started, even though in the early stages this is a comparatively easy process.

The key to any type of treatment is the maintenance of the normal balance between the soil and its cover, together with slope and water supply. Of these four the most susceptible of control is the soil, and the maintenance of the soil in good physical condition is the all important factor in lessening the tendency to erode and enabling

whatever is growing on it to develope to the fullest extent. In a soil it is desirable to have particles of variable grain size, organic and inorganic, with a flocculation tendency, the last being dependent on chemical factors and of the utmost importance. We try to bring this about in agriculture either by mechanical or chemical means or both. The former includes all types and methods of tillage and drainage, and the latter all methods of fertilizing.

Mulching is the addition of surface litter of some sort, dust mulching being the essential feature of "dry farming". It is most effective in regions of sub-irrigation like the Great Plains of America, and has been employed for centuries in Arabia and Egypt. Fertilizers and their action on the soil have been made the subject of detailed study for many years now, but it is still impossible to predict with certainty what effect they will have. In some cases the deterioration in physical condition more than counter - balances the extra supply of plant food.

The distinction between ordinary weathered rock material and what we term a "soil" lies in the organic material contained by the latter, or, more particularly, its humus content, by which we mean the amount of decomposed organic matter which has lost its original form and become colloidal in character.

It is in the organic portion, decomposed and undecomposed, that the microbiological processes of the soil take place, and it is essential that this portion be maintained at a sufficient level for this purpose and for retaining a good physical condition. It is reported by G.W.Robinson (3) that even on the steepest Welsh hillsides in cultivation erosion is imperceptible, probably because of the high proportion of organic matter in the soil.

The level may be maintained by adding matter either already in an advanced stage of decomposition (manuring), or in a fresh,green condition (green-manuring) in which case a crop is usually allowed to grow on a piece of land for the sole purpose of being ploughed under. If present in as much as 15 to 20 per cent the effect of organic matter may be to obliterate the distinction between different types of soil, or, on the other hand, the mineral composition of two soils may be the same out their fertility very different.

The condition of the soil is largely dependent on the vegetation growing on it, which also acts as a protection, promotes water circulation and enriches it. In guarding against erosion the method of planting with relation to the slope is very important, for to plant in rows down a slope would be fatal. The remedies are concerned, or should be concerned, with the usefulness of the cover to mankind, and

include tree planting, especially on lands too steep for stability on field or pasture, grassing of the land is gently rolling, nurse-cropping, i.e. shielding the young plants with others, and cover-cropping (e.g. grass planted in orchards) where the water supply is abundant.

A series of articles on the planting of trees for special purposes occurred in "Farming in South Africa" during 1935, written by J.J.Voorendyk of the Division of Forest management, and giving valuable information about their utility.

As this country is mainly pastoral it is the natural cover which should be protected and improved, chiefly by the regulation of grazing and, if possible, seeding with grass of a suitable type. A point to remember is that it is sometimes an advantage to graze with cattle rather than sheep, which cause more damage to the cover by trampling and in their method of feeding. Goats are even worse than sheep in this respect.

Innumerable methods have been tried for stopping further destruction and encouraging silting in dongas and gullies, the success or otherwise depending largely on local conditions Hardy plants like American aloes and spiniless prickly pear, both useful as supplementary stock food, various acacias and different types of bush, trees and grass have been grown in dongas, round the sides or across the drainage

lines, sometimes protected from stock by fences or helped by stone and wire dams. Descriptions of nearly all these methods have appeared in Government publications from time to time.

If the cover is removed or has degenerated most slopes are unable to fulfill their normal function of removing excess of rainfall without erosion beginning.

When this occurs the run-off must be regulated or prevented by contouring, or terracing where the slope is too steep for contouring. This may be done either quickly by engineering methods if the land is sufficiently valuable, or slowly, the farmer merely starting by laying out the terrace system and the reconstruction gradually following. Methods such as these have of necessity been practised in China, Japan, the Phillipines and other countries for generations.

When cultivation becomes as intensive as in Europe the soil may be protected by grading the slope, vineyarding, retain-walling or similar means. On long slopes forestation if practicable is the best method.

The last of the four factors to be considered in the prevention of soil erosion is that of water supply. The regulation of this, as has been described, is very much interconnected with the slope of the ground. One of the chief drawbacks in South Africa in connection with irrigation

is the general steepness of the gradients, whereby the difficulties of storage and the distribution of water are increased. Owing to the long distances the water has to be conveyed evaporation becomes an important factor, and the surface area of dams and canals must be made as small as possible, i.e. the depth must be increased as much as the locality and economy will allow.

The Drought Investigation Commission reported in 1923 that the development of Irrigation in South Africa was definitely limited to 1% of the total area, and that even then the catchment areas were suffering owing to deterioration in cover and to soil erosion. Since then an immense amount of development has taken place but the question of the catchment areas has not yet been effectively tackled. Lake Mentz in the Sundays River valley, for example, completed in 1922, is said to have now only half the storage capacity it had then, due to silting from the soil eroded areas of Pearston and Jansenville.

Realising the gravity of the situation, and that the protection of catchment areas is a matter of national importance, the Government decided last year, (1935) on a far-reaching policy for carrying out investigations entailing topographical hydrographical, aerial, botanical and soil surveys of the most important catchment areas of the Union. They may also ultimately proclaim "natural reclamation" and "national erosion control areas". Immediate work is being undertaken on the watersheds of the Tugela river in Natal,

including the establishment of a forestry settlement for the purpose of afforestation, anti-soil erosion works using unemployed, pasture research, veld improvement, and control of grazing and veld burning, with the co-operation of private owners. The experience gained on this scheme will determine to a large extent the future policy of the Government.

Another important source of water on South African farms is that of boreholes. It has been said that these lower the water table, but it is doubtful whether this does happen except perhaps locally if they are too numerous. There can be no doubt as to the immense value they have been in the cultivation of land previously of little use for anything.

Although the Government is only now taking action on a large scale in connection with anti-soilerosion works, the need for this action has long been known, and it is the sound financial position of the country at present which has enabled such large sums to be granted for the establishment of the different schemes. The Forest Bill of 1913 makes allowance for the expropiation of areas so eroded or sand-blown that they become a menace to the country and its inhabitants, but has not found practical application. In 1914 the Senate Select Committee advised the Government that instruction about erosion should be given in Agricultural Colleges, public schools, and to chiefs and headmen in native territories, while in 1918 the Soil Erosion Committee,

appointed by the Natal Provincial Council in 1917, recommended along similar lines, and advocated the publication of a condensed brochure on afforestation and an educational propaganda through the Press.

The reports of the Drought Investigation Committee in 1920 and 1923 gave detailed information and advice on this and other related subjects.

The Department of Agriculture is now taking active steps to combat soil erosion and reclaim, as far as possible, wasted areas, and to this end has engaged the help of the officers of various Government Departments, Provincial Administrations and Public bodies, as well as the land-owners. Questionnaires have been issued to the farmers, who are requested to fill them in, supplying details of erosion occurring on their farm, and forward them to the Department of Agriculture. In this way an immense amount of detail is being collected on the actual destruction that is taking place.

1933 saw the commencement of the nation-wide schemes for reclamation and improvement of these areas. Encouragement was given to private land-owners in the form of subsidies, and useful information and advice supplied by local officers.

Owing to the satisfactory headway already made these facilities have recently been extended and improved. A bonus of 25% is allowed on a maximum of £350 for each farm and £250 per dam with regard to anti-erosion works. If unemployed Europeans are used the State is prepared to pay

seven-eighths of their wages, the remaining one eighth to be paid by the land-owner after the work is completed, or the relative amount registered against his title deeds. Full details are available from the local magistrates.

The Department of Irrigation has also started a dam - building scheme, whereby a subsidy of 25% is paid on dams built of value more than £250 to a maximum of £500 per dam.

The enormous number of applications already received, particularly in the Cape, testifies as to the popularity of this work with the farmers themselves.

A point raised by the Drought Investigation Committee in 1923 is the need for the provision of cheaper fencing material, for if the veld is to be improved it is essential that farms be subdivided into camps more than they have been until now. It is to be hoped that the recent establishment of and Iron and Steel Works in this country will help to remedy the position.

A Comparison with Erosion in America and Preventive Methods there.

As far back as 1909 the National Conservation Committee (4) reported that in North America 16,097 sq. miles of farmland had been abandoned, and 6,076 sq. miles, or .2% of the entire area of mainland United States devastated by soil erosion and the amount has increased considerably since that date.

Extensive erosion has taken place in the rolling parts of the highland rim country over much of the Piedmont region, many parts of the Appalachian Plateau and the South of the Appalachian valley, the uplands bordering the Mississipi and Missouri Rivers and their tributaries, the black lands of Texas, while even the drier lands of the West and the comparatively smooth prairies and plains of the North Central States have not escaped damage. Since the clearing of the sloping and rolling areas and the destruction of the virgin sod in these northern states much costly washing, especially of the sheet erosion type, has taken place in Missouri, Iowa, Nebraska, Illinois, Indiana, Ohio, Wisconsin and other States.

In 1891 a law was passed stating that the President could reserve tracts of public land covered with forest or bushwhether the wood was commercially valuable or not. A quarter of a million acres, now Yellowstone Park, was immediately proclaimed by President Harrison, and since that time immense reserves have been created all over the country, many of which are leased out to farmers for grazing at certain periods under Govt. supervision. Some areas, such as portions of the Manti National Forest in Utah, had to be protected from grazing altogether because of the erosion and damage caused by over-

A scientific study of the problem of national soil conservation has only recently been undertaken in the United States. The first attempt to determine the quantity of run-off and erosion from a limited area of soil was carried out in 1915 by the Forest Service in the Manti National Forest, Utah. Erosion stations were later established by the Missouri Agricultural Experiment station at Columcia, Mo., the Texas Agricultural Experiments station at Spur, Texas, the Forest Service at San Bernardino, Calif., and the Bureau of Agricultural Engineering at Rayleigh, N.C., for the general purpose of demonstrating and evaluating the enormous damage done by soil erosion, and their work provided a good introduction to the more extended study afterwards carried out by the Department of Agriculture and cooperating agencies.

The first step in this extension was a reconnaissance survey during 1928-1929 for the purpose of locating and outlining the boundaries of the severely eroded areas in the United States. 18 districts were recognised in which erosion had become a serious menace. At the 70th Congress authorization was given for the establishment of erosion prevention and moisture-conservation stations in these areas, and in 1929 H.H.Bennett in the Bureau of Chemistry and Soils formed a series of Erosion Experiment stations in ten typical regions of the United States.

The Soil Erosion Service was established in September 1933 under the office of the Secretary of the Interior for the administration of a grant made by the Federal Emergency Administration of Public Works for erosion control activities

and in 1935 this bureau was transferred to the Department of Agriculture and renamed the Soil Conservation Service with H.H.Bennett as Chief. It is now vigorously undertaking research and demonstration projects on a national scale,and 15 control stations have been established for the former purpose. In each case the Government has entered into a five-year contract with the farmers within the experimental area, who agree to follow,with the practical help of the Bureau, the instructions given by experts. Forty demonstration projects of field work have also been formed in representative watersheds of the country where soil erosion is serious.

The methods of prevention adopted in America are on similar lines to those in this country, the main difference being the large number of reserves where grazing is State - controlled. Terracing of sloping areas has been carried on for a long time in the South East part of the United States,and the method has been extended across the Mississipi River, being extensively employed in Texas, Oklahoma, and Arkansas. It is only recommended, however, on lands which have eroded to such a point that vegetation is extremely slow,and the subterranean parts of the vegetation ineffective in binding the soil and preventing erratic run-off.

A recent example of the State-controlled work which is

being done in America to check erosion is to be found in the Tennessee Valley, which until recently has been regarded as a poverty-stricken area. Farming is poor and health conditions are bad, and it is in this unpromising region that the Tennessee Valley Authority has been started, mainly as an economic experiment for the generation of cheaper electric power than is provided by the private companies. It has been voted £10,000 to start with, and in the two years of its existence has achieved an amazing amount of good.

A series of huge dams is being constructed, partly for storage, partly for hydro-electric power, and for the improvement of navigation. Owing to the erosion taking place these would soon silt up and become useless if steps were not taken to prevent it, and so the Tennessee Valley Authority has acquired certain zones round Norris Lake and elsewhere which it is afforesting, and it is encouraging a sound forestry policy throughout this area. Also it is obtaining assistance from the Federal Government, which is trying to reduce agricultural over-production by putting poor land out of cultivation, in order to buy up such "submarginal" cultivated land and put it back under forest, and with the help of the Civilian Conservation Corps of young Unemployed men it is repairing eroded hillsides by filling up gullies,

building check dams and planting grass. Farmers are being encouraged to adopt terrace cultivation and other methods to prevent further washing. To restore some of the fertility to the impoverished soil the Tennessee Valley Authority produces phosphate fertiliser from local phosphate rock with the aid of its own electric power, and for nitrogen obtains commercial nitrates and leguminous plants suitable to the climate. Poor steep land that should not be cultivated is bought up and put back under forest, and "tree crops" are also planted.

In tis case the anti-erosion scheme is only part of a big project, but very necessary for the success of that project, and in many respects it is comparable to our own experimental scheme in the Tugela valley.

A Government officer was recently sent to America for the purpose of studying soil erosion and research in all its aspects there, and it is expected that the experience gained by him will be of great help in the work being done in South Africa.

RESEARCH WORK ON SOIL EROSION

(A) Wind Erosion

As wind erosion does not usually become a danger except in arid or semi-arid regions it is only natural that most of the research work being carried out is on water erosion. Yet the former has caused alot of damage in South Africa, and is the predominant type in many of the drier parts of the country. Experiments show that vegetation is the only satisfactory method of guarding against it, and by the use of wind-breaks, ploughing or planting at right angles to the direction of the prevailing winds, scattering brushwood and similar means, further destruction can generally be prevented, provided the land is sufficiently valuable to warrant such measures.

Drift sands are liable to cover up and render useless large tracts of fertile land if not properly controlled, and with this object in view many attempts have been made, some successful and others complete failures. Barriers, either wooden palings or brushwood, may stop the drift, but a better method is to plant with a suitable grass such as Marram grass (psamma arenaria) or Pypgras (Ehrharta gigantea), together with or followed by bush or trees of suitable species. Details of these methods were given by C.G.Laver, Government Forester, in "Farming in S.A.", February, 1936. Perhaps the most striking success was that attained at Port Elizabeth during the years 1893-1909, following a scheme formulated by Mr. Storr Lister, I.S.O., in which use was made in the first place, of town refuse. Today a huge area of what was once a considerable menace to the town and harbour is densely covered by trees, bush & grass, the Port Jackson Willow (acacia saligna)

proving of particular value.

(B) Water Erosion

Erosion by water depends on four main factors, on each of which research is being done:-

(1) Amount and (more particularly) intensity of rainfall.

(2) Slope

(3) Vegetation

(4) Specific nature of the soil

(I) Rainfall

Apart from the greater run-off and quicker saturation of surface layers caused by a heavy fall of rain, percolation may be much hindered in the soil if this follows a spell of drought, because the water table is lower, and the air within the soil together with the lack of a continuous film of wetted surfaces to lead the water down by surface tension after the top layer has become wetted prevent the water from reaching any depth until local displacementsof the air are set up.

It has been a long debated question as to whether man can or cannot influence the distribution and character of the rain fall. Elaborate experiments have been conducted in many countries in an effort to determine whether the desiccation which occurred in some of the ancient countries was due to deforestation, but this was not conclusively proved. It has been shown, however, that in places where large tracts of previous forest land have become bare veld the rainfall has become more erratic in character even if the total amount has remained the same, with the result that it is far less

beneficial in effect than before.

As the rainfall records in this country have for the most part only been kept for a short time evidence of this sort is scarce, but what there is seems to bear out this conclusion. The importance of recording the number of days on which the rain falls as well as the amount, is obvious, because of two regions with the same annual rainfall one may receive the full benefit of the moisture while the other suffers an enormous amount of damage owing to its torrential nature.

The Government is at present engaged in a fairly extensive afforestation scheme, and experiments are being carried out at various research stations (see below) on the most suitable trees to plant andtheir possible effect on the rainfall, but the private landowner in some areas is still very backward in this respect, preferring to remove what little tree-growth there is in order to raise the stock-carrying capacity of his farm rather than to help improve the country as a whole. In contrast, fortunes have been made by certain planters who have grown wood suitable for use on the mines, and by wattle growers in Natal, the eastern Cape Province and the eastern Transvaal, examples which might well be followed by those in other centres.

(2) Slope.

As the capacity of silt laden water for erosion increases geometrically with the amount of sediment carried, and the

amount of sediment carried increases geometrically with velocity, which depends on the surface slope, it follows that the rate of erosion varies in a geometrical ratio with the slope of the ground.

A large number of experiments have been and are being carried out in confirmation of this fact, mostly run-off experiments with the aid of lysimeters.

(3) Vegetation

This is more important than slope in determining the amount of erosion — the amount of sediment removed from the steepest slopes may be negligible if the cover is sufficiently dense.

Most of the scientific research work so far carried out in the Union has been in botanical and allied fields. The plant life of the country has suffered severely as a result of man's misuse of the veld, and it is essential that this retrogression be stopped. It is for this purpose that much of the Government research work on pasture and veld improvement is being carried out.

According to ecologists, the natural tendency is progresseively from lower to higher plant forms up to the highest form the locality and climate can maintain at the time. On the other hand if the natural conditions are upset the plant form may retrogress one or more stages. The normal succession is from grass (lower to higher forms) through shrubs and bush to forest. A fact noticed by many farmers on land

which through some cause or other has been denuded, partially or completely, of its vegetable covering is the appearance of the lower forms Aristida (wire-grass), Eragrostis, Cynodon etc., in place of the higher forms like Themeda (rooigras) or Cymbopogon. If left to itself, veld which has retrogressed would in most cases slowly revert back to its original form, but if any grazing at all takes place or other conditions interfere the new vegetation does not fully reproduce the original. Non-edible plants and quicker-growing forms of lower type, for example, would tend to multiply and predominate.

Erosion and soil-depletion bear a close relation to vegetative growth, and the following table (5) shows the amounts of salts important to the growth and development of plants in eroded and non-eroded soils.

Percentage-	Lime (CaO)	Potash (K_2O)	Phosphoric acid (P_2O_5)	Total N.	Loss on ignition
Eroded	1.26	1.53	.22	.156	6.64
Non-eroded	1.49	1.50	.53	.488	14.65

Eroded soils also have a much lower water holding capacity, and in general we may say that on badly eroded land years must elapse before the more desirable forage species can reoccupy the site on which they formerly predominated, certain rather inconspicuous plants first having to gain a foothold and gradually reinstate the vegetable matter and plant foods which are invariably lacking. This replacement

of one set of plants by another through a series of successive invasions is known as plant succession.

The improvement, however, can usually be hastened by artificial means, the only doubt being as to whether it can be done on a large scale on a paying basis. The Department of Agriculture is at present carrying out experiments on reseeding, either with native types or others which might be suitable, the "blending" of different grasses, selective tests with a view to breeding the most suitable nutritive and drought resistant types, on fertilizers and allied problems.

For this purpose grass and pasture research work has been considerably extended during the past few years. Three new pasture-research stations were established last year (1935) in the Transvaal; one at Warmbaths in the Bushveld, where work is being carried out on veld management, reclamation of damaged veld and the eradication and control of invading thorn scrub (for an article on this last, see "Farming in S.A.", March 1935, "Some Problems in the Restoration of the Veld", by J.D.Scott, Ecologist, Division of Plant Industry); one at Vereeniging on the highveld, where research is being done on veld management and on the reclamation of old lands covered by "steekgras"; and the third at Athole in the sour mountain grassland on the eastern slopes of the Drakensberg, experiments being started here on different methods of grazing

control, artificial pastures, veld-burning and methods of conservation.

Investigations on native vegetation are being continued, and helpful information collected for other institutions and the farmers at the National Herbarium, Pretoria, and at the Albany Museum Herbarium, where good progress has been made with grass-breeding trials and the "blending" of different grasses in one pasture. Experiments are also being carried on at the Rietondale station, Pretoria, on the management of the local sour veld and artificial pastures, and at the Prinshof Pasture Research Station on selection, contour banking, and inducement of germination of seed on a commercial scale. The influence of rainfall on the growth of local bushes, the water requirements and content of Karroo plants, the germination of Karroo bushes and grazing problems are being studied at the Fauresmith Veld Reserve, while at the Worcester Veld Reserve a study has been made of different grazing systems and the rate of recovery of the Natural veld if grazing is discontinued for certain periods. At the Kroonstad, Rustenburg and Hartebeespoort Stations grass variety tests are being undertaken, and pasture experiments are also in progress at the experimental farm of the University of Pretoria.

Sites for new stations in representative grassland areas in the Cape Province, Border, Natal and the Orange Free State have been inspected and recommended.

The four schools of Agriculture, the Stellenbosch—Elsenburg College of Agriculture and their sub-stations are still doing excellent work, of which fertilizer experiments constitute an important part. Pasture, silage and grazing experiments and research in every phase of Agriculture are being continued and extended.

Forestry problems are being studied to a certain extent at the Stellenbosch-Elsenburg College of Agriculture and more tho roughly by the experts of the Department of Forestry, from whom information as to the most suitable trees to plant in a particular area may be obtained.

Finally we come to the fourth factor determining the amount of erosion a locality will undergo viz;

(4) THE SPECIFIC NATURE OF THE SOIL

Under conditions which result in one soil being perfectly stable another may undergo rapid erosion, the type and character of the soil itself being the sole deciding factor.

(a) Work in the Union

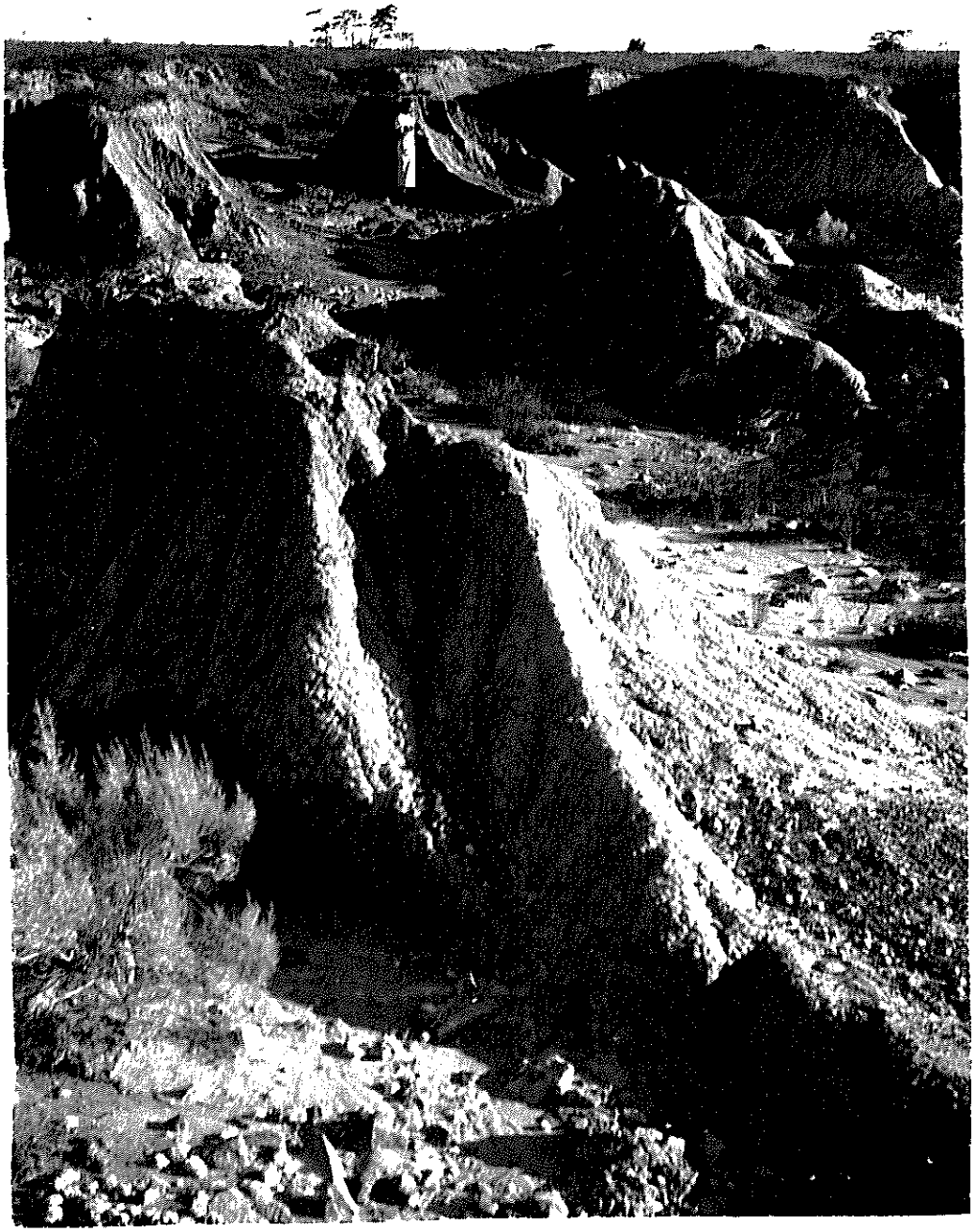
An immense amount of work has been done overseas on the fundamental properties and characteristics of different soils from the point of view of their stability, but in this country the subject has, until recently, been somewhat neglected. Since the adoption of the anti-erosion schemes in 1933, however, an intensive examination of the soils of South Africa,

beginning with soil surveys in various parts, has been commenced. The most important surveys during 1935 were in connection with the Loskop, Pienaars River, Clanwilliam, Egmont, Midden-in, and Upper andLower Riet River schemes. In addition data are being collected forageneral soil survey of the Union. The effect of brak salts on the physical and chemical composition of the soil is being investigated, and drainage experiments in this connection will shortly be commenced in the Great Fish River valley. The fundamental relationships between soil types and erosivity are being examined and a fairly detailed "erosion survey" will be made in some specially selected area. Useful work on the amount of run-off and sediment under varying conditions of vegetation, slope and soil type is still being carried out on the experimental plots of the University of Pretoria, while at the various schools of Agriculture soil fertility problems continue to receive a lot of attention.

(b)The Albany District.

For pasture research work and for studying erosion the district of Albany is especially suitable owing to its diversity in soil types, vegetation and to a certain extent even climate. The annual rainfall varies from between 25 and 30 inches in the South to a little over 10 inches in the North West. In the high rainfall area nearer the coast there is a good covering of vegetation, and it is only where this covering has been removed that serious cases of

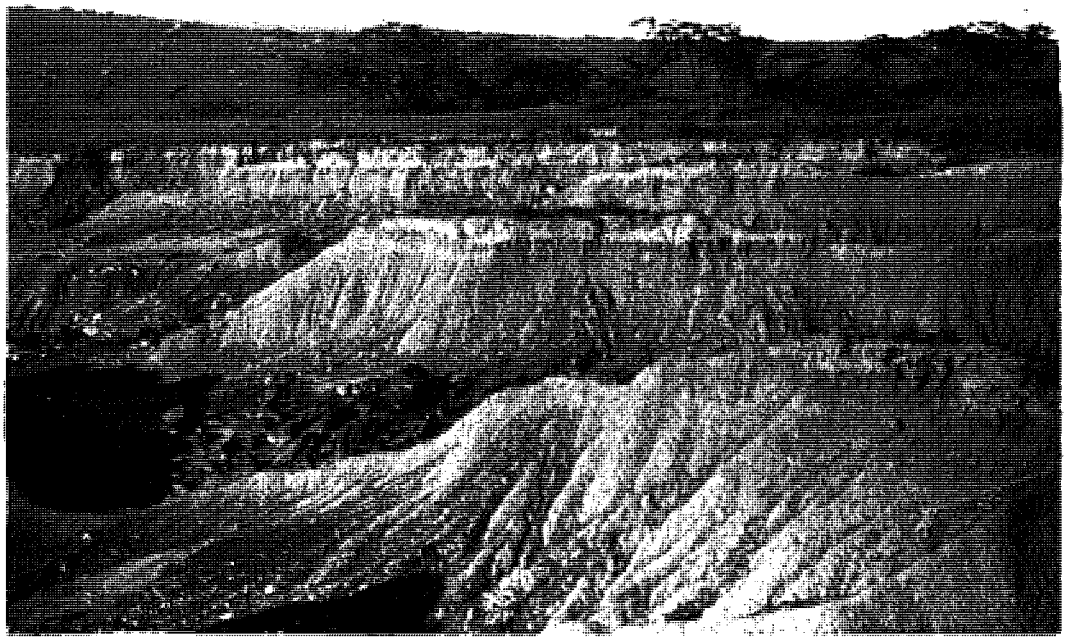
PLATE A

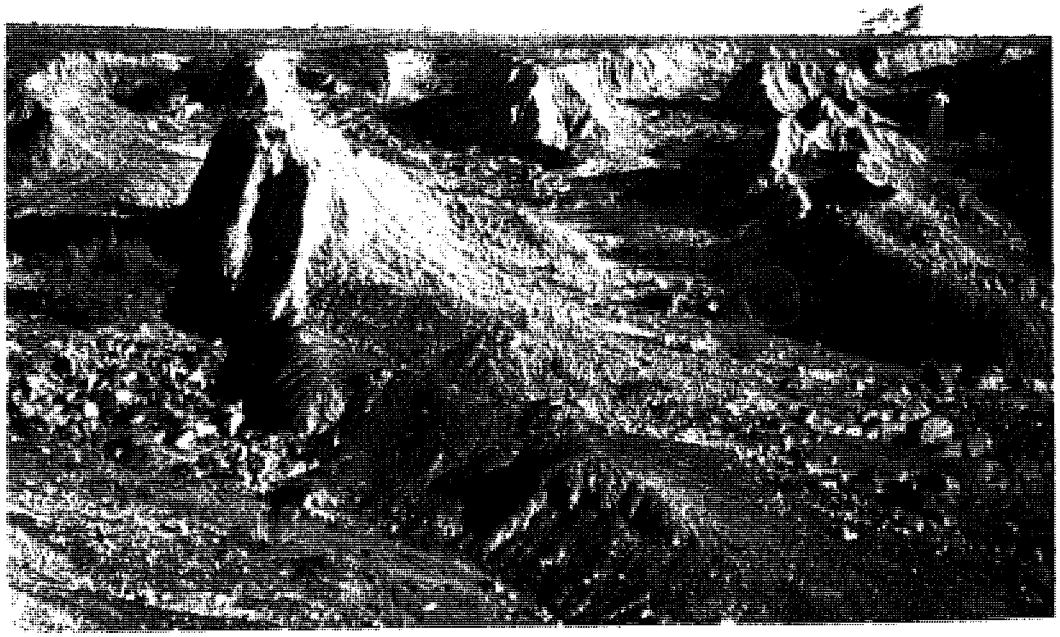


erosion, mostly gully erosion, exist. Once started, however, very deep dongas may result, provided the depth of soil is sufficient. The illustration opposite (Plate A) gives a good idea of the damage that may be caused on this type of ground.

Where the rainfall is lower conditions are different. The vegetation, except just after the rains, is chiefly Fish River scrub, mimosa, spekooom, prickly pear where not eradicated, small bush and similar species. Here sheet erosion has done serious damage, and in many of the valleys deep dongas have formed. Much of this was started in the first place by overstocking, but for many reasons the position has been aggravated. Firstly the small rainfall results in a somewhat scanty vegetation, and after a dry spell the grass disappears, leaving much of the surface bare. In the Fish River valley, where conditions are particularly bad, the average day temperature is very high, and the depth of the soil over the greater proportion of the area is only a few inches, except in the little valleys, with the result that the run-off is heavy, evaporation losses are high and a thick cover has no chance of forming. The soil is derived from the Ecca shales and sandstones and while the percentage of gravel is usually fairly high a large proportion consists of very fine material easily passing off in suspension.

PLATE B





The subsoil over the shales very often contains a big percentage of clay, bands of almost pure clay existing in parts, and when exposed these erode comparatively rapidly.

A similar subsoil is found over the Dwyka shales further south in the high rainfall area, and it also is unstable if the surface layer is removed.

In the upper photograph of Plate B the two types of soil— a comparatively stable surface layer underlain by an unstable subsoil generally of higher clay content — can easily be distinguished. The lower picture shows how such erosion may result in the removal of several feet of soil, leaving a stony area partially covered with a few inches of infertile soil consisting largely of deposited silt.

Soils containing a high percentage of silt and fine sand are usually fairly stable on level ground, but on steep slopes the looseness of texture and absence of binding material may result in rapid erosion. Gully erosion is common on soils of this type.

On level or gently sloping ground the percentage of clay is a far more important factor, the finer particles being more easily transported by slowly moving water, especially when dispersion of the colloid portion takes place. If the water is able to percolate downward particles may also be removed in this manner, as shown on Plate C. These photographs were taken at Westhill, Grahamstown, where a

Plate C

series of terraces were made on the hillsides in an attempt to stop the erosion takingplace there. The soil — in reality the subsoil over Dwyka shales — contains a very high proportion of good quality potclay, but very little in the way of plant nutrients, so that plant growth is difficult to establish. The terraces slope backwards, and the left - hand picture shows a hole formed on one of these as a result of the water which collects there during rain percolating downwardand carrying off the fine material in suspension. The second picture shows the bank below this terrace where the water emerges again. Several holes similar to this formed on the banks, and were followed by collapse of the overlying material and formation of gullies. On this type of soil plain terracing cannot do more than retard the rate of erosion.

In general the soils over the shales are reddish in colour and erode easily, while those over the sandstones and quartzites are grey to brown, of coarser texture, and less liable to erode. A clay subsoil has been observed by the author near Riebeek East under grey sandy loam with good grass and bush covering, which when exposed rapidly forms deep dongas, the case being rather unusual owing to the fact that it occurs over rocks of the Witteberg series, above which such clay is rare.

Many of the boreholes in the Fish River valley yield brak water, hence the work soon to be undertaken there on problems of this connection.

(c) General Investigation and Classification of the Soil

In an examination of the soil investigations take place along two general lines — Chemical and Physical — At one time it was thought that the fertility of a soil was entirely due toits chemical composition, and for this reason work on the soil was almost entirely on a chemical basis, as were early attempts at classification. These attempts were limited as a rule to the comparatively small areas which the investigator had had the opportunity of studying, and were found to fail when applied on a world-wide basis. Attention was usually restricted to the surface soil and perhaps the parent material, the nature of the soil profile being neglected altogether.

Dr.C.F.Juritz, who did a lot of work on South African soils, especially in the Cape Province, attempted to correlate the chemical character of the soil with the geological formations, but took no account of the extreme variations of climate encountered within the region covered. Later, first of all in Russia, where the system was successfully applied, emphasis was laid on climate factors and the resulting soil profile, little notice being taken of the geological origin. This method,again, however, was found to be somewhat limited in application.

In general, the basic characteristics of a soil in any region at a particular time are due more especially to the climate of that region if the soil is mature; if, due to

topography, erosion or other reasons it is immature,it may be influenced more by the geological formation from which it is derived.

Most soils in South Africa are immature, and it follows that any classification based chiefly on climate is bound to be incomplete. The attempt by C.F.Marbut in 1923 (6) to classify African soils in this manner was not marked with any great success. At the International Congress of Soil Science at Washington in 1927 he proposed a comprehensive system of classification to include all soils already known or likely to be encountered. The difficulty with this as with all other systems so far proposed, is that there remainso many soil types as yet unstudied in quantitive detail that it is doubtful whether they will ultimately be found universal in application. Until our knowledge of the soils in various parts of the world is extended it is unlikely that such a classification will be put forward, but when it does come it will probably be a modification of existing schemes, with the soil considered as the product of climatic, geological and topographical influence, while the nature of the soil profile will constitute an important part of each investigation.

When it was found that the ultimate chemical composition was not the basis of fertility various solvents (e.g. dilute HCl, citric acid etc.) were used in an effort to find

what was called the "available" plant food. These again, however, were only approximate, and it became more and more realised how important the physical stateof the soil was in affecting the value of the chemical analysis. Subsequently the mechanical analysis, i.e. the splitting of the soil into fractions each containing particles within some arbitrary size limit and hence the determination of the percentage of each fraction in the soil began to find more favour with soil workers.

The fundamental principle of all the variations of this method, apart from the mechanical sieving of the coarser particles, is Stokes' Law, which determines the rate at which a particle will settle in a liquid, viz.

$$V = \frac{2r^2(S-S')g}{9n}$$

where
- V - rate of settling
- r - radius of spherical particle
- S - density of particle
- S' - density of fluid
- g - 981 (gravity constant)
- n - viscosity of fluid.

It would be more correct to use the density and viscosity of the suspension than of the pure liquid.

Various assumptions are made in this equation and the practical method usually followed is somewhat rough, but satisfactory for the purpose. The chief difficulties arise.

in the pretreatment of the soils to effect dispersion. Some workers, e.g. in parts of Central Europe, prefer to give only a mild preliminary treatment, arguing that by so doing a better idea is obtained of the field conditions of the soil, but the International method and that adopted in most countries is to make dispersion as complete as possible, the results being then less empirical.

The most important factor determined by mechanical analysis is the percentage of clay, owing to the tremendous influence this has on the properties and utility of the soil. Yet if as much as 10-15% of organic matter is present the mechanical analysis loses much of its significance, because at the proper stage of decomposition organic matter has the effect of binding a loose soil (low percentage of clay) and lowering a heavy one (high percentage of clay).

In addition to mechanical analysis, other physical pr properties of the soil were measured; e.g. the early tests by Schübler (7) on cohesion, plasticity, shrinkage on drying, moisture-holding capacity, rate of water evaporation and uptake, heat of wetting, conductivity and others.

Later the investigations were divided into field and laboratory experiments. At Rothamsted in England, for instance the dynamometer is used to find the actual resistance experienced by the plough in moving through the soil. The

clay fraction , separated at least partially by mechanical analysis, was found to have special properties of great significance which were examined separately. The main difference today in measuring physical properties is in the more elaborate and accurate apparatus used, but a few new determinations have been introduced which have proved of great value in explaining some of the reactions taking place in the soil. The H-ion concentration or p-H value is an example.

The effect of the physical composition of the soil on its fertility may be modified by the presence of other factors, of which organic matter has already been mentioned, and the nature of the subsoil. Lime may have the effect of binding a light soil, and, by its coagulating tendency loosening a heavy one, as well as the liberation of various reserves of plant food by its chemical action. Other fertilizers may either improve the physical condition or affect it adversely. If the rainfall is light a high proportion of clay may be an advantage on account of its moisture-holding capacity, whereas the same soil with a heavy rainfall might be practically unworkable. The reason countries like South Africa with apparently poor soils can produce fair crops, given the necessary amount of water, is supposed to be due to the faster rate at

which "available" plant food is renewed by the process of weathering, owing to the warmer climate. Finally the presence or absence of soluble salts in the soil may have a profound influence on its texture, chemical composition, and stability.

In attempting to obtain an idea of the fertility of a particular soil and its likely reaction under different conditions, the best results are obtained by combining the mechanical and chemical analyses with observations on its physical properties and field conditions, provided this is possible.

(d)Relation of Soil Properties and the Colloidal Fraction to Erodibility

It is only comparatively lately that attempts have been made to determine the actual rates of erosion and to find mathematical expressions for this and erosion tendency, though the varying amounts different soils will erode has often been compared by measuring the run-off and sediment from experimental plots. Working with erosive and non - erosive soils certain investigators in America obtained some sort of measure of erosivity from laboratory data. Middleton in 1930 (8) measured it qualitatively with a fair amount of success by means of his "Erosion Ratio"

This may be expressed as;

$$E.R. = \frac{100\ AB}{CD}$$ where

A = % silt and clay suspended in water under standard conditions (suspension %)

B = moisture equivalent at 1000 x gravity

C = total % silt and clay by mechanical analysis.

D = % colloids by moisture absorption method. (9)

The moisture equivalent (B) is the amount of water held by the soil after centrifuging at the given speed. $\frac{A}{C}$ is called the "dispersion ratio", and is the fraction of silt and clay most easily removed by water — in other words the higher the dispersion ratio the more easily will the soil erode. $\frac{B}{D}$ measures the degree of absorption of water per colloid unit, and hence the effect the colloid has on the run-off.

In 1931 Slater and Byers (10) attempted to find a laboratory method for determining the field percolation rates of soils, and compared what they called the "PercolationRatio" — $\frac{AB}{D}$ using our previous nomenclature — with Middleton's erosion ratio, the two becoming identical for a hypothetical soil consisting of 100 per cent silt and clay. According to them, a comparison of these ratios showed that erosion was inversely proportional to permeability in terms of the

factors of the percolation ratio. In a later paper (11) Middleton, Slater and Byers state that the percolation ratio seems to be applicable to surface soils only, with which it may have qualitative significance.

Middleton then has developed as criteria of erosivity the dispersion ratio, and perhaps the silica - sesquioxide ratio, soils with a low silica-sesquioxide ratio being found difficult to disperse. These measurements of course leave out of consideration all influence except the soil itself, but from them it is possible to predict fairly well the type of erosion that will take place and the part of the profile most susceptible to erosion, though not the quantity. Combined with field data valuable results should be obtained on the tendency of the soil to erode and possible methods of control, but there are still many aspects of the relationship between soil-structure and erosion which need to be investigated before quantitative agreement can be expected.

A simple test, but one which enables the potential resistance of a soil towards erosion to be judged with a fair amount of accuracy, is to place a lump of the air dry soil in distilled water — or perhaps rain water would be a better criterion — and note the time before the lump disintegrates and loses its structure. Some break down immediately to a shapeless mass, in which condition they

would easily be removed by running water, while others retain their structure almost indefinitely. No account is taken of particle size and consequent ease of removal of the "slaked" mass, while for comparative purposes the size and shape of the lump would also have to be approximately constant (or corrected for), but nevertheless the test shows promise of being of considerable practical utility.

In this paper the effect of the colloid content, both inorganic and organic, on the chemical and physical properties of the soil and consequently its erosion tendency has, until now, not been stressed, but its importance cannot be over-emphasised.

Experiments have shown that the colloidal properties of the silt and sand fractions are only very small, so that the characteristic colloidal reactions of the soil must be ascribed almost entirely to the clay portion and the organic matter, and it is in this colloidal complex, as it is called, that the most important chemical and physical reactions of a normal soil take place, exceptions occurring only where large proportions of chemicals such as lime, gypsum or other salts are found.

The clay fraction, by which is generally understood the mineral matter whose particles would be below .002 mm. in diameter if spherical, is mainly of secondary origin, formed

from the weathering of silicate minerals such as felspar, which gives hydrous oxides of alumina and silica, together with iron in some form or other and small amounts of other minerals. It is on the colloidal part of this fraction and the colloidal organic matter that the fertility of a soil depends, and for this reason it has been subjected of recent years to an increasing amount of intensive study. The reactions which it undergoes and has undergone, however, are so complete that even they are the subject of much controversial literature.

As far as the constitution of clay is concerned opinions still differ, there being two opposing lines of argument. S.Mattson and his followers (12) regard soil colloids as complexes of indefinite structure and varying composition, and believes them to be amphoteric salts of weak acids (e.g. silicic acid) and weak bases (chiefly iron and aluminium) formed as a result of mutual precipitation of electropositive and electronegative cells at or near isoelectric conditions. However, later work, especially by means of X-ray analysis, and also by a study of the double refraction of the clay particles, has shown that the material is principallycrystalline in structure, and certain definite minerals were identified as common constituents.

Amongst them were beidellite ($Al_2O_3\ 3SiO_2\ nH_2O$), montmorillonite $[(Mg\ Ca)O\ Al_2O_3\ 5SiO_2\ nH_2O]$, halloysite ($Al_2O_3\ 2SiO_2\ 2H_2O$) and bentonite, similar in character to montmorillonite. Kaolinite, which was at one time regarded as the chief constituent of clay, is comparatively rare. The soil colloids are supposed to represent progressive stages of degredation of complex silicates through hydrolysis. Montmorillinitic and halloysitic acids are hypothetical acids of amphoteric type from which colloids in the form of partly neutralised salts are derived during some stage of the process, and a particular soil colloid may be expected to contain a mixture of colloid components. In addition to these crystalline minerals some amorphous material may be present.

Mattson attempts to reconcile this view with his own by postulating that the particles may be crystalline in structure, but that the surface layer is of indefinite composition. While the fact that there are difficulties in assigning definite formulae to the clay complex might seem to support his theory, this is more probably due to the presence of varying proportions of relatively simple crystalline compounds, or possibly to some extremely complicated type of compound of uncertain structure.

The composition of the clay complex is not uniform except moderately in restricted areas, probably owing to similarity in climate and geological conditions, and has been used as the basis of a broad classification of soils. H.H.Bennett (13) divides them into two classes with respect to their tendency to erosion:-

(i) Soils with clay fraction containing excess of sesquioxides, markedly resistant to erosion, probably owing to their tendency to assume a crumb structure.

(ii) Soils with clay fraction of a more siliceous type, more readily eroded owing to their tendency to deflocculation.

G.W.Robinson (3) also differentiates between soils whose clay fraction has a high silica-sesquioxide ratio (>2) which are generally greyish or brownish grey in colour in the absence of organic matter, and those with clay fraction of low silica-sesquioxide ratio (<2), usually brownish, yellowish or reddish showing the presence of free ferric hydroxide and by inference aluminium hydroxide.

Two clays, however, may have the same silica-sesquioxide ratio and yet be very different in composition. In general this ratio tends to be low in clays of humid tropical climates and high in arid and cold regions; in tropical humid regions it may increase downwards owing to removal of silicic acid from the surface, and in cool humid regions it often decreases with depth due to the loss of sesquioxides from the upper horizons.

Percolating or running water, in addition to altering

the composition of the clay complex, may carry off a large portion of the clay itself, if for any reason it becomes dispersed, in the form of a suspension. This may be deposited again lower down the soil profile, with the result that pores and seepage openings are clogged, the permeability of the soil is decreased and run-off increased, thereby reducing its utility and increasing the erosion tendency.

In dealing with the organic content of the soil we must distinguish between total organic matter, humus, and the organic matter present in colloidal form, often used synonymously with humus. Humus may be termed that organic portion of vegetable origin which has been decomposed by bacterial and/or chemical action and lost its original structure, becoming colloidal in character. It is a variable mixture of a number of substances; e.g. humic, ulmic, crenic and apocrenic acids, humin and ulmin were among those first isolated, mostly of somewhat indefinite structure, and later definite known compounds such as paraffinic acid ($C_{24}H_{48}O_2$), xanthine ($C_5H_4O_2N_4$) and many others. Substances very like natural humus have been synthesised by a number of workers, but it must be remembered that humus itself is variable in composition, even though it behaves in some respects like a single substance. Its carbon, nitrogen ratio, for example, however much it may be disturbed by added materials, nearly always returns to a value of about 10, it contains approximately

58% carbon, and its colloidal properties are fairly consistent. If the soil contains a lot of undecomposed vegetable matter, the percentage of carbon is lower than 58, whereas organic matter occurring in rock strata has a much higher carbon content, anthracite being almost pure carbon. The presence of sufficient humus in a soil with too high a percentage of colloidal clay may improve its physical condition, while in a sandy soil on the other hand, owing to its cohesive properties, it may result in the formation of compound aggregates.

Colloidal properties such as swelling, imbibition of water and absorption are shown to a greater extent by the organic colloids, but plasticity and cohesion are not so pronounced as in clay.

The tendency of colloids to absorb substances from solution is a well known characteristic of soils. Natural clays contain cations, the most frequently occurring of which are $Ca^{\cdot\cdot}$, $Mg^{\cdot\cdot}$, $K^{\cdot}$, $Na^{\cdot}$, and $H^{\cdot}$, that may be replaced, either partially or completely, by others. The replacement is known as "base exchange", the cations being called exchangeable or replaceable bases, and because the reaction reaches equilibrium very rapidly it is regarded as purely a surface phenomenon. This has been proved by the fact that when a number of different cations were substituted and X-ray photographs taken no characteristic lines of the substituted bases appeared, showing that the internal crystalline structure had not been affected.

The reaction between a normal soil containing Ca as the dominant replaceable base and the solution of a neutral salt such as KCl may be represented as follows:-

Ca soil + 2 KCl → K_2-soil + Ca Cl_2, the $K^{\cdot}$ being absorbed and an equivalent amount of $Ca^{\cdot\cdot}$ going into solution.

Even with dilute solutions, however, this reaction is not complete, some of the K remaining in solution, though by repeated treatment with fairly concentrated salt solution, removing the equilibrium portion each time, it is possible to replace the exchangeable base almost completely, the result being a K-, Na-, or other soil, according to the salt used. If excess is used, even a H-soil, which shows the weakest exchange capacity, may be substituted, free acid appearing in the solution. The order of effectivity of the common ions for replacement is, ceteris paribus,

H > Ca > Mg > K > NH_4 > Na.

The properties of the soil differ according to whether the dominant base is Ca, Na, H and so on. A Ca- soil is the normal fertile soil of humid and temperate regions, approximately neutral, and of good physical condition, a Na - soil is easily deflocculated and consequently very difficult to work, and produces an alkaline condition unsuitable for most plants, while a H-soil, commonly occurring in wet regions, is acid and not so good physically as a Ca soil. It is usually treated with lime or chalk to render it more fertile.

If a soil has been in equilibrium with $CaCO_3$ for a long time it is said to be saturated with exchangeable bases, and if the base-content be lower than this it is said to be unsaturated. Leaching with dilute acids may produce this condition, or even percolating water, such water usually containing dissolved CO_2, and the more unsaturated the soil is the more marked are its acid properties. The measurement of the degree of unsaturation is imporatnt economically in determining the amount of lime necessary to bring the soil to its most productive condition.

The humus fraction of the soil also shows base exchange properties comparable with those of the clay portion, its capacity for holding cations being much greater, weight for weight, than that of the clay (6 or 8 times as much). Cations such as Ca or Na in the humus may be exchanged by the H ions in HCl, for example, $CaCl_2$ and NaCl being formed in the solution. Attempts have been made from the reactions to calculate the atomic weight of "humus" but no consistent results have been obtained, nor can they be expected.

The actual mechanism of base exchange together with other absorption and adsorption phenomena in the soil has been somewhat confused by the majority of writers. It is quite clear that the reaction is a surface one, important because of the large surface area presented by colloidal matter, and

thus differing from the ordinary absorption of, for example, a gas by water. The fact that it may be a chemical process in no way detracts from the conclusion that this is a case of adsorption. Absorption, on the other hand, may be considered as a general term embracing all the reactions whereby substances are absorbed either from solution or from the atmosphere by the soil.

At any solid/liquid interface adsorption takes place to a greater or lesser extent, and at very low concentrations the distribution of the solute between adsorbent and solvent follows Henry's Law. The solvent as well as the solution may be adsorbed, so that in practice the values obtained from solutions represent the difference in adsorption of solvent and solute, the actual values being unknown.

Freundlich developed an equation empirically which held over limited ranges of concentration, viz:

$a = kc^m$ where { a- weight of material adsorbed per gram of adsorbent; c- equilibrium concentration; k and m are empirical constants.

In most cases m decreases from unity with increasing concentration or decreasing temperature, indicating an approach to a condition of surface saturation, and the equation does not hold accurately for strong solutions.

Langmuir deduced a rather more satisfactory equation theoretically which described the facts better in some cases, though for most practical purposes the Freundlich equation is still used. Langmuir's equation is

$$a = \frac{hc}{1 + bc}$$

where a = weight of adsorbed material per unit surface of adsorbing material (= weight of adsorbed material per unit weight of adsorbing material)
c = equilibrium concentration
h and b are constants

At very low concentrations bc is very much less than 1 and may be neglected, the equation reducing to Henry's Law, but at high concentrations it does not apply so well.

It is not surprising that a single simple equation does not fit all cases, because the latest work seems to show that the process itself is not a simple one. Langmuir emphasized the chemical feature of adsorption, and Taylor from thermal measurements distinguished between chemical and physical adsorption. In some cases adsorption forces may be classed with residual valence forces, or van der Waal's forces. The process is generally considered to be either chemical or physical or both, but at present the quantitative theories of greatest usefulness, e.g. that of Polanyi, disregard the exact nature of the forces as far as possible.

In addition to the adsorption of the ordinary cations, soils have the power of adsorbing phosphates from solution, though the anions of the common salt like nitrates, chlorides or sulphates are not appreciably retained but leach freely through the soil. The soil organic matter can also adsorb or combine with the phosphate. The equilibrium attained may again be expressed, within limits, by the Freundlich equation, and the phosphate is usually precepitated by the Ca, Mg, Al, or Fe in the soil.

If the solution is an electrolyte the process is complicated by the electrical phenomena introduced by the ions. Consider the colloidal material of a soil suspended in water. Each particle has an inner shell of anions(-ve charges) and an outer diffuse shell of cations (+ve charges)— the Helmholtz - Gouy double layer — and the electrokinetic potential in the particle increases with the distance between the two layers, which in turn increases with the hydration of the ions. The stability of the suspension depends on the electrokinetic potential and hence on the degree of hydration of the ions, while the electrokinetic potential is found to be higher the smaller the adsorbed cation (i.e. the lower the atomic weight) for rare gas type ions of equal valency. In terms of the associated cations the order of stability (and order of hyuration) is Li > Na > K > Rb > Cs > Mg > Ca > Sr > Ba > H. For this reason clay suspensions with

high silica-sesquioxide ratio and consequently high electro-kinetic potential (and hydration) are more stable than those with low silica-sesquioxide ratio (N.B. classification above)

As there is a portion of cations relatively remote from the particle and not associated with the anions, due to a slight dissociation having taken place, the particle carries an excess of negative charges. If now a small amount of electrolyte be added to the suspension the separate particles may aggregate into larger compound structures because the condition of individual behaviour of the particle is that its potential must be above a certain critical value, and by decreasing the number of cations moving freely in the solution the electrolyte causes the number of free charges on the inner sheath to be reduced, which decreases the electrokinetic potential.

Coagulation may also be brought about by decreasing the degree of hydration of the cations or by increasing the dielectric constant of the medium, by the addition of a liquid such as alcohol. More electrolyte is required to flocculate a clay with a high potential than one with a low potential, but in the case of the coagulator the more hydrated the cation the smaller is its coagulating efficiency.

If the flocculating electrolyte contains an ion not present in the particle exchange adsorption is bound to occur, and the flocculating effect depends largely on the nature of the ...

ion initially adsorbed. For any particular clay those ions which are poorly adsorbed yield high flocculating values, while those easily adsorbed produce coagulation at relatively low electrolyte concentrations. The coagulating power of a simple ion, i.e. its power to reduce the zeta potential (electrokinetic potential), increases rapidly with increasing valency, and for metallic ions of given valency increases with atomic weight (i.e. the greater the hyuration or ionic volume the lower the coagulating power).

Coagulation was divided by Wiegner into two kinds — perikinetic, occurring as the result of interparticle attraction and collision, or Brownian motion, and orthokinetic, which is the result of the mass movement of one group of particles relative to another, as e.g. larger particles settling through finer ones. Both these take place in clay suspensions. It may be caused not only by the addition of electrolyte to a sol, but also by mixing two oppositely charged colloids, the charges being neutralised and mutual coagulation occurring. According to Mattson this happens in the formation of clay colloids (see above).

If one ion of the electrolyte is more strongly adsorbed than the other, the charge on the particles may be increased instead of reduced with consequent peptization instead of coagulation. On treating a clay suspension or other negatively charged colloid with KOH, for instance, the coagulating action of the K ion may be counterbalanced by the preferential adsorption and strong peptizing action of the

OH^- ion. This fact is made use of in the dispersion of soil colloids for mechanical analysis, where it is found that of the dispersing agents most commonly used the one with the strongest action is NaOH. High concentrations of hydroxide may result in decomposition of the clay complex, or insoluble hydroxides may be formed of opposite charge to the clay colloid, resulting in mutual coagulation.

Cases of so-called anomalous flocculation may also be explained quite simply by considering the relative coagulating powers of the ions e.g. a suitable mixture of a chloride and hydroxide (NaCl and NaOH, say) on a H- clay is found to coagulate it, redisperse it and then coagulate it again as the concentration is increased. The first flocculation is of the H - clay by NaCl before any appreciable neutralisation by NaOH has taken place(H ions exchange weakly) then a Na-clay is formed, and as Na ions are weak coagulators peptization occurs, and finally reflocculation when the concentration of NaCl is sufficient. Also, on adding ferric chloride to a negative platinum sol coagulation takes place with low concentrations, but addition of larger quantities results in the formation of a positive platinum sol stabilized by adsorption of ferric ions. With still higher concentrations of ferric chloride this positive sol may be coagulated by the chloride ion. The example is a case of "charge reversal".

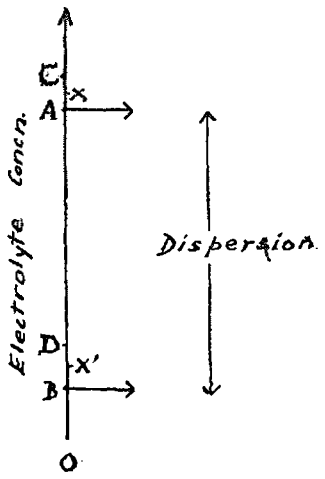
The colloidal organic matter in the soil undergoes similar reactions to the colloidal clay, its base exchange reactions having already been mentioned. In solutions of Na, K and NH_4 hydroxides it is so dispersed that it almost seems like a solution, yet it shows the Tyndall ray effect.

Humus suspensions are negatively charged and can be flocculated in the same way as clay, but require larger quantities of electrolyte. It was discovered by Schloesing that clay does not flocculate so readily in the presence of humus as when alone. This is due to the protective action of the humus, and the clay particles are supposed to become coated with adsorbed humus, thus requiring the high concentration of electrolyte for flocculation characteristic of humus. This retention of the humus by the clay keeps organic matter added to the soil in the upper horizons unless the clay is carried off in suspension. Sesquioxides are known to be removed from soils under climatic conditions which favour the formation of acid humus in the form of humus - protected sols. Different kinds of humus vary widely in their protective action, but if the amount is below a certain value sensitization may occur, and the clay will be more readily coagulated by oppositely charged ions than before.

In the case of water containing organic colloidal matter,

e.g. that from a swamp, the colouring matter is as a rule positively charged, and for this reason it is unusual to find water both turbid from clay particles and at the same time coloured, mutual coagulation of the positive and negative sols taking place.

Consider what might be called an "ideal" colloid in pure water; i.e. no electrolyte is present and no dissociation takes place. As there is no excess of positive or negative charges its condition will be one of coagulation. Cases similar to this have been observed in dialyzing experiments, when on removing adsorbed ions beyond a certain limit precipitation of the sol occurs. Very small amounts of electrolyte will have no effect, then on further addition dispersion will occur, and at still higher concentration the coagulation of the sol by the electrolyte as ordinarily observed will take place. The electrolyte range of coagulation below dispersion is very small, and in most cases adsorption of minute traces of dissolved salts, of $H^{\cdot}$ or OH^{-} ions from the water, or dissociation of the colloid causes dispersion. The complete range may be represented as follows:-



Between the points A and B dispersion occurs, and it is in this range that erosion is most likely to occur. The effect of humus on this is to raise AB to a position CD(say), the amount of protective colloid being proportional to the humus, so that the more humus there is the higher on the scale will be CD. If the normal position of the soil with relation to surrounding water and dissolved salts is at X, the effect will be to disperse the clay colloid, but there is a possibility (somewhat remote, perhaps) represented by the point X', that the effect will be one of coagulation. At any position between A and D dispersion will occur with or without humus.

If a clay is normally in a stable condition, i.e. in a position above A, the effect of rain water may be to reduce the amount of dissolved salts to below A, with the result that dispersion will occur and the clay pass off in suspension. Certain types of drak have this stabilizing effect on the clay colloids, dispersion occurring when they are removed.

Another case to consider is that of exposure of a subsoil with high clay percentage and, compared to the surface layers high electrolyte concentration, to the action of rain water by removal of surface material. The dissolved salts are leached out and dispersion may occur. The rapid erosion that takes place when the subsoil is exposed in many parts of

Albany, particularly in the Fish River valley, where the percentage of clay over the shales is very high and the ground water in many cases slightly brak, is very probably caused in this way. The subject has not yet been fully investigated. It is evident that in any examination of a soil in order to determine its erosive properties and in consequence the best methods of preventing erosion on that particular type of soil is closely bound up with an examination of the colloidal complex, both chemically and physically. Future work in this connection will be mainly along these lines, and the results should be of immediate and lasting benefit to practical farming, enabling us at the same time to make the fullest possible use of our natural resources.

The research started by the author in connection with Soil Erosion has so far been of a preliminary nature, and in investigating the problem from a physico-chemical point of view it was thought that the most practical means of approach would be an examination of the present methods of Soil Analysis and their limitations, particularly in regard to the disturbance, before the actual estimations, of the equilibria existing in the soil. It was for this purpose that the work appearing in Part 2 of this paper was undertaken, and it will be followed by more specific investigations along certain lines. In this connection Mr. N.G.Shirley, B.Sc., is already conducting experiments on electrodialysis of the different soil fractions, while the work of Mr.E.F.Verdier is mentioned further on (p 88.).

PART 2

MODERN SOIL ANALYSIS AND ITS APPLICATIONS

The first attempts at investigating soil properties and soil composition, apart from practical field considerations for agricultural purposes, were nevertheless made with the idea of finding out more about the fertility or otherwise of the soil — why some soils produced good crops of one sort and not of another, and why the same crops could not be produced year after year on the same soil without deterioration. Even at that time (about the 17th century) books had been in existence for hundreds of years on the method and practice of Agriculture, but the real significance of the soil constituents was not realised until much later. A period followed during which numerous books and pamphlets were written and experiments undertaken in connection with agricultural problems, many of them in an effort to predict the manurial requirements of the soil.

To explain soil phenomena and plant growth many hypotheses were put forward, of which a few were justified by later work but the majority shown to be erroneous. The idea that the plant depends on the mineral constituents of the soil for its growth was developed by Liebig, who produced an artificial manure based on his assumptions. Due more to his method of preparation than anything else it proved a failure, though,

because he believed that plants derived their nitrogen from the atmosphere, he also made the mistake of not including nitrogen compounds in the mixture. He himself realised the reason for its failure a few years later (1851) and from that time the value of chemical manures was established.

Quite naturally, it was thought that a chemical analysis would be all that was necessary in order to detect and remedy the infertility of a particular soil, and the early quantitative analyses were made solely for this purpose. The method employed was to extract the constituents from a known weight of soil with strong mineral acid (generally hot HCl), make to a standard volume, and estimate in the usual way, but the results were found to be somewhat limited in their application. Plants growing on soils apparently rich in plant food might give marked response to fertiliser treatment, while soils poor in one or more of the essential constituents produced good results, and it was soon realised that hydrochloric acid analysis gave little indication of the food immediately available to the plant. On the other hand it does give a fair idea of the quantities of reserve plant food, and some workers gain a certain amount of useful information by comparing the results they obtain with those from soils of known fertility. The HCl analysis does not show the true ultimate composition of the soil, some of the

most important elements, potassium in particular, being only partially extracted, nor does it give, as some writers have asserted, more than an approximate indication of the amount of weathered material. If the total mineral content is required the method used for rock analysis, viz., fusion with a suitable flux (usually sodium carbonate) followed by disintegration with hot water and analysis of the product, is adopted.

When the limitations of the results of an HCl analysis became evident attempts were made to find a liquid similar in its solvent action to the plant and soil acids. Many were tried, but most of them were found to be suitable for only one constituent; solvents which proved successful for some soils failed when used for others of a different type, and so on. The method most universally used is that proposed by Dyer in 1894 (14), with a 1% citric acid solution as solvent Yet in many cases even this does not give a true indication of the nutritive value of the soil, and alternative methods, of which the biological have been the most useful, have been put forward from time to time. E.A.Mitscherlich (15) studied the response of plants to increasing doses of fertiliser, hence finding theoptimum amount for a particular soil; H.Neubauer (16) obtained the information by analysing seedlings grown on the soil and noting their deficiencies.

After the discovery of the flourishing micro-organic life existing in the soil and the realisation of its importance to productiveness and physical structure, micro - biological and bacteriological methods were developed, based on the assumption that soils of high fertility are soils of high micro-organic activity. A variety of bacterial cultures, such as Azotobacter for example, are used to show particular deficiencies or general infertility, and provided care is taken in carrying out the experiments and interpreting the results in relation to external factors they may give accurate information about the manurial requirements.

Recently electrodialysis has been employed to determine the nutrient qualities of the soil, but insufficient work has been done as yet to prove the value of the method for general adoption.

By comparing the results obtained for available plant food with those for total or reserve plant food, it can be seen whether the lack of one or more constituents is likely to be permanent or only temporary. If the latter, it may be possible to make it available by some such means as liming or addition of a suitable organic manure which will liberate the substance in soluble form.

In addition to investigations conducted for the specific purpose of improving the soil agriculturally, however, research was started on more general principles, along lines

which showed no immediate practical application and yet which have since proved of tremendous practical value in many cases. The classification of the soil presented a problem which called for an intensive study of soil characteristics, and even now a lot of work remains to be done before a completely comprehensive system can be given that will be universally accepted.

The significance of the physical structure was realised, and physical determinations found more and more favour. The first obvious property and basis of a general classification is the proportion of different sized particles in the soil — estimated by what we now term the mechanical analysis. For this purpose the larger particles are determined directly by sieving and weighing the fractions, but for the smaller grains an indirect method must be used. The variations of this process are all of the same general type, depending on the rate of sedimentation of the particles in a liquid. Arbitrary size limits for the fractions have been chosen, but unfortunately they still vary in different widely used methods.

The degree of subdivision of the particles depends largely on the treatment they undergo prior to sedimentation, and as the main object is to find out about the ultimate particle size of the soil the best treatment would seem to be that which gives the greatest dispersion of the compound aggregates

without destruction of the single particles. Before the dispersion it is usual to remove cementing organic material, if this exceeds about 2%. by treatment with H_2O_2, and carbonates and exchangeable bases with dilute HCl. A number of dispersing agents have been tried, and until recently dilute ammonium hydroxide, which together with the acid treatment produces an ammonium soil, was the most popular among soil workers. Discrepancies were reported, particularly with soils containing gypsum, when the particles tended to flocculate, but with most soils comparative results were obtained.

It was then found that a sodium soil would give easier and more complete dispersion, so that most workers now replace the NH_4OH with a sodium base. NaOH has been shown to be the most effective, much more so than NH_4Oh, with the result that the time of shaking for complete dispersion can be considerably reduced.

There are various ways of grading the particles, of which the pipette, sedimentation, density and photoelectric methods are perhaps the best known, but for general convenience and rapidity the pipette method has not yet been superseded. S.Oden (17) was the first to express the results as a continuous function of particle size by means of his automatic balance, followed by G.Wiegner (18) who measured the change

in density of a sedimenting suspension, and G.W.Robinson (19) in the form of summation curves in which the summation percentages are plotted against logarithms of the settling velocities. Characteristic curves are claimed for soils of different types.

Examination of the fractions separately revealed the fact that most of the important soil properties were connected with the clay portion alone, so that in many soil laboratories today it is by itself the subject of detailed study. The increase in knowledge of colloid chemistry and discovery of soil colloids in this and the organic fractions was and is a great help in explaining many soil characteristics. Such determinations as moisture equivalent (the amount of moisture retained in a soil after being centrifuged under standard conditions), moisture content at the "sticky point" and different humidities, heat of wetting, volume change on wetting, and loss on ignition, so much in favour at the present time, depend largely or entirely upon the colloid content. They, together with a few less important estimations are the so-called "single - value" constants. Attempts have been made to find a single-value determination as a criterion of erosiveness, but there seem to be too many influencing factors to make this possible.

Chemical analysis of the clay fraction has proved of value for soil classification purposes, especially in finding silica-sesquioxide ratios, which seem to have some connection with

soil origin and certain soil properties. The subject is still undergoing investigation.

Several other ratios which appear to be of significance in relation to the condition of the soil and its environment are being examined under widely different conditions of climate and soil type all over the world today, and while the evidence is at present rather limited the results in some cases have been very interesting. The carbon-nitrogen ratio deserves special mention.

It has long been known that although the proportion of C : N in undecayed organic matter is about 40 :1, it narrows in soils to about 12 :1, remaining remarkably constant at this value over large areas. In the humid climates where this investigation first took place the ratio did not alter much but when examined later in arid and semi-arid regions it was found to widen considerably, while much narrower values were also reported. The insufficient evidence at present available does not allow the variation with climate to be completely correlated, but it does seem that the dryer and warmer the area the wider the C ÷ N ratio, due probably to the more rapid decay of carbon compounds under these conditions, the nitrogen not being affected to the same extent. With a high rainfall it is also probable that a greater proportion of nitrogen compounds are leached away — a fact which may also account partly for the decrease in

C - N ratio usually observed with increase in depth, because although both the C and N compounds found as the result of weathering and bacterial action in the upper layers of the soil decrease with depth the N compounds have more tendency to pass downwards in solution. Also, of course, even small amounts of undecomposed organic matter in the surface soil will widen the ratio.

In comparisons such as these the lack of a standard system of analysis is a source of great difficulty. Not only do the methods themselves differ in the case of direct determinations like "percentage carbon", but many of them are the result of conventions, adopted perhaps by one country and not by another. The determination of organic matter by C X1.724, N x 20, ignition loss corrected for moisture and carbonates, loss in weight by oxidation with H_2O_2, and variations, is an example often quoted. None of these methods is accurate, so that no one is universally used, and comparable results are not always obtainable.

Laboratory determinations which at first sight appear inaccurate may not warrant more precise work when the field error of sampling is taken into account. Thus if the clay content is, say, 25%, an error of 1 either way, i.e. 24%or 26% on different samples need not be considered very serious. Un fortunately very much greater errors than this may be introduced, depending on the method of dispersion and graduation.

pH determinations may be made with great accuracy, but the extra information, if any, gained by suchamethod is probably outweighed by the time lost in the laborious attention to detail involved, at any rate for routine purposes.

It cannot be denied that more accurate results are always desirable, but for soil work particularly the present aim should be for greater rapidity and simplification of the method, provided that the inaccuracy of the laboratory determination does not exceed the field error. If this is the case, and there are still a number of determinations where it is, improvements must be made before universal adoption will be possible. More consideration will probably have to be paid to the soil profile than is usual in most laboratories because the reactions of the surface soil are not isolated, but closely connected with conditions in the lower horizons.

Soil Analysis as a whole is still in the process of evolution, and it is to be hoped that the progress will be rapid and an International set of standard methods with its practical advantages and simplification in the work of Soil Classification and theoretical considerations made available before very long.

The foregoing discussion is not intended to be in any way a complete treatment of modern Soil Analysis — no mention has been made of many routine laboratory determinations,

including exchangeable bases, lime requirement, pore space and density, and others -- but to give some idea of the position of Soil Analysis as it is at present.

A few of the methods used in the Government laboratories at Pretoria will now be considered in more detail, and suggestions made for their improvement.

(1) Mechanical Analysis

This is admittedly an arbitrary method of analysis, but it would be convenient for comparative purposes to adopt a more universal method of procedure. It is more general today to use NaOH in place of NH_4OH, with the advantages already mentioned, while the times and depth ofsampling should also be changed. Clay, for example, is usually taken at 10cm. after 8 hours standing at 20° C, or appropriate depths at any other temperature.

(2) Hydrochloric Acid Extract

Mention has already been made of the rather limited information to be gained from an analysis of this extract, so that here particularly the method used should, if possible, involve only the minimum of time and trouble. The macro - methods which are still used by the majority of soil analysts are tedious and unnecessary, because practically without exception they can be replaced by a shorter and less expensive micro - or other method.

Micro-determinations necessitate greater attention to detail, but with a little practice accurate results can be obtained easily and consistently. The replacement of volumetric and gravimetric estimations by colorimetric methods is in many cases sufficiently accurate for soil work, and the labour saved by so doing may be considerable.

The micro methods described by J.L.Steenkamp in a contribution from the Pretoria Chemical Laboratories were used by the author on citric and HCl extracts and found eminently satisfactory. Alterations were made only in minor details.

Probably the most important determination in the HCl extract is that of Calcium. In the case of Potash and Phosphates the amounts available are more important than the total quantities, but with Calcium it is the reverse. Furthermore, N.I.Sokolov (20) reported that the amount of Calcium in carbonateless soils passing into the HCl extract nearly coincides with the content of exchangeable Calcium, the amount obtained hence giving a distinct idea of the exchange capacity of most soils.

The method of H.D.Chapman as described by J.L.Steenkamp was used with the alterations given below. In place of a wash liquor containing ammonium acetate and acetic acid it was found preferable to use that recommended by Bassett (21)

viz.,distilled water saturated with Calcium oxalate — prepared by passing the water through finely precipitated washed calcium oxalate contained in a filter paper of filtering crucible. This removes the danger of loss in the process of washing.

Another source of error here is the tendency of the precipitate to creep up the sides of the filter-paper and be washed down underneath. This loss is more serious with macro - determinations, and when micro-quantities are used it is counterbalanced either by the reaction of the $KMnO_4$ with minute particles of filter paper carried through by the H_2SO_4 and wash-liquor or by the action of the H_2SO_4 on the $KMnO_4$ when heated.

A comparison of the results obtained using Whatman No 42 filter paper, a Jena No 4 sintered glass crucible, and a porcelain filtering crucibe of about the same porosity is given below (Table 1). A standard solution containing .5198 gms. of pure dry $CaCO_3$ and a little SO_2 - free H_2SO_4 per 500cc. was used, and the amount in milligrams recovered from 10ccs. given in each case. The oxalic acid formed was titrated with $\frac{N}{100}$ $KMnO_4$, which gave a blank of .15 ccs. with the filter paper and .05 ccs. with the crucible.

Table 1 (mgs. $CaCO_3$ found in 10ccs. solution)

Theoretical	Whatman No 42 filter paper	Porcelain crucible	Sintered glass crucible
(1) 6.40	6.46	6.37	6.43
(2) 6.40	6.43	6.40	6.40
(3) 6.40			6.43

In each case the results are well within the limits of experimental error, and the individual worker will make his choice from the point of view of convenience only.

Slow suction is sufficient for the crucibles, but they must be carefully cleaned free of Calcium sulphate after every few determinations.

Use of Ceric Sulphate

This reagent has recently been replacing potassium permanganate and dichromate as a standard oxidising agent in volumetric analysis, and it was tested in the above determination for the estimation of Calcium. The method was that described in a booklet on Ceric Sulphate published (2nd. edition) in 1933 by the G.Frederick Smith Chemical Company, Columbus, Ohio. Accurate results were obtained on all quantities likely to be met with in ordinary SoilAnalysis. The reaction was carried out potentiometrically, but an indicator suitable for dilute solutions is described by the publishers. In stronger solutions the colour of the Ceric Sulphate itself may be used for the titration. The main

advantages to be gained in this case are:-

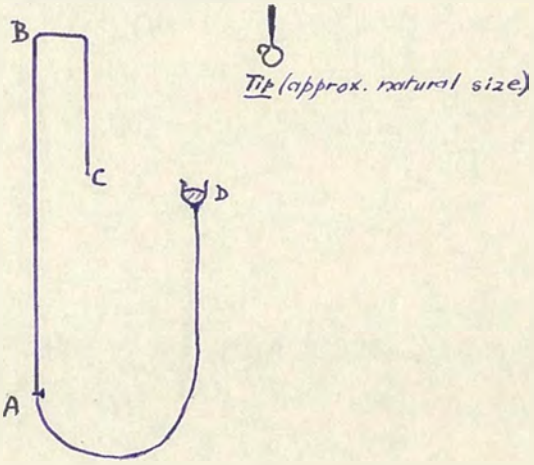
(a) The only valence change possible is $Ce^{++++} \rightarrow Ce^{+++}$ (Ceric → Cerous)

(b) The standard solutions are very stable over long periods.

(c) It can be used in the presence of HCl.

(d) Using Iodine monochloride as catalyst titration can be carried out in the cold.

For the delivery of this (or any other) solution in small quantities a special micro-burette was designed. A diagram of the burette is given below.



ABC is a capillary drawn out and bent as shown at the end, attached by means of rubber tubing to a mercury reservoir D. A graduated scale behind AB, previously calibrated by weighing successive deliveries and plotting on a graph, enables the volume used to be measured. Delivery, which takes place under the solution, is controlled by a tap at A. The whole capillary ABC holds between 4 and 5 ccs.

By means of this burette a stronger solution may be used for the titration with no loss in accuracy due to the small volume. If the solution reacts with the mercury (e.g. $KMnO_4$) a small amount of some non-reactive liquid must be placed between the two.

Organic reagents.

For the detection and estimation of ions in the HCl, citric acid and water extracts the use of these reagents shows great promise. Considerable practice is needed before the results can be consistently relied upon, but methods for the determination of most metals exist with considerable advantages over those usually employed.

As an example the case of Calcium may be quoted once more. This was precipitated and estimated as Calcium picrolonate by addition of Picrolonic acid as described by Hopkin and Williams (22), except that the precipitate was filtered through a No 4 sintered glass crucible in place of a No 3, which seemed to give low results. The precipitation may take place in the presence of magnesium and the alkalies in amounts up to ten times that of calcium, but not in the presence of copper or lead. The results obtained are very accurate, and the whole operation extremely simple.

In the detection of traces of minerals, which are often important in their catalytic or toxic action, and upon which

a lot of work still remains to be done, organic reagents may prove especially useful.

Finally, the possibilty of the introduction into Soil Analysis before long of an entirely new method of analytical procedure must be mentioned. The principle involved is that of the "dropping mercury cathode" introduced by Heyrovský in 1922, and estimations are made by means of an automatic registering apparatus known as a "Polarograph" In this a current is passed through the solution to be analysed and the polarising voltage increased gradually. An automatic photographic device records the variation in current and voltage graphically, and characteristic lines are obtained. A sudden rise of current without appreciable increase of voltage means that a cation present in the solution is being discharged ~~at the~~, the increase in the current at approximately constant voltage being proportional to the concentration of the ion, and the voltage at which discharge occurs indicating the particular ion. Tables may be obtained giving the voltage at which various ions are deposited at the mercury cathode.

In this way solutions containing a number of ions may be quickly and conveniently analysed qualitatively and quantitatively all in one process, with obvious advantages for soil extracts. Unfortunately difficulties exist at present in the estimation of certain ions — e.g. Na and K in the same solution — but these are being investigated.

Mr. E.T.Verdier, M.Sc., has recently started research

work at Rhodes University College on the use of this instrument, and the possibility of its adoption for routine analyses.

(3) The Determination of Total Nitrogen

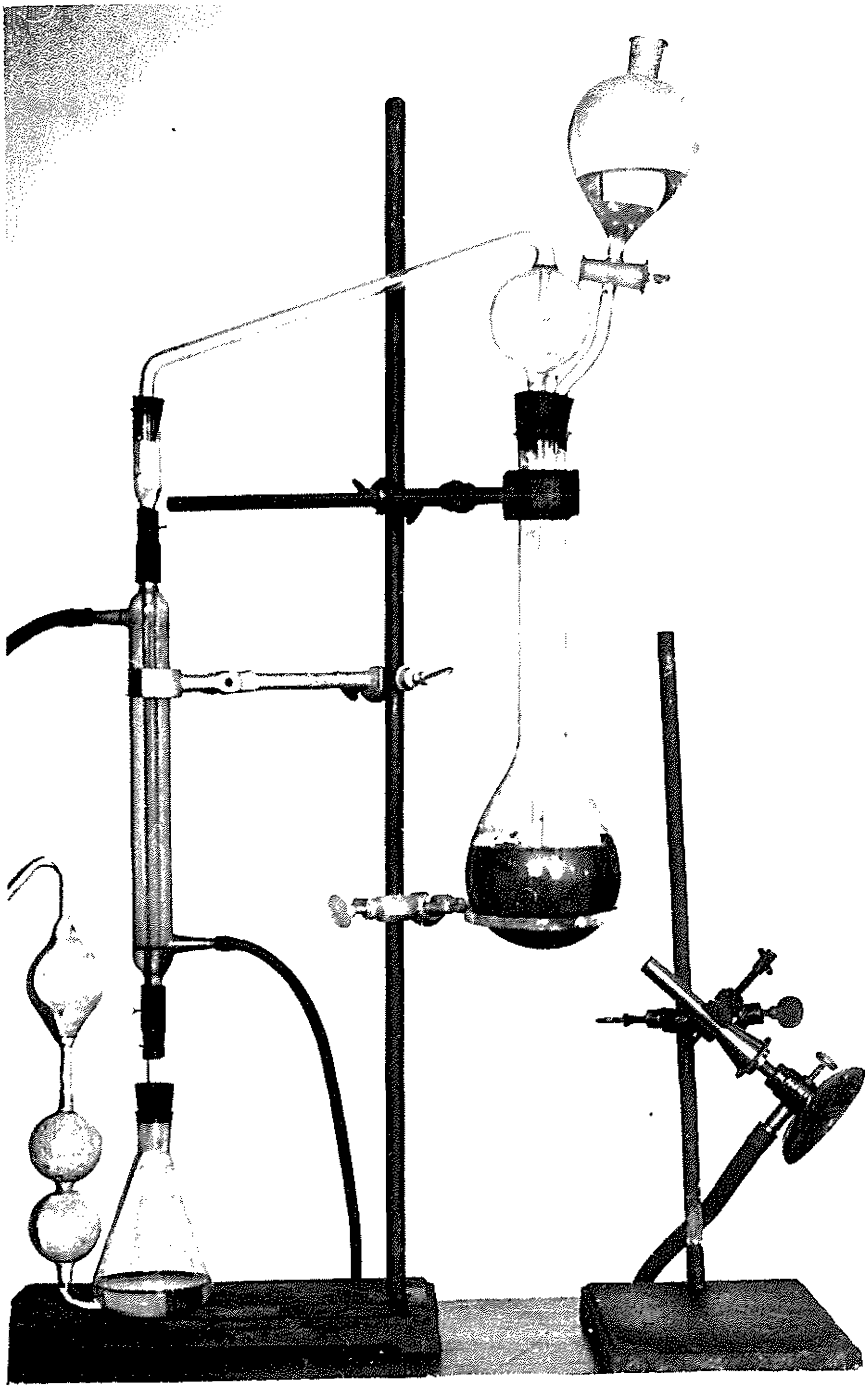
(A) Kjeldahl modification

For this purpose the normal procedure is that of the ordinary Kjeldahl method or one of its modifications, and provided suitable care and precautions are taken accurate and reliable results may be obtained with most soils. The method has many disadvantages, however, the main objection being the length of time necessary for the determination, and experiments were thereforeundertaken with a view to speeding up the process without decreasing its accuracy in any way.

The estimation takes place in three parts — digestion with concentrated H_2SO_4, distillation with caustic soda into excess acid, and titration with standard alkali; and in each case it was found possible to introduce certain improvements.

In the digestion process, after adding concentrated H_2SO_4, sodium or potassium sulphate is usually added to raise the boiling point of the mixture, and a small crystal of copper sulphate as catalyst. Other catalysts for increasing the rate of oxidation have been tried from time to time, the most suitable one of recent years being selenium

PLATE D



or sodium selenate. For these experiments a catalytic mixture of sodium sulphate (anhydrous) copper sulphate and sodium selenate in the proportions as recommended by Barker and Shuttleworth (23) was used, resulting in a very marked acceleration of the speed of reaction.

With the soils used a clear solution (apart from solid insoluble matter) was obtained in from 15 - 25 minutes, and in all cases results were accurate with a total heating time of 35 - 40 minutes. The flasks were heated with ordinary bunsen burners, six burners screwed into a length of metal piping attached to a gas jet being found to give ample heat for carrying out six determinations at the same time.

The distillation apparatus was modified (see Plate D) by the introduction of a piece of glass tubing ($\frac{1}{4}$"diameter) through the rubber stopper of the distilling flask, with its lower end just above the bottom of the flask. By attaching the absorption flask (see below) to a filter pump this enables a slow stream of air to be drawn through the apparatus.

There are several advantages in this procedure. In the first place the tendency of the liquid to bump is considerably lessened, and for most N - determinations stopped altogether. In the case of soils some workers prefer to transfer the contents of the Kjeldahl flask after dilution to another, leaving behind most of the residue, but for rapid routine work this is not convenient. It was found possible to overcome the

difficulty by attaching the original flask and diluted contents to the distillation apparatus and heating it from the side, just above the solid matter, instead of directly underneath, by means of a Bunsen burner clamped in a convenient position (see photo). The flask rests on a clamped ring, no wire gauze being used. With a little care in adjusting the position of the burner it is possible by this means, together with the slow air stream through the liquid, to prevent bumping entirely, even when a considerable amount of solid matter is present.

Owing to the suction the pressure inside the apparatus is decreased, and consequently the boiling temperature of the liquid is lowered, resulting in easier and more rapid, but nevertheless complete distillation of the ammonia. This decrease in pressure means less danger of ammonia leaking out through badly fitting stoppers, and by placing one's finger over the end of the tube projecting from the flask and noting whether bubbles cease to be drawn through the absorption liqui or not, any leaks in the apparatus are at once detected.

Using this suction method it is obvious that the absorption flask normally in use must be modified — in any case a desirability in many cases when complete absorption of the ammonia is somewhat doubtful. The type of flask used may be seen in the photograph (Plate D).

Flasks with the lower two bulbs attached were available,

but it was found necessary to have a third, either fused or attached with pressure tubing (to enable it to remain upright) above these. Each bulb has a capacity of about 50ccs.

From a consideration of the Kinetic molecular theory of gases it can easily be seen that absorption is more efficient than with the old method of the tube dipping under the surface of the liquid. Absorption takes place over the big surface area at the bottom of the flask, and also while the gas is bubbling through the liquid in the bulbs.

Complete distillation of ammonia was obtained by distilling over only about 80 - 90 ccs., i.e. until the distillate just reaches the third bulb, and does not occupy more than about 30 ~~35~~ minutes.

Finally, it was thought that an indicator more suitable than methyl orange could be used for the titration of the excess acid in the absorption flask. Methyl Orange has a very poor end-point, and different workers have different ideas as to when this end-point occurs. Methyl red is often used, but a mixture of equal parts of methyl red and bromphenol blue as recommended by S.G.Shuttleworth (23) wasfound to be even better and to give a very sharp end-point in either direction. (Red in acid ⟶ yellow in alkali). The change takes place at approximately pH 4-5, so that by titrating just to yellow the neutral point is obtained almost exactly.

Detailed Procedure.

Weigh out 10-15 gm. of fine air-dry soil (3mm. in this case) into a Kjeldahl flask (500 cc.) and add about 15 gm. of a catalytic mixture of sodium sulphate (anhydrous), copper sulphate (crystalline powdered), and sodium selenate in the proportions 9:4:1. Shake to mix, and add 30 ccs. concentrated H_2SO_4. Heat gently at first and then boil for 1½ times the time taken for the liquid to clear. Allow to cool, dilute to about 200 ccs., and attach to the distillation apparatus. The absorption flask contains 15 ccs. $\frac{N}{10}$ HCl (for soils containing about .1% of N) and a drop or two of the indicator mentioned (vide supra). Draw a slow stream of air through the apparatus and then add excess of concentrated NaOH solution.

Most of the ammonia comes over in the first few minutes, so that heating should be gentle at first. Then heat sufficiently (from the side) to keep the contents of the flask boiling fairly vigorously until the distillate reaches the third bulb.

The flame may then be removed (the air-stream prevents sucking back) and after cooling somewhat the excess acid titrated with standard $\frac{N}{10}$ or $\frac{N}{20}$ NaOH.

The method was tested first with a weighed sample of Merck's G.R. $(NH_4)_2SO_4$ (dried) and then with a standard solution of the same substance containing 6.773 gms. $(NH_4)_2SO_4$ per 1000 gms. solution, i.e. .144% N, in portions of 25 cc. and 50cc. The results obtained are shown

in Table 2.

Table 2

$(NH_4)_2SO_4$	% N
.3164 gms.	99.8% of total weight
25 cc. of standard solution	.143
25 cc. " " "	.144
25 cc. " " "	.144
50 cc. " " "	.144
50 cc. " " "	.144
50 cc. " " "	.142 (diluted to 350 cc. before distillation)
50 cc. " " "	.144 (diluted to 200cc. before distillation)
50 cc. " " "	.144 (diluted to 150 cc. before distillation).

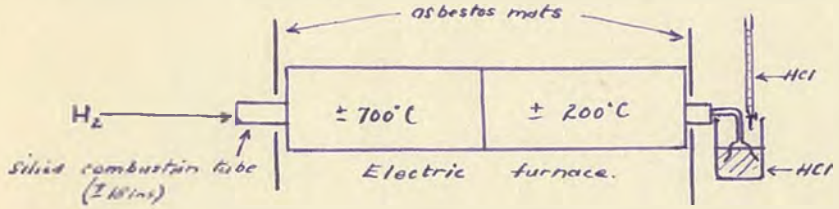
It will be noted that if the contents of the flask are diluted too much the result tends to be low, owing to the small proportion of liquid distilled over, but accurate results may be obtained if the volume before adding NaOH solution is not more than 250 ccs.

Duplicate results with soils containing about .1% N were found to agree within 1%. Considering the probable variation in N content of even so-called duplicate soil samples, greater accuracy than this is neither to be expected nor necessary.

(B) Hydrogenation Method.

The application of this method to the estimation of nitrogen in leathers and certain improvements in the apparatus as originally given in the German literature are fully described by S.G.Shuttleworth (23), and it was decided to try it out as a routine method for the determination of nitrogen in soils.

Essentially the method consists in the conversion of the N in the substance to NH_3 by heating with hydrogen in the presence of a suitable catalyst, and estimation of this NH_3 with standard acid. A diagram of the apparatus is given below:-



The hydrogen is purified by passing through acid and alkaline permanganate. As catalyst finely divided Nickel is used, prepared by heating Nickel formate at about 250° C. for two hours and cooling in a stream of hydrogen. ½ - 1 gm. of this is mixed with the substance, in this case about 2 gms. of fine air-dry soil, in a fairly large porcelain boat, the whole being covered with Ni-formate and then moistened with water. The second half of the tube is filled with asbestos fibres upon which the Ni has been deposited by mixing with Ni_2O_3 and heating.

The furnace must be so constructed that it is possible to heat the two halves independently, the first half to about 700° C, and the second half to about 200° C. After placing the boat in the tube (first half) heat the second half and pass a slow stream of H_2 to get rid of N_2 introduced in the air when inserting the boat. In the absorption vessel is a little water with Universal Indicator, kept neutral by means of the acid in the burette. For soils $\frac{N}{100}$ HCl was used.

When ammonia has ceased coming over note the level of the acid in the burette and heat up the boat, gently at first, and finally to bright red heat, until no more NH_3 is given off. It is advisable to heat about ½ hour after the Indicator has ceased to change colour to make sure. By using Universal Indicator and keeping approximately neutral it can be seen at once when the reaction is complete. Alternately, excess acid might be added at the beginning and titrated with standard alkali at the end of the experiment, provided sufficient time is allowed to make sure that all the N has been converted to NH_3.

The whole determination takes place in the one process, as distinct from the three separate stages of the Kjeldahl, and is complete in from 1 - 2 hours. No modification is needed when nitrates are present.

As a routine method it has distinct possibilities, because

once the apparatus is set up it needs very little attention and is cheap in operation.

A disadvantage is the fact that the furnace must be allowed to cool before each experiment, so that where a number of estimations are to be made several furnaces would be needed for rapid work. In the case of soils the use of such a small quantity of material (2 gms. as compared with 10 or 15 gms. in the Kjeldahl experiment) rather detracts from the accuracy and value of the method. The samples would need to be very finely ground and well mixed to ensure a correct result.

A comparison was made between the hydrogenation and Kjeldahl methods for a number of Albany soils, the results of which are given in Table 3, but it has not yet been tested over a sufficiently wide range of different types of soil to know whether it is universally applicable or not.

Table 3 (N per cent)

Soil No.	Hydrogenation	Kjeldahl
1	.044	.044
6	.112	.112
7	.136	.134
8	.163	.162
9	.059	.057
10	.113	.110
11	.111	.108
12	.122	.122

Table 3 (contd.)

Soil No	Hydrogenation	Kjeldahl
13	.150	.148
14	.167	.163.

The hydrogenation results tend to be slightly higher in some cases, possibly a more accurate figure for total nitrogen and in any case not a serious discrepancy.

(4) Electrical Resistances of Soils and Soil Extracts.

It is often desirable to make quick approximate determinations of electrical resistances when investigating soil properties, the value of the determination usually not warranting more accurate work. The conductivity of a soil - water mixture or water extract, for example, gives a rough idea of the salt content, but as the result must of necessity be only an approximation there would be no advantage in precise measurements. The increase in Specific Conductivity of a soil suspension on standing is used also as a measure of the fertility of the soil. (In the method of A.Sen and C.H.Wright (24) the difference between Specific Conductivities at the end of 24 hours and 8 days respectively is taken, the temperature being kept constant.)

The resistances are generally measured by the Wheatstone bridge method, using alternating current from a small induction coil and determining the null-point on the bridge by means of

a telephone detector. A better sound and minimum is obtained by using a valve-oscillator in place of the ordinary coil "buzzer". It gives a note of higher frequency, and the frequency, i.e. the pitch, can be adjusted to suit the worker.

The disadvantage of the apparatus is the space it occupies together with the time and trouble involved in setting it up, unless it is in constant use, and the possibilities of replacing it with a small portable apparatus were therefore investigated.

The instrument used was of German make, manufactured by Rudolf Kiesewetter (Excelsior Werk, Leipzig), enclosed in a case of dimensions 22x22x11 cm. and weighing 2.8 kilograms. A small flat 2 volt dry battery placed in the side of the instrument provided the current (4 volt would be better), either direct current measured on a small galvanometer with a sensitivity of .2 milliamp., or alternating current, a buzzer and telephone also being included.

Any resistance from .01 to 100000 ohms can then be measured in a few seconds by simply attaching to the terminals on the instrument, finding the point of minimum sound on the circular dial and reading the resistance directly.

For soils, a cup of standard shape and size, the brass sides of which act as terminals, is sometimes used in place of a cell for the measurement of resistances. With the high

resistances usually encountered this is sufficiently accurate for the purpose and eliminates not only the need for determining the cell constant and finding the Specific Concuctivity, but also the danger of breakage. Polarisation effects were not serious except where the electrolyte concentration was high, in which case it was impossible to obtain reliable values.

Readings were taken with solutions of KCl of varying strenghts using both the dipping electrode and the standard cup, and the values obtained with the portable apparatus compared with those given by a valve oscillator and by a coil "buzzer" connected in turn to a Kohlrausch slide wire and low inductance resistance box. Comparative determinations were also made on soil-water mixtures prepared by adding sufficient distilled water to the 1 mm. sample to form a thin mud and leaving to stand 20 minutes before placing in the cup.

The results are given in Table 4. In each case the value given is the mean of several readings obtained with different standard resistances.

Table 5 contains a number of resistances of Albany soils determined by means of this apparatus in the field. These values are more reliable than would be those obtained from the same soils in the laboratory, because the danger of an alteration in the electrolyte concentration is excluded. It was found, for example, that the resistances

of moist soils placed in new unwashed soil bags had in some cases altered by as much as 50% on redetermination at the laboratory a few days later, evidently due to absorption of some chemical from the bag.

In examining the relative erosiveness of different soils in the field these measurements also act as a check, because two soils apparently of the same type with different electrolyte contents may have very different erosive properties.

Table 4. (Resistances in ohms)

(a) Dipping electrode.

Unknown	Valve oscillator and Kohlrausch slide wire	Coil buzzer and Kohlrausch slide wire	Portable Apparatus
KCl solution	57	57	56.5
" "	58	56	55.5
" "	240	238	245
" "	775.5	766	770
" "	1020	1015	1025
(c) Standard cup			
KCl solution	210.5	211.7	205
" "	760.5	759	750
" "	1349.3	1349	1350
Soil No 9	1502	1495	1500
" " 10	550	552	527
" " 15	1623	1616	1650

The temperature was approximately constant throughout the experiments, the solutions for the dipping electrode being kept in a thermostat at room temperature.

Table 5

(Resistances in ohms of some Albany soils, using standard cup)

Sample No.	Type	Resistance.
15	Reddish brown loam	245
16	Grey brown sandy loam	950
18	Reddish brown silt deposited in dongas	1250
19	Brown-black deposited clay soil	535
20	Grey-brown sandy loam	580
21	Grey-brown sandy loam	580
22	Yellow clay-loam subsoil	240
35	Red clay-loam	780
36	Brown-grey drak soil	39
37	Grey sandy loam	1240
38	Yellow-grey sandy loam	1250
39	Red loamy subsoil	79
40	White loamy subsoil	35
41	Grey sandy loam (above 39 and40)	350
42	Brownish sandy soil	192
43	Red sandy loam	530
44	Grey sandy loam	820
45	Dark grey sandy loam	1060
46	Yellow-white clay subsoil	210

The low readings cannot be regarded as accurate, owing to the fact that they were obtained with the cup, which is not reliable at these concentrations. They are sufficient to show, however, that the soluble salt content is high. For accurate work the resistances would have to be adjusted to a uniform temperature (60°F))

It would seem that for soils particularly the apparatus described above might with advantage replace the older type, making possible extremely rapid work with all the accuracy needed.

Analyses of Some Aloany Soils

These figures (Table 6) were obtained while testing out the different methods of analysis, and the details followed were those supplied by the Pretoria Chemical Laboratories, with the modifications previously mentioned. pH determinations were made with the Follen colorimeter, in which use is made of gelatin strips containing various dyes covering a large range of H ion concentration. These are immersed in the soil suspensions for a definite time and the colour then compared with a standard range. The value of this instrument in the case of soils containing high percentages of colloidal matter is at present open to question.

Table 6

Percentage		Sample No 6	7	8	9	10	11
Stones		1.15	.18	.95	1.80	.11	.06
Gravel		1.01	1.24	1.93	2.68	1.56	1.53
Moisture		2.66	2.37	2.28	3.09	2.65	4.43
Loss on ignition		6.48	5.93	6.41	2.64	3.60	3.99
Soluble salt		.642	.437	.479	.507	.508	.488
Silt		9.6	9.4		5.9	10.7	13.8
Fine silt		9.3	10.11		1.5	6.4	1.9
Very fine silt		7.1	2.5		8.8	2.9	6.9
Clay		16.9	19.3	15.5	12.1	14.3	13.6
HCl extract	Insoluble res.(ignited)	80.30	82.00	79.71	85.85	84.45	82.53
	$Fe_2O_3+Al_2O_3$	8.25	8.49	10.44	5.97	7.99	7.67
	CaO	.248	.184		.124	.204	.202
	P_2O_5	.043	.039	.011	.024	.036	.065
	K_2O	.259	.204	.314	.348	.312	.375
H_2O extract	Total solids (95°C)	.225	.274	.220	.141	.138	.120
	Total non - volatile solids	.052	.152	.160	.070	.048	.068
	Loss on ignition	76.99	44.52	27.23	51.43	65.16	43.10
Total N		.11	.13	.16	.06	.12	.11

Table 6(contd.)

	6	7	8	9	10	11
pH of soil suspension (1:1)	6.1	6.1	6.1	6.1	6.3	6.2
pH of H_2O extract	6.4	6.5	6.3			
Swelling test	No change	No change	No change	No change	Small shrinkage	Small shrinkage.

Carbonates, chlorides and sulphates were tested for but proved to be absent.

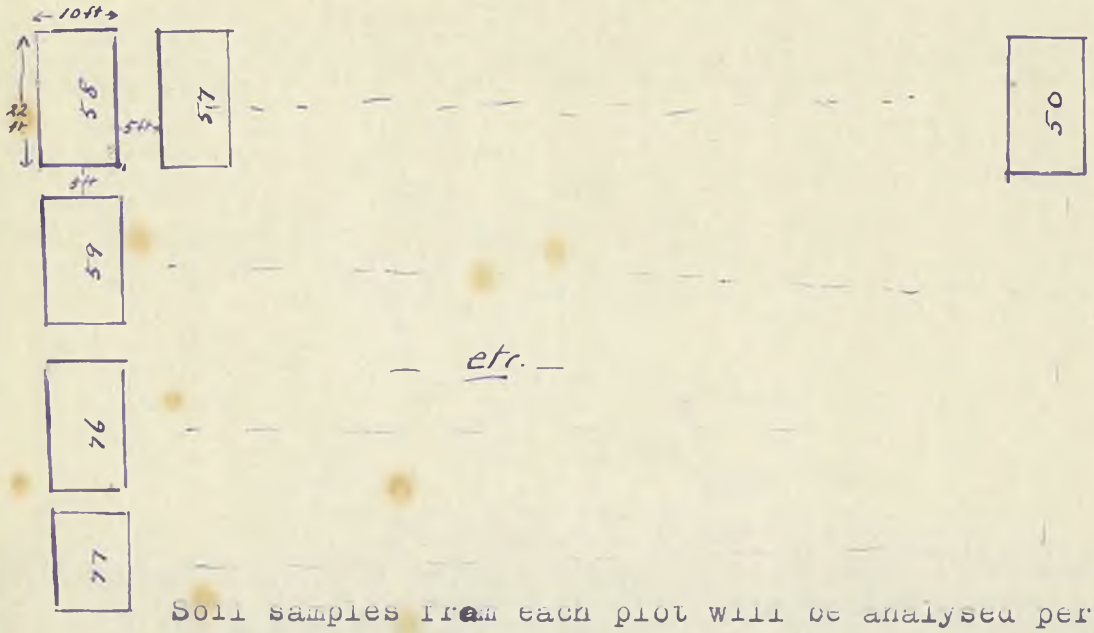
The percentages of clay in a few samples were determined with the following results:-

Sample	1	5	A	39	40	41	48	49
Clay	24.9	10.7	18.1	18.3	13.8	11.8	27.2	15.6

The figures in some cases, especially numbers 1, 5 and A, were suprisingly low for the type of soil. These three were taken from clay bands, numbers 1 and 5 deposited by evaporation of water and A the original clay subsoil. It is possible That NH_4OH did not effect complete dispersion for these samples.

Grahamstown Grass Breeding Station

A grass breeding experimental station has recently been established in Grahamstown under the direction of Mr. C.B.B. Liebenberg of the Department of Agriculture. In connection with fertiliser experiments designed to test the effects of various treatments on the composition of grasses and on the residual soil over a number of years a set of 36 experimental plots has been laid out as shown on the accompanying plan:-



Soil samples from each plot will be analysed periodically and the results of the preliminary analysis are shown in Table 7. It appears from the figures that the soils are initially fairly uniform over the whole area, though very deficient in plant nutrients.

Table 7

Sample No	Percent available (1% citric acid) CaO	P_2O_5	K_2O	Total N %
50	.056	.0012	.0055	.054
51	.042	.00098	.0033	.072
52	.045	.0016	.0041	.065
53	.048	.0014	.0054	.076
54	.052	.0013	.0047	.083
55	.049	.0016	.0074	.083
56	.056	.0012	.0051	.089
57	.063	.00092	.0034	.080

Table 7 (contd.)

Sample No	CaO	P_2O_5	K_2O	N
58	.064	.0011	.0048	.088
59	.062	.00063	.0074	.105
60	.066	.0012	.0055	.089
61	.060	.00086	.0068	.086
62	.046	.00092	.0066	.089
63	.050	.00083	.0042	.095
64	.038	.00083	.0048	.066
65	.052	.00068	.0042	.073
66	.041	.00087	.0040	.067
67	.056	.00091	.0058	.069
68	.052	.00087	.0041	.069
69	.052	.00067	.0057	.058
70	.043	.00078	.0083	.067
71	.057	.00071	.0057	.087
72	.054	.00061	.0048	.072
73	.046	.00072	.0052	.077
74	.043	.00058	.0032	.075
75	.072	.00065	.0038	.083
76	.068	.00053	.0053	.078
77	.058	.00064	.0057	.094
78	.053	.00058	.0045	.078
79	.050	.00064	.0044	.080
80	.049	.00067	.0078	.079
81	.048	.00054	.0059	.065
82	.054	.00071	.0064	.070

Table 7 (contd.)

Sample No	Ca O	P_2O_5	K_2O	N
83	.041	.00061	.0073	.074
84	.048	.00066	.0065	.066
85	.050	.00075	.0068	.067

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