

## SYMPOSIUM ON SOIL COMPACTION

Introduced by Dr. T. G. CLEASBY

In introducing this symposium, I refer back to November, 1959, when the South African Sugar Association Industrial Field Mechanisation and Labour Saving Committee held a symposium on In-Field Transport and an important paper was submitted dealing with the compaction of soils. Since that symposium, the use of tractors and trailers for in-field transport has developed rapidly and also there has been a significant increase in the use of tractors for other field operations such as cultivation, planting, fertilization and weed control. For this reason it was thought that the time was now opportune to have a full discussion on the compaction of soils and its effect upon the cultivation of sugar cane. There is no doubt that soil compaction is a problem which is with us at the present time, and one which must grow. I say this because I believe that as our industry develops, it must become more mechanically minded in its agriculture. In time labour will become less available, more expensive, and in particular, unwilling to do the labouring tasks which it does today. It is for example, anybody's guess as to how long we can expect labour to trash, cut, carry and bundle or load sugar cane. We all hope it will be for some considerable time, but quite definitely the day will come when labour will not be available. Already in-field transport has developed to a stage where the cutter is assisted by mechanical loading, which eliminates carrying cane long distances and loading into trucks or wagons. Experiments have been carried out on the mechanical loading of cane in the field. It is worth noting that it is a phase which many other sugar producing countries have already passed through, and one which in the relatively near future our own industry may have to resort to. Furthermore, the Mechanisation Committee is importing mechanical harvesters for the purpose of experimentation.

My reason for mentioning in-field transport and harvesting is to show the inevitable trend whereby more tractors and other vehicles will have to go into our fields to do jobs which at the present time are done by hand or by animals. This must give rise to more compaction of the soil and unless steps are taken to combat it, based on reliable research, crop losses will result.

Irrigation, particularly overhead irrigation, can also result in compaction of the soil. I believe that this is significant because of the increasing area in the sugar belt which is being put under irrigation.

Irrigation can also affect the compaction of soils by the physical effect of the spray falling on the soils, and maintaining them at a higher moisture level, since at this higher moisture level the soil is more susceptible to mechanical compaction. Another aspect which must be mentioned is that there are already certain soils in the sugar belt which are highly compacted even in their natural state. The correct management of these soils is therefore very important if substantial crop losses are to be avoided, particularly in ratoons.

I mention these points to show that soil compaction is something which already affects practically everybody who grows sugar cane. I do not subscribe to the view that because of the dangers of soil compaction, a farmer should not go in for self-loading trailers, or put his land under overhead irrigation, if these developments are desirable. That to my mind would be putting the cart before the horse, or allowing the tail to wag the dog. I do, however, believe that it is absolutely vital for every planter to appreciate the dangers which can result from compaction of the soil. Also that it is necessary to carry out research to show exactly what can and cannot be done with different soils, the order of the resultant losses in yield if compaction exceeds certain threshold values on various soil types, and finally how effective corrective action can be taken on these soils. Planters who at the present day say they do not allow a vehicle into their fields are absolutely correct in doing this if they can. But I do urge them to think ahead to the day when this might not be possible, and what effect this is going to have on their fields and on their crops.

The main problem with soil compaction, as I see it, is its very insidious nature. In the discussions you will hear how difficult it is to measure, and how little we know about the order of loss occurring in different soils subject to different levels of compaction. We are all very familiar with the bare patches in fields where tractors have come out, but we do not know what damage has been done in fields where the tractor has travelled. Probably what we sometimes say is ratoon stunting disease, could, in actual fact, be compaction from in-field transport.

I have done a theoretical exercise to illustrate this, taking one rectangular acre of cane yielding 50 tons. I have assumed that 3 ton bundles were loaded per trailer, and 17 trips made to get the cane out. I have assumed also, for simplicity, that the bundles were all loaded across the centre of the one acre and that the tractor and trailer only travelled parallel to one side. Again assuming that the two wheels of the tractor and the trailer covered a width of two feet, this gave me the surprising figure that approximately 7,000 square feet of the one acre would be compacted by that tractor in getting the cane out. If we take 4 ratoons, and assume that each time the cane is taken out mechanically, this gave a total of 28,000 square feet compacted, or two-thirds of the acre. The objects of this symposium are therefore:

1. To spotlight the general problem of soil compaction.
2. To hear something of the basic nature of the problem from the people who are sitting with me. What is compaction of the soil, and how does it affect the plant; the degree of compactibility of the various soil groups found in the sugar belt and, the effect of moisture on compaction. Also, some work done overseas on compaction will be reported and the mechanical aspect of soil compaction discussed,

and, in particular, what can be done to minimise compaction caused by vehicles going into the fields. Dr. Beater will mention a recent preliminary experiment which shows quite clearly some of the losses which can be incurred from vehicles going into the field.

3. Leading up to a general discussion, I hope that you will:
  - (a) Ask questions relating to the compaction of the soil;
  - (b) Comment on the problem as you see it, particularly on methods used to correct soil compaction where it was incurred;
  - (c) And finally, suggest ways of investigating this problem critically and possibly indicate priorities in any such investigation.

The procedure I propose to adopt is to ask each of the four speakers to address you, and then throw the meeting open for discussion.

The contributions will be as follows:

1. Mr. J. N. S. Hill will speak on some of the fundamental aspects of the compaction of soil.
2. Dr. B. E. Beater will mention a preliminary experiment which shows that losses can be incurred by soil compaction.
3. Mr. G. S. Bartlett will deal with mechanical aspects of soil compaction, touching on ways and means of minimising the damaging effects of vehicles which have to go into the fields.
4. And finally, Dr. G. W. Shuker will mention some work done on soil compaction with sugar cane and other crops while he was overseas.

**Mr. Hill:** Soil compaction may be defined as the packing together of soil particles resulting in an increase in soil density through a decrease in porosity. I have some figures here to illustrate this point. In this figure at the top we see spherical particles packed in square formation, with 50 per cent pore space. If, however, these particles are shaken so that they pack in hexagonal formation, they fit more closely together; the density of the mass is increased but its porosity is reduced to 25 per cent. In the field the same thing will happen as I have tried to illustrate in this second figure. Here we have a porous soil with a good crumb structure, but once the structure is destroyed by a compacting agent, it will form a dense mass with very little pore space.

There are several agents responsible for causing compaction, both natural and artificial ones. Of the natural agents responsible, I think rainfall is probably the worst. Cases have been reported in the literature where rainfall has reduced the porosity of the surface soil by as much as 30 per cent. This is due to the action of the raindrop pounding on the soil and breaking up the soil aggregates to form a dense mass. For artificial causes we come straight to mechanisation in the field, and to illustrate how compaction affects crops, we must first of all look at its effect on the soil. Compaction exerts its greatest influence on infiltration

of water into soils, and I refer to my paper earlier today. In these two soils, the Windermere and Avoca series, where compaction has increased, the infiltration capacities and percolation rates have decreased. I have interpreted these results in graphical form to illustrate how infiltration decreases with increasing compaction.

Compaction also increases the power of a soil to hold moisture by reducing the size of the pores, since water is held more strongly in finer pores.

The significance of compaction in sugar cane agriculture is shown here in this little table showing the response of cane to various treatments in Hawaii. These three fields A, B and C on the Hilo coast of Hawaii are close to each other. Field A has not been harvested mechanically, B field has had 2 mechanised harvests, whilst C field had 3 mechanised harvests. The hilos in Hawaii actually enter into the fields and cause considerable compaction. Here we have the yield, tons cane per acre, dropping from 88.4 to 60 to 37; and the yield, tons sugar per acre, dropping from 7.5, to 5.9 to 3.9. These have accompanied the somewhat small soil bulk density change of 0.49 to 0.56. If this is reproduced in graphical form we see the sharp decline in yield with increase in bulk density.

You have been shown a drawing published by Dr. Bayer, showing the cane sett growing in a compacted soil. You could see clearly the very limited formation of secondary roots in the compacted zone of the soil, whilst about 10 inches down where the soil had good physical properties and was adequately aerated, secondary root development was very marked indeed.

Going down below to these figures, Cornelison and Humbert in Hawaii have compacted cores of soil to different degrees and placed them under the cane furrow. After some months of cane growth these cores have been dug up and examined. In all their soils the same trend was noticed, namely that root development was good in normal soil but roots became flattened and distorted as bulk density increased until a certain value was reached at which roots no longer penetrated the soil.

I might say at this stage, that a large amount of contradictory evidence concerning the effects of compaction on plant growth, has been presented in the literature. Probably the whole trouble has been that different soils have been involved since bulk density readings and relative increases in bulk densities within various soils, are of little value in comparing the effect of compaction on plant behaviour. You see, some soils can be compacted without much influence on plants, whilst with some other soils only very slight compaction can have deleterious results on plant growth. It is generally accepted, however, that slight compaction improves the germination of most plants but that later it reduces the yield.

A lot of factors influence the degree to which a soil can be compacted. These have been fairly well established, and I will just run through them briefly for you.

The amount of compaction depends on the degree to which the stress applied to the soil overcomes the resistance the soil offers to deformation. This means

how compact was the soil in the first place? If it was very loose it is not going to offer much resistance to the compacting agent, and it will compact badly. If it was compact in the first place, obviously it is not going to compact very much more. Also, the resistance that a soil offers depends very markedly on its moisture content. Dr. Beater will go into that for our own soils here, but generally you can consider that the wetter the soils are, up to a certain value, the worse they compact.

The texture and structure of the soil are important factors as well. Soils with an even distribution of the various particle size fractions compact the most, since the smaller particles pack tightly between the larger grains leading to a dense soil.

Organic matter content. There have been many reports that the organic matter content in the soil will influence its compactability. There are possible chemical factors also such as sodium ions which encourage the breakdown of soil crumbs when they become wet.

These aspects have been fairly well explored, but as far as compaction effects on plant growth are concerned, results reported in the literature are too contradictory to make any generalisations. Probably the only way to make progress here is to establish what values of bulk density, or compaction in each of our various soils affects cane roots to a degree which is going to reduce yields.

**Dr. B. E. Beater:** Before discussing the field work done at the Experiment Station, I would like to illustrate a few preliminary laboratory experiments which will give a lead to the subject we are dealing with in this symposium, namely compaction. Our first step was to ascertain to what degree we could compact our various soil types under laboratory conditions. For this purpose we use a hollow metal jar of robust proportions, which has a detachable portion of known dimensions and consequently of known volume. Soil at a known moisture content is placed in this apartment and with the aid of a specially designed hammer a known number of blows is levelled at the surface of the soil. This device ensures that the identical treatment is given to every soil placed in this metal cylinder and consequently the relative compactibility of the different soil types can be accurately obtained.

A further interesting laboratory demonstration is shown by this thick-walled glass jar. The procedure was to add an inch of granulated soil, followed by a thin layer of white powder, in this case kieselguhr. A further inch of soil, followed by a further thin layer of powder was repeated until the jar was full. At this stage a sharp blow was delivered to the surface of the soil, and the result is, as you see, a rhythmic lowering of the soil as illustrated by the succession of curved rings, almost down to the bottom of the jar. The force delivered at the surface has penetrated the whole plough depth of the soil.

The same effect is obtained in this other experiment where the whole of the interior of the glass jar has been lightly brushed with white powder. Soil is carefully added down the centre so as not to disturb the powder and when full, a blow delivered at the surface to simulate sudden compaction. The many lines

radiating down through the soil are illustrated by the etching effect on the powdered surface.

We have found that the moisture status of the soil is most important in compaction. Sandy loams compact most at about 15 per cent moisture, loams at about 20 per cent and clay loams at about 30 per cent. In the case of our high organic matter soils, as for example mist belt soils, optimum moisture for compaction is as high as 40 per cent. These figures which I have quoted represent the soils' moisture at or just below field capacity. For most purposes, field capacity can be defined as the soils' moisture content about two days after good soaking rains have ceased, in other words when all gravitational water has drained away. In a paper presented by Dr. R. R. Maud of the Soils Section, to the Technologists Conference in 1960, it was shown that the various soil types had quite different properties in respect of compaction. Soils with near equal proportions of the textural fractions, coarse sand, fine sand, silt and clay compacted the most, while soils which were predominantly clays, as for example black dolerite soils, compacted the least.

Following these preliminary remarks I will now proceed to read a short paper I have prepared on a field experiment at Mt. Edgecombe. It is entitled "*A preliminary field experiment to examine the effect of soil compaction on sugarcane ratoons.*"

*Experimental:* Four small plots were selected in adjacent fields of ratoon canes (N:Co.310 and Co.330) for compaction by a Ferguson tractor drawing a Ferguson trailer loaded with 2½ tons cane. The soil which was at field capacity at treatment, had the following textural composition:

Plot	Coarse	(Gravel	Fine	Silt	Clay
	sand and gravel	included)	sand		
	%	%	%	%	%
N:Co.310, control	12.9	(1.5)	39.4	18.8	28.9
compacted	12.5	(1.7)	45.5	13.7	28.3
N:Co.331, control	14.3	(1.5)	46.2	14.1	25.4
compacted	14.2	(1.2)	46.8	14.4	24.6

Compaction took place soon after the crop was harvested, the trash remaining as a blanket over the plots. Earlier experiments had shown that a trash blanket has little effect in minimising soil compaction by heavy machinery.

The plots were top-dressed in the normal manner and lightly weeded by hoe when necessary. During the twelve months cycle of growth allowed, 33 inches of rainfall (838 mm.) were recorded, with a rather dry growing period during September and October.

*Measurements and analyses:* Growth measurements were carried out at 1½, 3½, 7½ and 12 months age, respectively, by counting the number of shoots and measuring the length from ground level to the topmost visible collar of each shoot. The following table represents the results of these measurements:

Plot	1½ months		3¼ months		7¼ months		12 months	
	Number of Shoots	Average Length in inches	Number of Shoots	Average Length in inches	Number of Shoots	Average Length in inches	Number of Shoots	Average Length in inches
N:Co.310 control . . . . .	817	6.19	837	12.17	642	22.38	646	31.35
N:Co.310 compacted . . . . .	774	4.81	1,688	8.38	1,420	14.57	947	22.88
Co.331 control . . . . .	422	8.12	694	14.86	628	28.92	616	42.46
Co.331 compacted . . . . .	398	6.65	741	11.73	701	20.26	679	33.17

The above table shows that in the case of N:Co.310 there is a great increase in the number of small shoots due to compaction, but that a relatively larger number of these shoots die as the cane becomes older. In the case of Co.331, this increase in the number of shoots with compaction is not so apparent.

There was little if any difference in weight of young stalks between the two control and the two compacted plots due to cane variety. On the other hand, up to the stage of growth at which this experiment was harvested, a stage which was in fact not at normal maturity, the actual reduction in weight of millable cane stalks was 22.6 per cent. While this reduction in growth in undoubtedly a fairly true reflection for sugarcane at this particular stage of growth, it is not suggested that the same percentage reduction will be found in mature cane. In fact it is by no means impossible that the reduction may even be greater.

The bulk density and porosity of the soil at the commencement of the experiment was as follows:

	Control plots	Compacted plots	Difference due to compaction
Bulk density of soil	1.30	1.55	0.25
Porosity	49.2	39.4	9.8

It was found that the bulk density and porosity of the plots remained almost unchanged over the duration of the experiment.

Chemical analyses of third leaf samples indicated a lowering of N, P and K in the leaf due to compaction. There was also a lowering of the chlorophyll content, a fact which was evident in the slightly less green appearance of the compacted plots in the field. The analyses were as follows:

Analyses of third leaf samples taken at 8 months from compaction experiment

	N:Co.210		Co.331	
	Control	Compacted	Control	Compacted
Oven dry leaf—				
N%	1.39	1.32	1.42	1.28
P%	0.17	0.16	0.18	0.17
K%	1.02	0.94	1.01	0.83
Chlorophyll— (m.g./gm.)	0.90	0.67	1.02	0.87

There were indications that sucrose content and juice quality were adversely affected by soil compaction. But these aspects will have to be examined more closely in future experiments before definite conclusions can be drawn.

**Dr. Cleasby:** Mr. Bartlett will now deal with the mechanical side of soil compaction.

**Mr. Bartlett:** Before I proceed, I would like to ask Dr. Beater what the moisture content of the plots was when he compacted them?

**Dr. Beater:** It was just below field capacity. About 18 per cent moisture.

**Mr. Bartlett:** From what has been said, it appears that compaction through mechanisation is a factor to be considered, and if farms do experience a reduction in yield, as has been said could happen, then this certainly is an extremely important subject which should be investigated further.

It has been said that there are three basic factors affecting the degree of compaction, namely, soil moisture, force or pressure applied to the soil, and thirdly, the number of times that this pressure is applied to the soil.

There are two approaches to this problem. First of all, from an engineering standpoint, one can try and eliminate or reduce this ground pressure, and secondly, one can try and rehabilitate the soil after it has been compacted.

Of course there is very little a design engineer of equipment can do about the soil moisture, other than telling the farmer to keep his equipment out of the fields, or else to try and put some control on the weather. Mechanisation has arrived in this industry, and it is going to increase as time goes on. We have already tested a cane loader, and as you may have heard, this season we hope to have three harvesters operating in the cane belt, the Massey-Ferguson, the Crichton and the J. & L.

These machines will probably compact the soil even more than is being done at the present time, although most of the compaction will occur in the inter row, and not on the row itself. To give you some idea of what is involved, the Massey-Ferguson harvester will result in 12 passes of wheels, 6 from the machine itself and its tractor, and 6 from the transporting vehicle and its trailer. Each row is covered twice with 6 wheels so there is a total of 12 passes of wheels.

With the J. & L. harvester there will be 4 passes for every row with the harvester, and 9 or 10 passes with the loader and transport unit, for every two or three rows. As some of you may be aware, the J. & L. harvester cuts 5 rows and puts them in one windrow so there will be fewer rows actually compacted by the

loading and transporting vehicles, than there would be by the cutter.

With the Crichton machine, there will be 4 passes with the cutter on each inter row, plus another 4 to 6 passes along the inter row with the loader, and possibly 3 across the inter row, that is across the rows of cane with the transport vehicle, depending on the pattern of loading.

There is very little we can do about soil moisture, and that is why I asked this question as to what the soil moisture was in these trials.

In Hawaii we recently saw a field that had been harvested with track-laying equipment and a tremendous amount of damage had been done to the field and the cane stools. This was mainly because the soil had been very wet and had been churned up by the tracks, rather than being damaged purely by compaction.

Wheel tractors on the other hand can exert as much as 50 pounds per square inch on the soil surface. The maximum ground pressure allowed on wheel tractors, if you are going to abide by the recommendations of the tyre manufacturers for those tractors commonly in use in the cane belt, is between 24 and 48 pounds per square inch for the front wheels, and between 16 and 22 pounds per square inch for the rear wheels.

At this stage I would like to say a few words about the relationship between the air pressure within the tyre and the ground pressure. It has been said that as a rough guide, providing you are loading the tyre concerned to the recommended weight for a particular pressure within the tyre, the ground pressure, or the pressure exerted by the vehicle on the ground, will be approximately the same as that pressure within the tyre.

You have probably all noticed when selecting trailer tyres that the tyre manufacturer gives you a table which shows the allowable loads at various tyre pressures; for example, at 65 p.s.i. you can load a tyre to, let us say, 3,500 pounds. In order to obtain the maximum life from a tyre, you should try and keep the profile, or bearing surface, on the road at the design profile. When the load is increased, the tyre deflects and if it deflects too much you are going to get excessive wear, so the recommendation is to put more pressure within the tyre, which straightens it out to its design profile.

Some of our trailer tyres are pumped up to as high as 85 pounds per square inch. You will probably find, taking into consideration the surface area of the tyre which is in contact with the soil, that a tyre which is pumped up to 85 pounds per square inch is exerting a pressure of about 70 pounds per square inch on the soil. Nine by twenty, eleven by twenty and ten-fifty by sixteen tyres for instance, vary from about 65 pounds per square inch to 85 pounds per square inch, depending on the ply rating and the tyre size.

Some years ago we conducted loadometer tests and found that on occasions farmers do overload their trailer tyres beyond the recommended pressures, which means that the ground pressure could possibly exceed

those I have mentioned. They could go as high as 90 or 100 pounds per square inch.

From the foregoing it is apparent that existing equipment exerts pressures on the soil from as little as 5.17 pounds per square inch to as high as 100 pounds per square inch. Increased flotation, that is reduced ground pressure, can be obtained by adding more wheels. This could possibly be a solution to our problem. This is either by adding dual wheels to existing axles, or by equipping the trailer with tandem axles. Another alternative is by using larger tyre sizes. I believe that in the Gingindhlovu area for instance, some farmers are using 1300 by 24 tractor tyres on trailers. They have found that this greatly reduces the draught on the tractor and enables it to pull out of very muddy conditions with far less effort than was required before. This is due, firstly, to the increased rolling radius of the tyre, and secondly, which is probably the more important from the compaction point of view, increased flotation.

Unfortunately, because of their size, these wheels must be placed well to the rear of the trailer, especially in the side loading trailers, which thereby upsets the weight distribution required by the Natal Provincial Administration on the tractor, thus requiring a special type of hitch. In addition, 1300 by 24 tyres only have 3,125 pounds carrying capacity, at 18 pounds per square inch, whereas with 900 by 20 tyres, 5,500 pounds can be carried at 80 pounds per square inch.

You can argue of course, that by placing the trailer axle further to the rear, more weight is being carried on the tractor thereby reducing the weight on the trailer axle. This, however, could lead to overloading the tractor axle.

It has also been suggested that possibly very low pressure tyres could be used, such as Goodyear's Terra-tyres which operate at 7 p.s.i. These are used in Florida on some of the infield trailers in the Lake Okeechobee area. I personally feel, however, that this type of tyre is only suitable for specialised operations such as in swampy or very sandy areas. The high initial cost, the high maintenance costs, and their short life, eliminates the use of this kind of tyre in Natal.

The answer to the problem of reducing the ground pressure of machines and transport vehicles operating infield, I feel, lies in the engineer paying more attention to the maximum allowable infield ground pressures and designing high flotation undercarriages, with either dual wheels or multiple axles, of such size as to keep the pressures within the desired limits.

The immediate question asked by a trailer manufacturer will be "what are these limits?" He will want to know what unit pressure he can allow on the soil at a particular soil moisture content, without damaging the cane rooting zone.

The work being conducted by the Experiment Station at the present time, and I believe they have an experiment planned for the near future, will give a lot of information which no doubt will be very useful to the people building our equipment for us. Of course the variations in soil types and moisture con-

tents can be far too great to economically enable the farmer to have the correct undercarriage for every condition. A compromise would therefore have to be made.

The third factor affecting the damage of the rooting zone, namely, the number of cycles, can, I feel, be controlled to some extent. Better farm planning and lay out of road systems can reduce the amount of in-field travel, while more exits from a particular field is also effective, providing it is agreed that it is better to compact a greater area with one pass of the machine, than a lesser area with multiple passes.

These notes have so far discussed one approach to the reduction of the compaction problem, namely, to eliminate or reduce the degree of compaction.

The second approach is the rehabilitation of the compacted soil, that is, by post harvest tillage or cultivation. This could quite possibly be the answer to the whole problem. Interrow sub-soiling followed by chisels and cultivating tines, discs or possibly even rotary tillage tools, could re-aerate the soil to quite a degree. Some indication as to exactly how much the compacted condition can be eliminated, should come from the proposed experiments which will be carried out by the Experiment Station.

This method, however, will be greatly restricted should the field in question be covered by a trash blanket. This problem will not arise where existing production-made cane harvesters or cutters will be used, since none of these machines has been designed to trash cane. So if we are going to use cane cutters or cane harvesters which are at present being used elsewhere in the world, the trash problem will not arise.

**Dr. Cleasby:** Thank you, Mr. Bartlett, for that most interesting talk. Until we agriculturalists can give Mr. Bartlett the answers to what our soils can stand in the way of pressures, and the agronomist can say what damage these pressures can do in terms of loss of yield, you will not be able to help us much. We have dealt with some of the fundamental aspects, some work which has been done on our own soils, our own experiments, and on the mechanical side as far as Mr. Bartlett can take us at the moment. We now have Dr. Shuker who will deal with the other aspect which Mr. Bartlett just touched on, the rehabilitation of compacted soils. The work which Dr. Shuker is going to mention, is, I believe, work which he actually carried out in Louisiana while he was studying there.

**Dr. Shuker:** With more emphasis being placed on mechanisation, the problem of compaction becomes more important. This is particularly so in the sugar industry in Louisiana where most of the agricultural operations are mechanised. They fertilize, cultivate and harvest by machine. It is with this in mind that I would like to bring to your attention the results of work which was done in Louisiana in 1954, 1955 and 1956 which was aimed at combatting this problem of compaction.

Experiments involving deep-ploughing, subsoiling and deep placement of fertilizer were conducted on compacted soils with cotton and corn in 1954, 1955

and 1956, and these were extended to sugar cane in 1956.

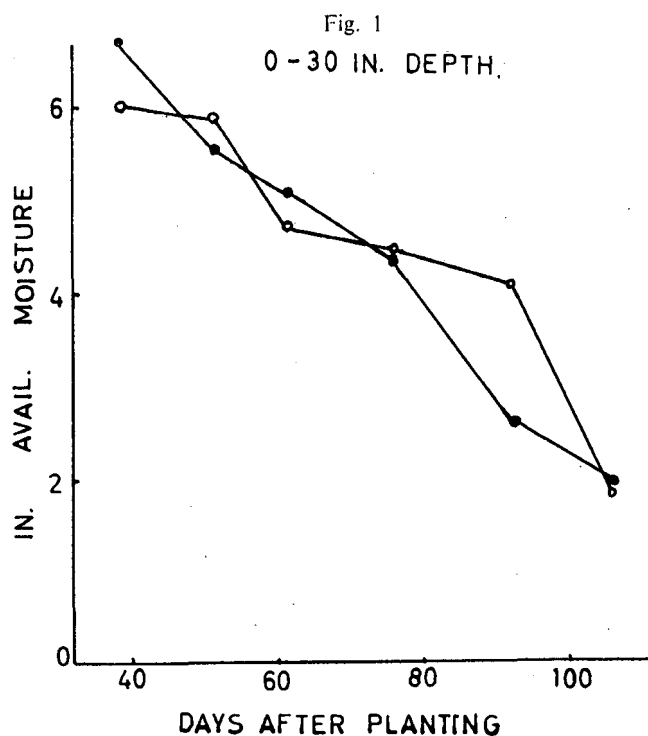
Sizeable and significant increases in both cotton and corn were obtained from deep tillage in 1954, these increases amounting to nearly 30 bushels of corn, which is approximately eight bags, and about 800 pounds of seed cotton.

The responses obtained from deep tillage and deep fertilizer placement varied from year to year and appeared to be conditioned largely by soil moisture. During the 1955 season there were few periods of deficient soil moisture and this largely accounts for the lack of response to deep tillage. The responses were very marked in 1956 and even more so in 1954, when periods of soil moisture stress were experienced. As a matter of interest, the rainfall during the growing period from March through to August for the years 1954 and 1955, was 23 and 33 inches, respectively.

A summary of the results showing the effect of subsoiling and deep placement of fertilizer on the yields of sugar cane are shown below in Table I.

The responses to deep tillage are self evident. The L.S.D. at the 5 per cent level was 2.28 tons of cane per acre. It was observed during the course of these experiments that deep tillage might have increased both the supply of available soil moisture and the efficiency of extraction of subsoil moisture. A study of the available soil moisture during the 1956 season substantiated this observation.

Fig. 1 shows the available moisture in the 0-30 inch zone. Early in the growing period more available moisture was present in the subsoiled than the non-subsoiled plots. Not only was more water present in the deep tilled plots but water was extracted more rapidly from the subsoil. The rapid decline in the available moisture began 40 days after planting, and



this was caused by a dry period that lasted for about 4 weeks. The higher concentration of roots in the subsoil of the deep tilled plots enabled the plants to extract more water from these lower depths, and to better withstand the moisture stress period. This increased moisture utilization, as a result of deep tillage, was reflected in higher yields.

The result of this study after three years of experimental work, indicates that increases in yields can be obtained from deep tillage and deep placement of fertilizer in seasons where a deficiency of soil moisture exists, and on soils with compacted layers that restrict root penetration and water movement. In growing seasons with an ample supply of water, these increases in yield may not occur. During seasons with high rainfall, however, no decreases in yield resulted from deep tillage or deep fertilizer placement. From the results of this study it appears that deep tillage may be of value in years of below average rainfall on soils subject to compaction. Where we in Natal are subject to seasons of high and low rainfall, this must very surely apply.

TABLE 1

Treatment	Yield Tons/Acre
1. Fertilized at 3 in. depth. Subsoiled . . . . .	26.61
2. Fertilizer at 3 in. and 13 in. depth. Subsoiled . . . . .	27.20
3. Fertilized at 13 in. depth. Subsoiled . . . . .	25.69
4. Fertilized at 3 in. depth. Not subsoiled . . . . .	23.89
5. Not fertilized. Not subsoiled . . . . .	23.38
L.S.D. 5% 2.28	

**Dr. Cleasby:** You have heard various speakers on this subject. You have heard the problems explained, you heard something of the effects it can have on cane yield. Dr. Shuker has touched on the all important problem of subsoiling or cultivating damaged fields. The symposium is open for general discussion.

**Mr. Barnes:** I did not hear from the speakers anything about the movement of man and animals in the fields and their effect on this problem of compaction. There is no doubt that compaction has been present since man first learned to use a digging stick and before he ever invented a hoe. Going back into my own experience, I well remember the low yields firstly due to the compaction of the soil caused by the movement of men and animals during wet weather, and secondly the effect of the very shallow tillage practised in those days. The yields of those early days were of the order of 20 to 22 tons of cane per acre and have subsequently been doubled. That doubling has persisted over the years, although compaction is now becoming evident. I cannot think, or see any reason for the yields falling back to where they were previously, in spite of modern methods of land cultivation and cane harvesting. In certain soils ratooning goes on for a very long period, whereas in others, which are apparently more easily compacted, it is not possible to take off more than two ratoons. The types of soil I have in mind differ for reasons that are evident from what Mr. Hill has told us. In the case of long ratooning, the soil particles are of a more uniform size, whereas in the other they are heterogeneous. It is rather frightening to think that by introducing

modern methods we may be undoing some of the good work that has been done during the past.

**Dr. Cleasby:** The improvement in yield over the years is of course a combination of many factors. The question of compaction and its effect on ratoons is a very important one. At Tongaat we have improved varieties, improved fertilization and we have improved methods of land preparation and cultivation, and in certain areas we have irrigation. It is therefore a disappointment to find that the life of our ratoons has not been prolonged to the extent that I would have anticipated. I feel sure that soil compaction is a factor in this and I would like further comment on this question, particularly from people who have introduced in-field transport in recent years.

**Mr. Hill:** I would like to add to what Mr. Barnes has just said about the effect of animals and man on compaction of the soil in the field. There has been work done by Americans on this particular point, and I quote here . . .

“Johnson, 1952, studied the effect of grazing on infiltration, and found that on heavily grazed fields infiltration was reduced by 91 per cent compared to ungrazed fields.”

Also of interest is the data of Blair and Lutz, who estimated that the trampling effect by man could reduce infiltration in recreational areas, picnic grounds and so forth by 86 per cent.

**Mr. Pearson:** Are we not blaming machines too much and not looking sufficiently to the effect of water, either as rain or irrigation, or the actual water in the soil. It has been mentioned that compaction increases with the soil moisture up to field capacity. In the cane belt we cut cane in any weather, often after very heavy rain. Possibly when the soil moisture is over field capacity and water is lying about on the soil, we may get a flotation factor, which may cause more compaction than any form of added weight to the soil under dryer conditions. The effect of rain is over the whole acre and not on the two-thirds covered by the tractor wheels. I feel that it is important to define the factors that cause compaction. Is it by applying weight as with a wheel, or is it the flotation effect caused by the water in the soil, or is it water being precipitated on the soil? As Mr. Barnes said, compaction existed long before the internal combustion engine.

**Dr. Cleasby:** I am quite sure that there are soils in the sugar belt which are compacted solely through water. I am thinking particularly of some Tongaat soils which crack in dry weather, and puddle in wet weather. These soils definitely compact under natural causes once the cane has been planted and closed in.

**Mr. Hill:** In reply to Mr. Pearson, I have said soils do compact badly up to field capacity, but perhaps I should have given the whole story. As the soil moisture content increases from say, dry to saturated, the compaction increases to field capacity and then decreases. As the soil becomes wetter and wetter, beyond field capacity, and into the saturation range, then flotation does probably exist, because we know the compaction does decrease very sharply in this moisture range.

**Dr. Cleasby:** In other words what you are saying is that it would probably work in the opposite way to what Mr. Pearson has suggested.

**Mr. Hill:** Yes. The whole point is that these soils will compact most at that particular value represented by field capacity. As it gets wetter, it decreases, or as it gets dryer, it decreases.

**Mr. Barnes:** When the soil is supersaturated, the soil moisture exceeds field capacity, the pore space is filled with water, and you get a resistance to further compaction.

**Dr. Cleasby:** I think that is limited to soils of good structure. In soils of poor structure I do not think that would be the case, as I have mentioned earlier.

**Dr. Sumner:** The importance of falling raindrops must not be overlooked, especially on bare ground. Not so much from the force inflicted on the soil by the impact of the raindrop, but by the dispersive effects of the raindrop hitting a structural unit and breaking it down, thereby closing up pores. This is not actual compaction, but it will manifest itself in the same way in the fields of soil moisture. Water will no longer penetrate that soil, and there will be low infiltration capacity, although the soil will only be compacted in the top centimetre, whereas a tractor will compact the soil in the top foot or nine inches. Regarding compaction in the wetter stage, what happens when you pass a vehicle over a soil above field capacity, which is saturated with water? In this case you are not getting compaction, but dispersion, which gives you the same net result. You are puddling the soil and blocking pores, not necessarily compacting it to a great depth, because it is saturated with water. This can result in crusting on the top surface of the soil, causing a low infiltration capacity.

**Dr. Beater:** When a soil is moister than field capacity, the moisture film acts as a sort of lubricant. We tried experiments with a tractor on a very moist soil, and what happened was it just squelched it out, and there was no increase of density at all.

**Mr. Cheves:** After 23 years of handling cane with mules and main line I now have to handle this cane with in-field transport. We have heard a lot about compaction this afternoon, but I do not think that anybody has given us the answer, or told us what to do to alleviate the problem. My estate comprises three-quarters hard soil, and I want to find out from somebody who has had this experience before, what to do when I cut these fields and am affected by rain and compaction. If the cane is there, it must be got out to keep the mill going. We have been told all about compaction, but what is the answer to alleviate this?

**Mr. Hempson:** I think a simple answer, is to probably organise your in-field transport so that if you have to have a delay of 24 hours before going into wet fields you have other fields reserved where you can work.

**Mr. Grice:** Two points have been made today. One by Mr. Wilson, when he said, "Is it necessary to plough, why not subsoil?" The second by Mr. Bishop

on a question of looking after the 9 inches of top soil. I think it is a practical necessity that Mr. Cheves' question be answered. On Natal Estates we have had to accept that compaction is one of the evils which follow from in-field transport. The incorporating of organic matter into the critical 9 inches of top soil when the land is prepared, followed by subsoiling ratoons will tend to answer the question. Although working throwout fields is a thing of the past, there is a very substantial root structure in the top 9 inches of soil which integrates in the soil, and brings about a certain amount of soil porosity and microbiological activity. Another point that has not been mentioned is the value of green cropping carried out for many years at Natal Estates. It is a thing of the past today. Nevertheless, I believe the whole question is looking after that top 9 inches of soil.

**Professor Orchard:** I would like to make two points. I think it is in the Australian literature that one finds they have also worked on this problem. It is stressed in one paper that the great roll of organic matter acts as an anticompaction agent. I do not know whether it is the springiness that it imparts, or what it is, but from the experimental data it certainly does seem to have an effect. I wonder if your trash could be arranged for use as roadways? I do not know whether this is a practical proposition. The other point I want to make is that it is all very well to have these experiments to show that porosity is reduced, infiltration rate is reduced and yield is reduced, but one must not lose sight of the fact that it is important to know exactly why the yield is reduced. A point that has not been mentioned here this afternoon is the question of aeration. In many soils the reduced yield may have to do with moisture relationship, but I am quite certain that in other soils it may have to do with lack of aeration. We know that if there is not enough air in the soil, the plant cannot take up nutrients and the whole process comes to a stop. Remember the aeration factor. If you can find out why your yield is reduced, then your solution to the problem becomes simpler too. We must not only keep our eye on the water side.

**Mr. Wilson:** I am glad Professor Orchard brought that up because I was going to ask Mr. Wood if he had any contribution to make at this stage. I do think it is rather important to try and sort out the various factors that are concerned in the effect of soil compaction on crop yields. There is the aeration factor and the drying out and nitrification factor, which could all have a profound effect, particularly on annual crops, such as Dr. Shuker was dealing with, and possibly on sugar cane. Mr. Glover might have something to tell us here, because he was associated with work in East Africa on the effects of Napier Fodder on soil structure which would have a parallel with sugar cane. I have always understood that Napier Fodder improves soil structure as it ages and one would imagine that successive ratoons of sugar cane, with root systems dying out after each crop and regenerating, would offset the effect of compaction on the surface.

**Mr. Wood:** There can be little doubt that with the drying out of the soil, and rewetting, nitrogen is released. I do not think that that was what Professor Orchard was talking about. What he had to say was

extremely important. One of the recognised methods for determining compaction is to look at the non-capillary pore space. A considerable amount of work has been done on undisturbed cores, by actually saturating them and then subjecting them to water tension at various levels. They can then be classified by the amount of the soil pore space which is air filled or water filled at these given tensions. Apparently this can be very important in measuring compaction, rather more important, it would seem, than bulk density measurements as such. I know of cases where soils have very low bulk density down to 1.1 or 1.2, but there has been severe root impedance because of the low non-capillary pore space. So it does not necessarily mean that because you have low bulk density that you are not going to get compaction. One of the things we have not talked about very much this afternoon is reliable methods of actually measuring compaction. This is the sort of work we are planning to do in the future.

**Dr. Sumner:** There are a few points arising from what Mr. Wood has just said. I agree with him about bulk density. It is not a very good measure of compaction on an absolute scale, but it is satisfactory on a relative scale. Mr. Hill showed us in the results from Hawaii, that there was a bad bulk density of .5. Those are very fluffy soils, whereas the average bulk density of our soils here is about 1.2 or 1.3. The non-capillary pore space is the part of the pore space that is reduced during compaction, and the capillary pore space, that which is filled with water at field capacity, will not be greatly affected. The major reduction will come in the non-capillary pore space, in other words the air space. This, of course, leads on to what Professor Orchard said that the aeration in these soils will probably account for greater reduction in yield than will any change in the amount of water that is held. There is some indication in the literature that compacted soils contain more available water than non-compacted soils. This is purely on a laboratory basis using tension plate methods and is probably due to the fact that the amount of capillary pore space has been increased at the expense of the non-capillary pore space. There is more available water, but less air which in the long run does not give rise to good yield.

**Mr. Glover:** I agree completely about aeration. You can restore soil structure by natural methods such as by leaving it under grass for a long time, but unfortunately the new soil crumbs do not last for more than a year or two.

**Mr. Boule:** Dr. Beater quoted the extreme where the whole acre had been covered, and Dr. Cleasby quoted a theoretical case where two-thirds of the acre would be covered. About three years ago Dr. Maud read a paper on compaction. I think that he said the maximum compaction was reached at the third pass of a vehicle. If that is so, and accepting the figure of two-thirds of an acre, then surely the answer to Mr. Cheves is to use one road out of the fields. I have found from practical experience that the puddling, or whatever you might like to call it, takes place when the soil is wet, therefore if you use one road out of the field, you have a minimum area to sub-soil to minimise the effect of compaction.

**Dr. Cleasby:** Thank you Mr. Boule. I was hoping someone was going to raise that. I believe that in actual fact 80 per cent. of the damage is done, not after three passes, but in the first pass.

**Mr. Stewart:** Once the soil is compacted, pore space is reduced. By cultivating or subsoiling, you are merely breaking that soil up into relatively large lumps which would tend to fall back, and compaction will prevail again.

**Dr. Cleasby:** There was some work done in Hawaii, where they have roads in their fields and high compaction under wet conditions. There was a long term experiment which showed that in actual fact the yield never came back to what it was in the uncompacted conditions. I am quite certain that subsoiling and cultivation is only part of the answer because of the point you make.

**Mr. Thompson:** We have shown that for several soil types we get a considerable increase in crumb structure under trash, but I do not think that answers the question as to whether the trash being there will make compaction better or worse.

**Dr. Beater:** We did try compaction under trash with wheel transport, and we found it had very little softening effect. In other words we still compacted the soil very badly to about 80 per cent of bare ground. The experiment I quoted this afternoon was done on a trash blanket and there was a reduction of 22 per cent. there.

**Mr. Dicks:** I would like to quote an actual experiment which was conducted on Mr. Chance's farm. It was a phosphate trial, designed to compare various forms of phosphate. Unfortunately, the trial was laid down too close to a drain, and in cultivating, the tractor had to pass many times over a certain number of plots — actually six out of forty-eight plots. On an average, the yields from the treatments on those plots compared with the same treatments on non-compacted plots, were reduced by 36 per cent. However, speaking with Mr. Chance before this symposium started, it would appear that the six plots are affected not only by compaction, but being near the drain they have a shallower soil depth, and this may account for a further reduction in yield. Another reason may be the actual damage to the plant by the tractor, but this was apparently negligible compared with the length of the row. In this experiment the reduction in porosity compares very favourably with the results shown by Dr. Beater earlier for the experiment here at Mount Edgecombe.

**Mr. Robillard:** All the remedial measures proposed against compaction seems to be taking place in the inter-rows. When the new roots take over they have to develop in the region where compaction still exists and where the sub-soiler has done no work. So the retardation of the cane should be at the initial stage. At one time in Mauritius they used a practice of forking around the stool in the region of the roots. That was supposed to correct compaction and bring aeration to the roots. It was considered one of the best ways to keep yields up and to increase the number of ratoons.

**Mr. Gibbons:** There is a very big difference in the amount of rubber in contact with the ground with various tyres. Is that going to make any difference to the compaction of the soil? It seems to be a vicious circle, in which the tyre manufacturers offer a tyre which will work under extreme conditions of moisture but should they not try making a flatter tyre which slips under those conditions but reduces compaction?

**Mr. Bartlett:** The type of tyre to use in muddy conditions is the type of tyre with a big lug, such as we are using at the present time. The big-walled tyre that Mr. Gibbons is talking about is usually used in very sandy conditions. It is a low pressure and very wide tyre to give more flotation. In mud, the only way you can get additional traction, provided you have got the lugs on your tyres, is with increased weight. As you know, 100 pounds of increased weight gives you from 40 to 60 pounds extra pull, depending on the soil type. The type of tyres you are suggesting just spin in the mud, and you would not get any traction at all. The greatest amount of compaction at the present time is, I feel, coming from our trailer tyres, not necessarily from our tractor tyres.

**Mr. Whitehead:** The timber industry has similar problems of compaction. Some timber mills have big problems during wet weather, particularly in monsoon areas. The British timber industry is working at the present time on a hovercraft principle for taking out large timber from forests. The weights carried are very large indeed, but as far as I am aware the thing is only in prototype stage.

Here we have a principle which could have potential application in the sugar industry.

**Dr. Cleasby:** I think this is looking into the future, although it is probably a very good suggestion.

**Mr. Wyatt:** A point that comes to mind with the subsoiling is that, is not subsoiling at the right moisture a very important consideration?

**Dr. Cleasby:** It most certainly is. This is something that we know very little about, but there is an optimum moisture condition to do these operations at, on a particular soil with a particular instrument. But we are a long way from knowing what that might be.

**Mr. Bartlett:** Using a subsoiler under wet conditions you are actually wasting your time. The idea of a subsoiler is basically to rip and shatter, i.e., to get underneath and lift the soil from a depth of 18-22 inches. To do this you should really subsoil when the ground is very dry. The idea is to shatter it, then afterwards to use other tools to give you the tilth. In the case of ratoons you could possibly shatter the soil to a depth of 18 inches, and then use other tools such as rippers or light tines, depending on the soil types, to give it more aeration. Alternatively, some people

are using rotavators with the centre blade removed. They select the tilth they want through the gears on the rotavator and by placing the tail board at a certain height, it gives them the right amount of disintegration. In answer to Mr. Cheves, who was asking what he could do to offset the effect of compaction from in-field transport, I suggest as far as his vehicles are concerned he could go in for a better and more expensive type of undercarriage. He could put dual wheels on his axles which will reduce the ground pressure quite considerably, and give him higher flotation, so that he can pull his vehicles out of the field more easily, without all the slipping and skidding which does a lot of damage.

**Dr. Cleasby:** From what has been said, there is no doubt that the problem of soil compaction is a real one, and from figures we have heard from Mr. Hill, Dr. Beater and Mr. Dicks, the losses one can get from soil compaction are frightening. I do not say we are getting these losses generally in our fields today, but they do show what can happen in certain areas. These experiments have been carried out and the results are factual. The overall point from this symposium is the complete lack of basic information relating to the problem of soil compaction. We have not even a reliable method of measuring soil compaction and have touched on the merits of bulk density, non-capillary pore space and infiltration rate. With regard to renovating compacted lands, we have heard people talk glibly of subsoiling and cultivation to improve them, but, as Mr. Robillard said, is this the whole story? Here again we do not know what we are doing, as we have no reliable confirmation of the effect of these operations. We believe these operations are efficient, but to what extent we do not know. I do not think one could get two individual planters in the industry to agree on the best way of preparing a given soil, whether it was compacted or not. The majority of questions that have been asked cannot actually be answered. All we can say is, we think this might be the case, or that might be the case. I hope that we have opened up this subject which will be taken up as a major research project by the Experiment Station and by individual companies, and that we will in the future conduct laboratory and field experiments which will give us reliable data relating to the points which have been discussed this afternoon. I can mention that a start has been made, and an experiment planned to study the field side of soil compaction will be put down at Tongaat or Natal Estates, wherever a suitable site can be found. It is being run by Dr. Beater and Mr. Hill, but also interested in this experiment through their various departments are Mr. Bartlett, Mr. Bishop, Mr. van de Meiden and Dr. Roth. The experiment is to be put down on a burnt ratoon, and it will be to study the effect of soil compaction on cane yield, plant populations, soil bulk density and porosity, soil structure and infiltration rate.