SOIL STRUCTURE AND SOIL FERTILITY

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In the growth of plants, whether crops or weeds, many factors play their part. Some of these are soil factors; others, such as sunshine and rainfall, are climatic or regional. Some factors may be to a greater or less extent controllable by man; others are beyond his control. When the term "soil fertility" is used, too often the idea of plant nutrients, especially nitrogen, phosphate and potash, comes first to the mind, but there are many more aspects of soil fertility to be considered.

At various times, many papers have been read before this Association dealing with manurial experiments and the results obtained from various applications of fertilizers, supplying nitrogen, phosphate and potash, singly or in various combinations. During recent years composts, their preparation, uses and value have been discussed, including the important aspect of minimising the constant drain of mineral plant nutrients from our soils and their ultimate loss into the sea.

In this paper it is proposed to discuss an aspect of soil fertility which is becoming more important and which is attracting more attention as the results of previous neglect are becoming more apparent. That aspect is soil structure, its relation to soil fertility, its maintenance or, as too often the position is, its restoration.

The terms texture, structure and tilth are often used in a haphazard manner, and it may be as well to define these terms as used in soil literature.

Texture indicates the size of the ultimate particles in the soil as revealed by mechanical analysis, *i.e.* gravel, sand (coarse and fine), silt and clay. In preparing a soil for mechanical analysis these ultimate particles must be "dispersed," that is, the soil crumbs must be broken up and their cementing or binding material dissolved or destroyed, so that each particle, whether of sand, silt or clay, is separate.

Structure refers to the building up or aggregation of these particles or units of soil material into larger compound particles known as "crumbs," which may contain varying proportions of sand, silt and clay, usually with more or less organic matter or humus and always with some colloidal cementing material, whether clay or humus. Unlike texture, the structure of the soil can be altered for better or worse by various cultural operations or farming systems.

Tilth is the term used to describe the physical condition of the seed bed with respect to its mellowness and firmness. When a soil has a degree of fineness and firmness suited to the germination of seed and the growth of the crop, it is said to have a good tilth. Tilth depends on both texture and structure and, like the latter, it is influenced by cultural operations and varies from season to season according to the treatment the soil has received.

The advantages of a good crumb structure in a soil are obvious. A silty or clayey soil without any aggregation of its ultimate particles into crumbs would consist of a fine dusty powder with only fine pore spaces. Water would have great difficulty in penetrating into such a soil when dry, whilst if it were wetted drainage would be impeded, aeration restricted and root penetration difficult. Such a condition would be found in a heavy raw clay subsoil deficient in organic matter. A soil of the same texture, *i.e.* of the same mechanical analysis, but with a good crumb structure, presents a very different picture. The crumbs themselves contain fine pores, but the pore spaces between the crumbs are relatively large. Water can penetrate easily, so permitting of ready absorption of rain, whilst if the rainfall is heavy the excess water readily drains through the soil.

Soil erosion is one of our main problems in any branch of farming, and nothing accelerates erosion more rapidly than departing from nature's system of good soil cover. Bringing soils into cultivation not only exposes them to the eroding influences of rain and weather, but by destroying the original good soil structure rapidly reduces their powers of resistance to such influences.

Thus two soils might give similar results when submitted to chemical or mechanical analysis, but, on account of differences in structure, would have different powers in regard to crop production, and so they might well be said to differ markedly in regard to fertility. In one the original good structure may have been preserved, whilst in the other the constant growing of annual crops, with yearly ploughing and frequent inter-row cultivation, may have broken down the crumbs, leaving a powdery soil in which both rainfall and root penetration are impeded. As a result the plant is restricted to a limited volume of soil for its supply of plant-food, and there is only a limited reserve of water in the lower depths of the soil on which it can draw during dry periods, even if its roots did penetrate to such depths. Better crop returns would be obtained from a poorer soil of good structure than from a richer soil of bad structure.

In our own experience at Cedara, we have seen the results of the ploughing and cultivation necessary for the production of annual crops—particularly those calling for inter-row tillage—over a number of years. Our original veld soils have a good "nutty" structure, but on lands which were originally similar this good structure has been gradually destroyed and a dusty soil has been produced which blows badly in dry weather and tends to become muddy and not satisfactory to work during rains. Crop yields on such soils have also deteriorated. During recent years our system has been changed and we have attempted to improve matters by imitating nature and putting such soils back to grass for a few seasons. After a few years under pasture, with liberal fertilizing and grazing by the dairy herd, the land has in some cases been ploughed up again and annual crops grown for a few seasons before being put under grass for a further period. The result of this system has been an improvement of the soil as indicated by crop returns and by the appearance of the soil profile.

In preparing samples for chemical or mechanical analysis no attention is paid to the original structure of the soil in the field; in fact, that structure is destroyed in the crushing of the sample to permit of the obtaining of the "fine soil" and in the further process of the analysis. Of late years, more attention has been directed towards this question of structure and towards methods for measuring it. In Uganda, Dr. W. S. Martin, Chief Chemist of the Department of Agriculture, has done much work on the subject and has devised a method for studying soil structure and for expressing the results on a numerical basis. He has also correlated his findings on the determination of the soil structure of many samples with their history and productivity. As a result he can, on the basis of the structure of a soil, advise as to what its future treatment should be. Naturally his method of analysis must be applied in conjunction with a study of local soils and conditions before it can be adopted in other regions and under other conditions.

Briefly, his method is : Samples drawn from the field are air-dried and, after removal of roots and stones, are passed through a 3 mm. wire-meshed sieve. No rubbing or mortar should be used, clods being gently broken down with the fingers. After mixing and quartering, 100 gm. samples are moistened over-night by capillarity before being transferred to the top member of a three-sieve bank (2 mm.). The sieves, 15 cm. in diameter, fit into each other and each joint is protected with sections of motor inner tube, which also hold the wire handle in position. The bank is then lifted and lowered gently into a 4-gallon petrol tin of water until the fraction on the top sieve is well defined. The top sieve is then removed for air-drying. The operation is repeated for the 1 mm. and ½ mm. sieves; the soil suspension is then poured slowly through the two fine 100- and 200-mesh sieves. The fractions are air-dried and weighed. The weights are read as percentages of the original sample.

The first thing to decide is at what point in the scale of sizes should one enter to be sure of obtaining a true picture of the soil structure, in so far as it affects the field properties of the land, in particular its pore space or penetrability by water. In this work, all that is sought is a rapid and reasonably accurate means of assessing the value of a resting cover, or, on the other hand, the degree of deterioration or degeneration of arable land. For this purpose the ½ mm. point was decided on, partly because the use of the smaller sieves increases the time required inordinately, and partly because the majority of the particles larger than ½ mm. are aggregates, whereas greatly varying proportions of the residue on the ¼ mm. sieve are non-aggregated. In any case, under tropical conditions of rainfall, it is doubtful whether particles or crumbs smaller than ½ mm. exercise any beneficial effect on the water or air conditions of the soil.

The effect of cultivation on soil structure is illustrated by results he obtained from some soil samples from Barberton. The farm land had been under cultivation for fifteen years, alternately with maize and cotton, whilst the "veld" outside the boundary had carried a natural grass cover of 1½ to 3 feet high and had been grazed. The figures indicate percentages of water-stable particles over 0.5 mm. diameter.

Sample.	Cultivated per cent.	Veld per cent.
1	26.6	52.9
2	29.1	53.5
3	27.0	53.3
4	31.3	56.3
5	32.4	51.4
6	36.6	57.8
7	32.3	52.5
8	28.4	45.8
Mean...	30.5	52.9

Dr. Martin carried out many field experiments on methods of restoration of old and worn-out soils, judging results by the wet-sifting method of analysis previously outlined.

In general, he found that the application of farmyard manure or other organic manures or the ploughing-in of green manure crops had little effect on soil structure, but that putting the land down to grass, or allowing nature to restore a cover of grass, weeds and bush, did have the desired effect.

It is of interest and value to quote some of his results. They differ from results obtained by investigators in Europe, but that can be expected in view of the differences in climate. Under tropical conditions it is well known that applications of farmyard manures disappear from the soil much more rapidly than in the cooler European climate and that their effect on crop production is less lasting.

EFFECT OF MANURES.

In an experiment to compare varying dressings of farmyard manure applied in conjunction with green manure, lime and green manure and green manure alone, soil samples were taken after the plots had received three dressings of manure. The rotation followed was cotton, cotton, groundnuts, the manures being applied before sowing the green manure.

Treatment.	Water-stable particles over 0.5 mm. diam. Per cent.
Control...	28.5
Lime 2 tons	26.2
F.Y.M., 10 tons	25.9
,, 20 tons	27.9
,, 30 tons	27.3
Significant difference...	None

In another experiment, cotton seed in conjunction with green manure was applied, but with similar results in regard to the effect on soil structure.

Treatment.	Water-stable particles over 0.5 mm. diam. Per cent.
Control...	31.2
Cotton seed, 4 tons per acre (alternate years)	28.1
Green manure (*Crotalaria juncea*)	26.6
Cotton seed and green manure	29.9
Significant difference...	None

EFFECT OF GRASS COVER.

In Uganda, under the native system of shifting cultivation, elephant grass (*Pennisetum purpureum*) establishes itself on abandoned fields. In an experiment on regeneration by planting elephant grass compared with natural bush cover the following results were obtained :—

Treatment.	Water-stable particles over 0.5 mm. diam. Per cent.
2 years grass, 1 year cotton...	48.2
3 years grass	57.1
4 years grass	63.1
3 years natural bush...	56.2
Significant difference...	8.5

In studying the effect of the time of rest under grass a progressive improvement of the soil was noted :—

Treatment.	Water-stable particles over 0.5 mm. diam. Per cent.
4 years cultivation, 1 year rest	35.6
3 years cultivation, 2 years rest	36.9
2 years cultivation, 3 years rest	42.0

These few extracts from a wide field of work point to the outstanding value of grass in restoring soil structures. This result cannot be due merely to the amount of organic matter added as additions of farmyard manure or green manuring, showed little effect. Grass has a fibrous root system and when growing vigorously soon develops a thick mat of roots. The root-forces in action along and between the widely dispersed fibrous roots of the grass grip and bind the soil particles far better than does the normal tap-root system of the legume. Even if the root system of the grass only added the same amount of organic matter per acre as supplied in a dressing of farmyard manure or compost, it is in intimate contact with the soil particles and so must be more efficient in regard to its effect on the physical properties of the soil; it is a biological instead of a mechanical distribution of the organic material.

Sugarcane is a grass with a deep root system, but it differs from a pasture grass in that it does not provide a long period of complete undisturbed soil cover. Although the crop occupies the land for several years, the surface soil between the rows is disturbed to a greater or less extent after every cutting of cane. This means an interference with the fibrous roots in the upper layers of the soil, although the deeper roots remain undisturbed. Thus there must be some effect on soil structure such as Dr. Martin's work with elephant grass on Uganda soils revealed. Cultural methods practised on cane plantations have, in general, been planned with a view to controlling erosion, as, for example, planting along the contour in the usual hilly country of the cane belt. The root system of the cane no doubt must also receive some credit for this erosion control.

How far Dr. Martin's work can be applied to our cane lands remains to be seen, and there is scope for much work in that direction. Structure is not so important in the case of the more sandy soils, as in such soils texture dominates any factors that may affect structure.

The areas of heavier alluvial soils afford a field for the application of this newer method of studying soils and their productive powers, and for observing the effects on the soil of the root system of the cane.

After the war, and after the period of reconstruction and re-establishment of the wrecked sugar industries of countries overwhelmed by the tide of war, the question of the utilisation of surplus land, particularly marginal lands, in our sugar areas will become more urgent. Whatever system of farming may be adopted on these lands, the effect of that system on the structure of the soil must be kept in mind. The tragedy of that ill-balanced system—or lack of system—of farming totally unsuited to the soil and climatic conditions of the lands of the central plains of the United States which produced the devastation of the great Dust Bowl, should be a warning to us, despite the higher rainfall of this part of South Africa.

References.

Martin, W. S., and Biggs, C. E. J. (1937): Experiments on the Maintenance of Soil Fertility in Uganda. East Afr. Agric. Jnl. vol. 2.

Martin, W. S. (1944): Grass Covers in their relation to Soil Structure. Empire Jnl. of Exper. Agriculture, vol. 12.

Martin, W. S. (1944): Soil Structure. East Afr. Agric. Jnl. vol. 9.

Russell, E. W. (1938): Soil Structure. Imp. Bureau Soil Science Tech. Comm. No. 37.

Mr. TAYLOR said after he had written his paper he completed certain studies in soil structure at Cedara. These samples were taken from areas under various treatments, e.g. original veld, fields under annual crop and established pastures of various ages.

The soils were all chocolate loams of the doleritic type common on the hillsides of the College farm. The soils under annual crop obviously had lost much of their original humus content, especially in the case of No. 4.

Samples 7 to 15 were taken from the Botanist's experiment plots where various grasses were being tried out under uniform soil conditions. Prior to being used for that purpose this area had been under various crops for a number of years and was subjected to surface erosion. The plots from which samples were taken had (except for No. 10) been planted to the grasses specified for at least eight years.

Determination of Crumb Structure.

CEDARA SOILS.

Sample No.	Crumbs retained by 2mm Sieve. Per cent.	Crumbs retained by 1mm Sieve. Per cent.	Crumbs retained by 0.5mm Sieve. Per cent.	Total Crumbs above 0.5 mm diam. Per cent.
1	33.3	26.9	7.2	67.4
2	48.9	24.3	6.3	79.5
3	35.1	27.8	8.9	71.8
4	13.7	20.4	6.1	40.2
5	20.7	19.4	7.9	48.0
6	25.0	23.7	8.8	57.5
7	15.5	30.0	9.2	54.7
8	9.8	24.4	7.9	42.1
9	16.6	29.0	8.8	54.4
10	11.8	24.1	7.6	43.5
11	15.0	20.1	7.7	42.8
12	9.8	21.5	9.6	40.9
13	15.3	23.6	7.7	46.6
14	21.3	21.4	8.1	50.8

The mechanical analysis of a typical veld soil at Cedara taken from the same area as No. 1 in the above table some years ago gave the following data :—

Fine gravel	1.9 per cent.
Coarse sand	7.4 per cent.
Fine sand	10.2 per cent.
Silt	6.9 per cent.
Fine silt	3.9 per cent.
Clay	35.3 per cent.
Loss on ignition	15.1 per cent.
Moisture	19.3 per cent.
	100 per cent.

Sample No. — Description.

1. Veld never ploughed. Originally Themeda triandra, now largely pioneer grasses.
2. Veld never ploughed. Themeda completely vanished.
3. Adjoining No. 2 veld ploughed up 10 years ago; now under Paspalum dilatatum, not ploughed since establishment.
4. Land under continuous annual crop for about 40 years. Humus largely lost and soil tends to blow when dry. Contains some lateritic gravel.

Sample No. — Description.

5. Land under continuous annual crop for about 30 years. Soil not so deteriorated as No. 4.
6. Adjoining No. 5 and originally under same treatment. Put down to Paspalum dilatatum 12 years ago and not ploughed up since then. Soil shews improved physical conditions as compared with No. 5.
7. Botanist's plots. Kikuyu.
8. Botanist's plots. Paspalum virgatum.
9. Botanist's plots. Paspalum notatum, 8 years.
10. Botanist's plots. Paspalum notatum, 3 years.
11. Botanist's plots. Raemarthria fasciculata.
12. Botanist's plots. Pennisetum purpureum.
13. Botanist's plots. Panicum maximum near stool.
14. Botanist's plots. Panicum maximum stool dug up.

Mr. HAMMOND said that it was suggested in this paper that after the re-establishment of the sugar industries at the end of the war the problem of surplus land would become more urgent in this country. The reason for this suggestion was, however, not quite clear. In the past there had been apparent overproduction of sugar in the world, but that was due to the fact that sugar consumption was abnormally low in certain areas and distribution poor. We were now given to understand that serious attempts would be made after the conclusion of hostilities to see that the requirements of the world as far as essential foods were concerned were fully met. If that were done he could only visualise a great shortage of sugar. Some people had only one solution to the problems of the South African sugar industry and that was restriction. That was entirely the wrong approach. It might be found that restriction was unnecessary; what was wanted was rather an increase in the yield of sugar per acre, and an increase in the markets for the South African producers who could produce sugar as cheaply and in many cases cheaper than 75 per cent. of the sugar producers of the world.

Mr. TAYLOR said that enough foodstuff had never yet been produced to feed the population of the world adequately. Distribution in the past had been very poor. Mechanical means of distribution immediately after the war might still be inadequate and he was not optimistic enough to expect all the talk about reconstruction and a new, better world to come true. He thought political-economical restrictions would again operate. The facts were that Great Britain had increased her production of beet sugar, and the same might be expected in the rest of Europe. What would happen in the East we did not know, but in his paper he mentioned the question of utilization of surplus land and particularly marginal land. The best use of such land would become an important factor when competition between sugar growing countries became keen again.

He did not suggest in his paper that grass should be used as an alternate crop for sugarcane as the latter was itself a grass and differed only from a permanent pasture in that superficial layers were periodically disturbed. Sugarcane, therefore, to a certain extent fulfilled that condition of a cover crop. He was mainly thinking of the effect of other alternative crops on the soil structure, and he would be very interested to see what the effect of sugarcane was on soil structure, although it was rather difficult to study this problem on a sandy soil.

This work could only be regarded as being of a pioneering nature as so few samples, all from one type of soil, were investigated. A study of the effect of sugarcane growing on the structure of soils of the cane belt might be both interesting and useful.