THE COMPACTION OF SUGAR-BELT SOILS AT VARIOUS MOISTURE LEVELS

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Introduction

Along with other forms of organised agriculture elsewhere, the South African Sugar Industry has become increasingly aware of the importance, and indeed, the ultimate necessity for mechanisation in various agricultural practices. With the rapid progress of engineering of recent years, it is now common to observe numerous loading appliances and cane transporting vehicles distributed throughout the field of the industry whereas in former times, loading was almost entirely manual, and cane transportation restricted to the cane line and 'gollovan', or small rail truck.

Mechanisation committees have been established within the industry to investigate mainly those aspects of field mechanisation concerned with labour efficiency. A futher aspect not being neglected, is the deleterious effect of the passage of heavy machinery over the soil, compacting and destroying its structure, thereby inducing conditions less favourable for plant growth, with resultant loss in crop yield.

The Effect of Compaction on Plant Growth

With the use of heavy machinery in fields, soils are compacted by the reduction of pore space between the soil particles. Restricted soil aeration and moisture movement are an important limiting factor in the development of an extensive root system such as sugarcane. It impairs the respiration of an established root system, thereby retarding water and consequently nutrient uptake, also preventing normal biological processes. Comprehensive field examinations of compaction by tillage and transportation machinery in Hawaii, for example, showed that where roots had grown in a compacted soil they were flattened and distorted, while those in uncompacted soil were rounded in cross-section. In addition to the above ill-effects resulting from compaction, a soil that has been compressed may cause impedence to roots because of increased mechanical strength, the roots having to exert greater forces to penetrate the soil mass. In Hawaii, in a basalt soil, it was found that a soil with a bulk density of above 1.55 is impenetrable to roots while the critical density affecting root penetration is 1.46.[2]

The Effect of Pressure on Soil Density

The process of compaction in a soil is of course dependent upon a number of factors, amongst which may be included the mechanical and mineralogical composition, the moisture content and the natural consolidation of the soil itself. Thus compaction resulting from pressure on the soil is not directly related to pressure alone, but modified by these other factors.

The most important single modifying factor in soil compaction is the moisture content. The effect of varying amounts of moisture in soil during compaction of Sugar-Belt soils is the subject of this paper and will be discussed below.

A further modifying factor in soil compaction is its textural or mechanical, and its mineralogical composition. Thus a pure sand will not undergo compaction to the same degree as a loam in which sand and clay minerals are present in about equal amounts. On compaction of a loam, especially in the presence of some moisture, the platy clay minerals are compressed into the voids between the sand grains yielding a concrete-like structure. In a clayey soil, with little sand, compaction is not so great as these soils are fairly coherent and little deformation can take place. A complicating factor in this case, however, is the tendency for some clay minerals to swell on hydration yielding a hard dense structure on dehydration. It is in its effect on soil clay minerals that the degree of moisture present has its most profound effect.

Initial consolidation affects compaction in so far as an already fairly compact soil will not compact much further or to the same degree as one of low initial consolidation.

The Effect of Moisture on the Compaction of Soils

The relationship between water content and degree of compaction, when the soil is pounded by a falling hammer in a standardised manner is illustrated in the Figure I. It will be seen that increasing water content at first assists the rearrangement and closer packing of the soil particles, but above a certain optimum water content for maximum compaction, additional water prevents further close packing by occupying the remaining pore space. As stated previously, for a given method of compaction, the highest densities are attained in those soils that have a wide particle size range as in sandy loams. Thus from the figure it will be seen that the light Red Sand, T.M.S., Dwyka, Middle Ecca, Granite and heavy Red Sand soils fall within this group, as their particle size range is wide and they are all classed as coarse and fine sandy loams. High densities are not reached in soils that have coarse or fine particles only. Thus the Grey Sand, as will be seen from the figure, is somewhat below the sandy loams, it being classed as a sand on particle size analysis. Similarly predominantly fine grained clayey soils do not attain high densities as can be seen from the figure in the case of the red and black dolerites. The Lower Ecca and Tugela Schist soils although containing predominantly fine grained constituents do also have larger sized particles. This accounts for their somewhat higher maximum densities as can also be seen from Figure I.

In the case of the Mist Belt T.M.S. soil, compaction is considerably less than in any other type of soil on account of the high organic matter content (±10 per cent). With increase in organic matter content compactibility decreases as has been proved by Free[1] in the United States. The behaviour of the Mist Belt soil is in agreement with this.

The method on which Figure I is based is that developed by Proctor,[6] and is commonly used by civil engineers in roadway construction. It consists of ramming a soil at varying moisture contents in a standard manner in a standard cylinder. This is not ideal for compaction studies involving machinery in motion, as the pressure in the latter case is applied in a different manner.

It was found by Weaver and Jamieson,[7] however, that compaction under tractor wheels yields a water-content-compaction curve similar to the falling hammer method of Proctor.

The moisture contents for maximum compaction of the common Sugar-Belt soils as found by experiment are given below in Table I.

TABLE I

Soil Type	*Maximum Density*	*Per cent Moisture @ Maximum Density*	*Per cent Porosity @ Maximum Density*
Tugela Schist	1.62	24.5	32.2
Granite	1.84	13.0	25.8
T.M.S.	1.93	11.0	25.8
T.M.S. Mist Belt	1.21	41.5	42.5
Dwyka	1.92	11.5	22.9
Lower Ecca	1.64	21.5	35.9
Middle Ecca	1.90	12.5	21.8
Red Dolerite	1.50	30.5	33.9
Black Dolerite	1.49	28.0	35.2
Light Red Sand	1.95	6.5	27.2
Heavy Red Sand	1.85	16.0	31.7
Grey Sand	1.75	10.0	33.5

In general the sandy loams and sands undergo their maximum compaction at about 10 per cent moisture, intermediate soils at about 20 per cent, while the more clayey soils undergo maximum compaction at about 30 per cent moisture. Mist Belt soil maximum compaction moisture is about 40 per cent.

These figures are in agreement with what is known of the water holding and field capacities of these soils. Indeed with the possible exception of the Mist Belt soil with its peculiar properties, maximum compaction in the other soils takes place at a moisture content very near their field capacity.

Density of the soil is not the only factor to be taken into account in the study of the compaction of soils. Another important factor is the percentage porosity which gives an indication of the degree of "openness" of the soil. The porosity governs the circulation of both air and water in the soil as well as providing channels for root growth. From Table I it will be seen that the Middle Ecca and Dwyka soils suffer the most reduction of porosity during compaction. Anyone who has had experience with these soils will bear this out. Compaction affects the porosity of the other soils to varying degrees, the Mist Belt soil being again the least affected.

It is interesting to observe to what degree the porosities of the soils can be reduced by extreme compaction with adequate moisture under laboratory conditions. These are given in Table II.

TABLE II

Soil Type	*Maximum Density*	*Per cent Porosity @ Maximum Density*
Tugela Schist	1.72	28
Granite	2.06	17
T.M.S.	2.05	21
T.M.S. (Mist Belt)	1.84	22
Dwyka	2.06	17
Lower Ecca	2.24	12
Middle Ecca	2.02	17
Red Dolerite	1.64	28
Black Dolerite	1.40	39
Red Sand...	1.97	27
Grey Sand	1.77	33

In this case it is the Lower Ecca that has been affected the most, followed by the Granite, Dwyka and Middle Ecca soils. The Black Dolerite has been affected the least.

These results are somewhat different to those in the previous table as they were not derived under the standard conditions as were those of Table I. The organic matter content has probably affected the Mist Belt soil less in the second than in the first table on account of extreme compaction conditions. The black dolerite soil with a large amount of moisture present, deformed plastically, thus not yielding such a high density as in the previous case. This soil also swells on hydration giving a larger volume and thus a lower density.

Work yet remains to be done in determining at what degree of compaction cane growth is affected in each of the soil types and it is expected that this will be commenced shortly. Preliminary work has been done on the rate at which a soil undergoes compaction. This is illustrated in Figure II.

The compaction was effected by running a tractor and trailer with a three ton load, a number of times across a bare field of Middle Ecca soil at almost optimum soil moisture compacting conditions. As

FIG. I

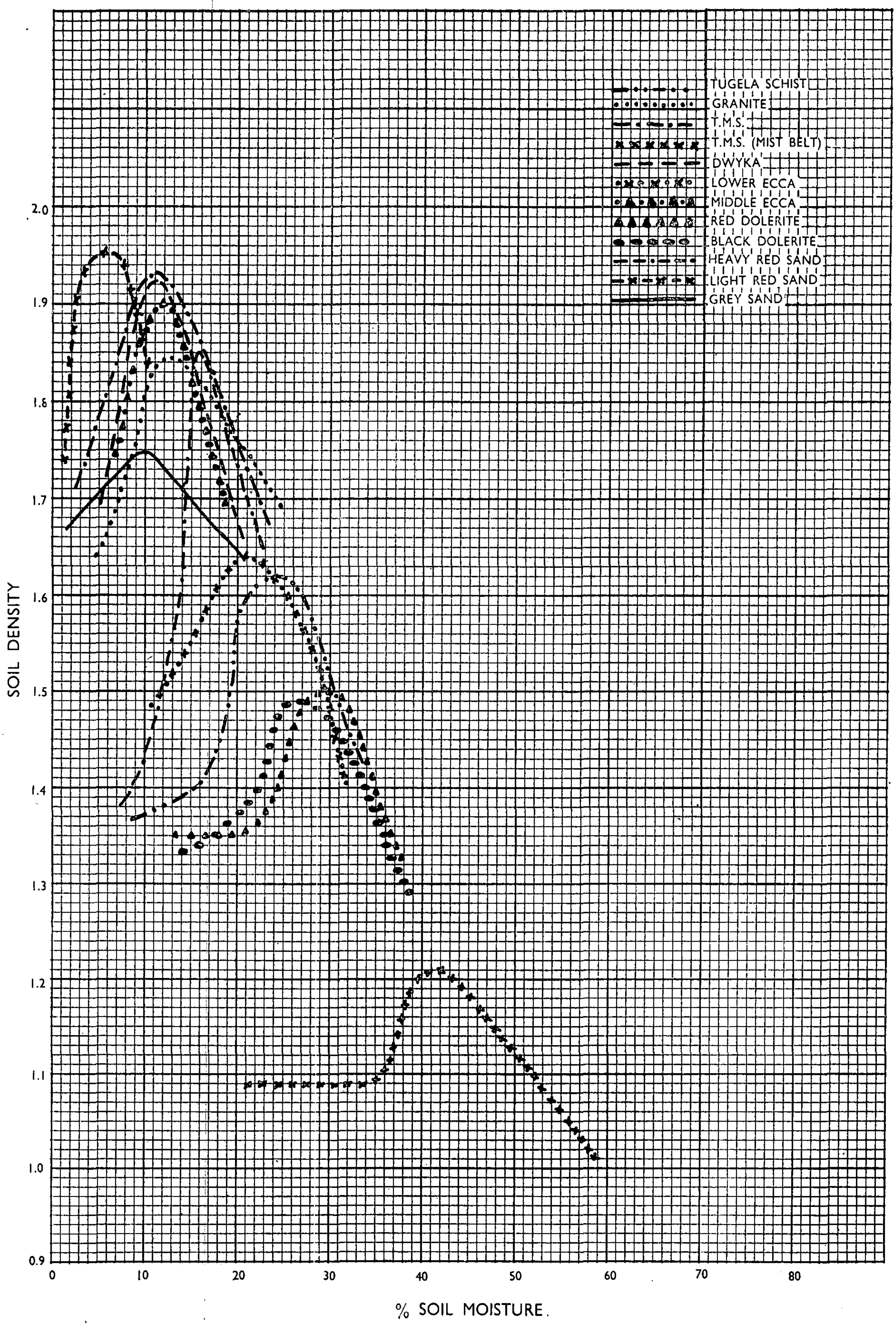
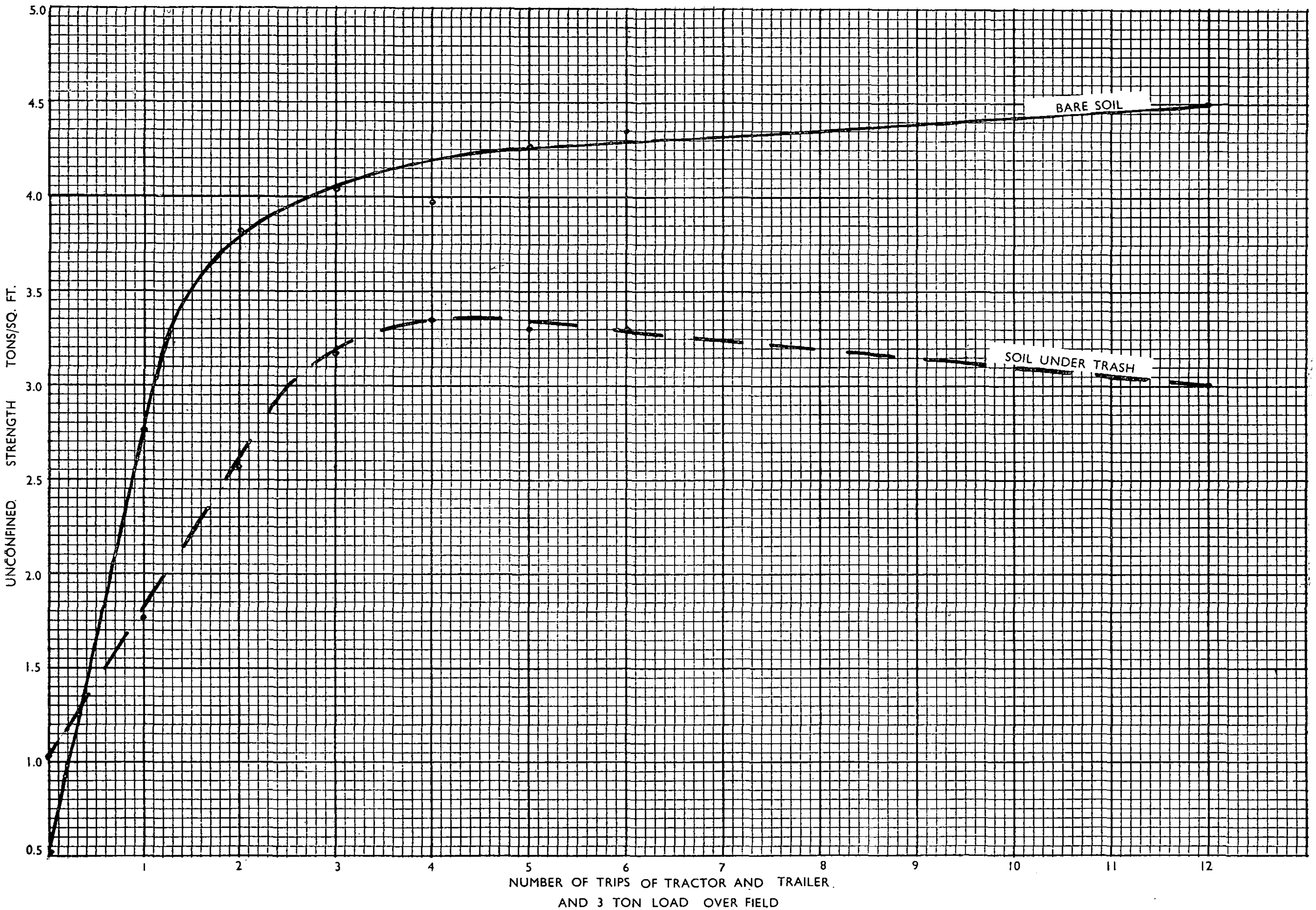

TUGELA SCHIST
GRANITE
T.M.S.
T.M.S. (MIST BELT)
DWYKA
LOWER ECCA
MIDDLE ECCA
RED DOLERITE
BLACK DOLERITE
HEAVY RED SAND
LIGHT RED SAND
GREY SAND
SOIL DENSITY
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0
10
20
30
40
50
60
70
80
% SOIL MOISTURE.

FIG. II


BARE SOIL
SOIL UNDER TRASH
UNCONFINED STRENGTH TONS/SQ. FT.
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1
2
3
4
5
6
7
8
9
10
11
12
NUMBER OF TRIPS OF TRACTOR AND TRAILER
AND 3 TON LOAD OVER FIELD

can be seen, compaction increases very rapidly initially but falls off after about the third trip whereafter further compaction is slow. Much the same condition was obtained by running the loaded tractor and trailer across trash covered soil, the difference being that the initial compaction was not as rapid, although in both cases after about the third trip further compaction falls off. Thus there is no essential difference between compaction of bare soil and that under trash. Indeed the trash by conserving soil moisture may induce increased compaction by maintaining a moisture content near that required for maximum compaction, whereas a bare soil would have dried out to considerably below this value in the same time. The incorporation of trash in a wet soil would yield a brick-like structure on ultimate complete drying.

In the case illustrated in the figure as mentioned previously, the bare soil was at a moisture content conducive to maximum compaction, whereas that under trash was considerably more moist even yielding by plastic flowage. With lighter loads also, the initial compaction was not as rapid. From this it is evident that the number of times a soil is subjected to compactive forces should be reduced to a minimum if deleterious effects to the soil are to be avoided.

Soils compacted and subsequently broken up by subsoiling and similar operations do not give the same yield as one not subjected to compacting conditions. In Hawaii, it was found recently, that a reconditioned roadway plot yielded 79 tons per acre and 10.9 tons sucrose per acre while non compacted control plots yielded 108 tons cane per acre and 14.4 tons sucrose per acre.[5] Thus it is better to minimise the risk of compaction rather than to have to recondition soils at a later stage.

Summary

The common Sugar-Belt soils when subjected to compaction, attain their maximum density at differing moisture contents. Sands and sandy loams compact most at about 10 per cent moisture, intermediate sandy clay loams at about 20 per cent while for clay loams the figure is about 30 per cent moisture. Mist Belt soils are affected the most at about 40 per cent moisture. These moisture values are very close to the respective field capacities of these soils. Compaction proceeds very rapidly initially but drops off subsequently, reconditioned compacted soils having reduced yields compared with uncompacted soils. It is better to minimise the risk of compaction than to attempt rectification at a later date.

BIBLIOGRAPHY

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The Chairman, Dr. McMartin said that this was an initial step in opening up an important subject. A change seemed to be taking place recently in our ideas of the function of the soil. Now that fertiliser was applied in greater quantity the grower could look at the soil not so much as a source of minerals, but rather as the carrying agent for the minerals applied to it. Hence the physical properties of the soil should receive more attention than in the past.

Mr. Maud said it was not possible to put down hard and fast rules, such as to say that after 2.5″ of rain not to put a tractor on Middle Ecca soil, because there might have been a long period of drought prior to that or conversely it might have just experienced a heavy rain. It was better in this case to express the water in the soil as a percentage rather than in terms of the amount of rainfall that it received.

Mr. Bartlett considered that Mr. Maud's work was a start in obtaining some of the necessary basic information which was required to ensure that local designers produce machinery best suited to Natal conditions. He stated that this paper, carried a step further, would be of assistance to manufacturers in tackling the problem of compaction caused by cane haulage units.

Mr. Black asked if Mr. Maud could give a pointer as to possible field management with regard to use of vehicles and other implements, particularly cane harvesting trailers. He wanted to know if it might not be better to sacrifice acreage of cane to establish roads which could remain there for the life of the farm.

Mr. Maud replied that he thought that permanent roadways were desirable. He considered that the more vehicles were confined to permanent roadways, the better. The matter required further study.

Mr. Bartlett said that the mechanisation committee had considered this problem, but had decided not to proceed any further until they had received more information such as the figures given in the paper.

Mr. A. C. Barnes said that this problem loomed as a major factor in sugar cane agriculture, but he did not consider that soils were necessarily damaged by carrying heavy loads, provided the loads were moved when the soil was in a good condition to carry them. Last year this Congress discussed removal of cane during harvest under the worst conditions, with particular reference to Umfolozi. Various suggestions were made, but he was not sure with what result. It was fortunate that the reaping season in this country corresponded with the driest part of the year. It was obvious that a planter could not stop moving his cane because of a shower of rain, so that equipment must be so constructed so as to impose the least compaction on the soil. He agreed that vehicles should run in well-defined permanent tracks, especially from the point of view that cane soils are required to bear ratoon crops. It should be possible to determine actual loadings on different soils so that the grower could be guided upon the equipment he should use.

Mr. Boulle said that he did not agree with indiscriminate running over the field with the tractor, but this might be better than confining them to particular paths. It was not possible to have permanent roads when a field was planted.

Mr. Maud agreed that the more the load could be distributed on the field the less compaction could be expected, but rather than risk even a small amount of compaction over a wide area, he thought it would be better to establish permanent roadways on which cane would never be planted.

Mr. Barnes said that one question of importance was how the equipment was moved over the field.

Mr. Main said that at Umfolozi some growers tried trashing but had to give it up. This applied particularly to the flats. On the flats he thought that compaction was a problem, but if one cultivated deeply after removing the crop, there was no sign of compaction. On silty coils conditions could be different from hillside soils.

Mr. Pearson asked Mr. Bartlett to consider a system of roads not based on the slope of the ground, but on the carrying distances of harvested cane.

Mr. Bartlett said that there was a continual demand for further mechanisation and it was desired to eliminate, wherever possible, the necessity for carrying cane manually. When further mechanisation was applied one would have to go into the question of equipment best suited for carrying cane from the field. He appreciated that on extreme slopes the cane would have to be removed manually, and that the carrying distance should be considered when laying out a system of roads.

Mr. Pearson enquired about the use of smaller vehicles carrying a smaller load but using wide tracks.

Mr. Bartlett replied that there were a number of farmers in Zululand who were building systems which used smaller trailers for infield work. The merits of system would be studied this coming season.

Mr. Boulle asked if the compaction was caused by the front wheel of the tractor or the back wheel of the tractor.

Mr. Maud replied that tractor front wheels cut into the soil, but the rear wheels, which were driving wheels, actually exerted as much pressure as the front wheels as they were usually carrying a greater load. In addition much of this load was applied to the soil from the relatively small area of the tyre-lugs in contact with the soil.

The Chairman said that a certain amount of criticism of late had been directed against the bulk density method of determining compaction. The reason for this was that in the bulk density measurement the range of figures was very narrow. It was possible that compaction could affect the root development long before the obvious effect of heavy implements was felt.

Mr. Maud replied that that was why he included soil porosity as well as maximum density. Referring to Table I, he quoted that whereas in this case the T.M.S. soil had a density 1.93 and a porosity 25.8 per cent, the natural soil in an uncompacted condition had a density of 1.70 and porosity of 33 per cent. Likewise uncompacted Mist Belt soil had a density 1.13 and a porosity of 50 per cent, Dwyka a density of 1.65 and porosity 33 per cent, Middle Ecca, density 1.65, porosity 35 per cent, Dolerite density 1.43, porosity 38 per cent, and Red Sand density 1.61 and porosity 36 per cent. The porosity value was independent of the actual densities of the soil minerals. Thus the density of the quartz particles which predominate in a sandy soil is about 2.6 while the density of the clay particles which predominate in clayey soils is usually somewhat less.

The Chairman said that compaction was spoken of as something new but he asked what the compaction might be, with a large gang of Natives cutting cane in small areas, together with animals and implements. He understood that the pressure by animals' hooves was very great, greater than that caused by wheeled implements.

Mr. Maud agreed that the pressure by animals was great. This principle is incorporated in the "sheep's-foot" roller used in roadmaking to compact fills and unconsolidated material.

Mr. Palmer asked about the effect of soil compaction caused by large sized tyres as compared with track tractors.

Mr. Maud thought that compaction with track tractors would be much less than with wheel tractors. The larger the area over which a given load could be distributed, the smaller would be the compaction resulting from it.

Mr. Palmer asked about the organic matter in T.M.S. mist belt soils, and wondered what the effect of burning would be on such soils, and would not ploughing-in of trash prevent some compaction?

Mr. Maud replied that the organic matter in the T.M.S. mist belt soils as it was in the form of humus was in a different category as compared with trash. The soils that he mentioned were very springy, and were not usually very compactable.

Mr. Sexton said he had seen a shallow strip of land on which a number of vehicles travelled. The effect of compaction on this strip was most noticeable in that the germination was better.

Mr. Maud replied that in a well formed crumb structured soil there were much larger voids than in finer sandy soils. He said slight compaction might aid germination but if one went further it would affect germination detrimentally.