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SOME FUNDAMENTAL RELATIONS BETWEEN SOIL STRUCTURE AND TREATMENT.

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SUMMARY.

Five soil types from coastal Queensland, representing humid tropical, relatively dry tropical, and relatively dry sub-tropical districts, were examined for changes in structure induced by various kinds of physical treatment.

In order to assess change in structure, measurements were made of relative percolation rate, maximum water-holding capacity, total pore space, hardness of soil crust, and dispersion of silt and clay. Treatments applied were dry working, wet working (at moisture equivalent and at sticky point), cropping to beans, partial sodium-saturation and some combinations of these.

All treatments caused responses in some of the properties measured, indicating the dynamic nature of the soil's physical state. The same treatment had varied effects on different soil types, showing that in the present state of our knowledge the correct cultivation of each soil type is a separate problem.

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Water-holding capacity is not a constant for each soil type, but undergoes positive and negative changes of considerable magnitude depending on the method of manipulation. Pore space varies in a similar fashion but to a lesser degree.

Soil puddling caused by ingress of sodium ions is not identical in its physical effects with puddling induced by mechanical means.

The best treatment for restoring a hard-crusted soil surface to normal is continued wetting and drying.

The Bundaberg red volcanic loam showed a phenomenal increase in percolation rate after wet working at or a little above its moisture equivalent.

Partial sodium-saturation appears to render some soils particularly sensitive to subsequent mishandling.

The methods evolved in this work could be usefully applied in characterizing soils whose physical properties are not known from field experience.

INTRODUCTION.

Although reliable methods are available for estimating the plant nutrients in a soil, the same cannot be said for the evaluation of its physical condition, and consequently the complete agricultural value of the soil cannot be adequately determined in the laboratory. This limitation can be especially hampering when, as with virgin lands, there exists no previous field experience upon which to form an opinion as to the behaviour of the soil under cultivation. When irrigation of such lands is contemplated the problem becomes greater. The paucity of sound methods for assessing the physical characteristics of a soil is probably due, in the main, to two factors. Firstly, the costs of cultivating the soil are regarded as unavoidable expenditure, and the extra costs of struggling with an intractable structure induced in the soil are "unseen" costs and come to be regarded as equally inevitable. The fertilizer necessary for producing a crop of sugar cane, for example, may cost no more than is expended on cultivation operations, but whereas fertilizer is an obvious charge against crop returns, costs of cultivation and especially excessive costs are not seen in this way, particularly where the farmer does the work of cultivation himself. Secondly, apart from the absence of an economic factor acting for the encouragement of work on soil structure, the present lack of good physical tests is due to the need for more knowledge of fundamental facts. The discoveries of cation exchange and phosphate fixation have given a background of fundamental principles upon which the student of nutrient deficiencies may work, but no adequate background exists in the field of soil physics. The investigations reported in the present paper were concerned with the collection of fundamental data, in order to further the time when theories of soil structure will be more the natural development from ascertained facts than they often are at present. It has seemed to the writer that the present-day tendency is to study what constitutes good soil structure (usually attained by tremendous additions of organic matter and demonstrated by measurements of the size of water-stable aggregates) and to neglect both the opposite condition of bad structure and the study of those soil properties, such as pore space and permeability, which are directly affected by changes of structure. As an illustration of this, a search of the literature failed to reveal a single complete definition, based on experiment, of a "puddled" soil. As a consequence of the tendency referred to, the general conclusion is reached that if the soil is kept well supplied with organic matter the number of large aggregates will be high and the physical condition of the soil satisfactory.

Under tropical and sub-tropical conditions it is not practicable to keep the organic matter content high, so in these cases the advice becomes a counsel of perfection; moreover, such an outlook does not help in elucidating the changes which take place in the nature of the soil when it undergoes a change in structure.

SCOPE OF THE WORK.

In the present investigation various mechanical treatments were applied to soils and an endeavour was made to measure the effects of these treatments upon five properties of the soil—the relative percolation rate; the maximum water-holding capacity; the total pore space; the hardness of the soil surface upon drying; and the degree of dispersion of the silt and clay particles.

The significance of these properties will be realised when it is considered that irrigated tropical and sub-tropical soils should (*a*) possess a high degree of permeability, (*b*) be capable of storing a large amount of water, and (*c*) retain a friable surface condition upon drying under a hot sun.

The implications of such desiderata will be considered further under the discussion of the individual tests.

MATERIALS.

The investigation was commenced using in part ordinary laboratory soil samples, although it was suspected that the normal preparatory treatment necessary for soil fertility studies might be much too severe for the projected work. The normal treatment for fertility studies in the laboratory of the Bureau consists in air-drying a sample of about five pounds of soil until it is in the best condition for passing through a 2 mm. sieve, and then continuing the drying (in a thin layer on a metal tray) until there is no longer any visible change taking place. Sometimes the sample is already dry when received and it is then crushed using a wooden hand-roller and an iron baseboard. When the soil sample is very dry considerable pressure is necessary, and the preliminary studies showed that this treatment may entirely alter the physical condition of the soil; all the later work was therefore performed on bulk samples, of about one bushel each, which were taken in the moist condition and given as little crushing treatment as possible. For this reason the values given in the tables for the earlier and later samples of the same soil type do not always agree. In two cases virgin samples of the soil type under consideration were obtained, in order to separate inherent tendencies from mere effects of past workings. The soil types used are described in Table 1.

Table 1.

DESCRIPTION OF SOIL TYPES USED IN LABORATORY EXPERIMENTS.

Soil.	Colour and Texture.	Lab. No.	pH.	Total Nitrogen.	Mechanical Analysis.				Moisture Equivalent.	Optimum Moisture.	Remarks.
					Coarse Sand.	Fine Sand.	Silt.	Clay.			
				%	%	%	%	%	%	%	
Cairns red schist	Red loam ..	6351	4·8	0·12	7·7	50·5	16·4	25·4	15·2	19	
Russell River alluvial	Yellowish brown silty loam	2412	5·0	0·16	8·0	37·6	23·9	30·5	23·8	28	
		6352	4·7	0·21	10·1	20·5	31·1	38·3	28·6	24	
Burdekin alluvial	Dark grey silty clay loam	4825	6·0	0·18	13·9	40·6	20·9	24·6	22·5	15	Virgin soil
		6350	5·8	0·11	2·6	54·0	19·7	23·7	21·4	13	
Bundaberg red forest	Red sandy loam	2411	5·5	0·10	31·6	24·2	14·1	30·1	13·5	13	
		6353	5·4	0·11	46·4	23·8	6·2	23·6	11·3	10	
Bundaberg red volcanic	Red loam (lateritic)	6354	7·1	0·43	22·6	9·5	23·8	44·1	31·5	25	Virgin soil
		2410	6·3	0·20	14·6	10·2	15·7	59·5	25·0	25	
		6355	6·0	0·17	12·8	8·6	18·4	60·2	27·1	25	

Many cultivated phases of the Lower Burdekin alluvial were also examined and some further tests were made on the series of partially sodium-saturated soils used by Cassidy (1944) in a previous soil study. Meteorological data for the four localities from which the soil types were obtained are given in Table 2. The first two localities represent the humid tropics, the third the

Table 2.

METEOROLOGICAL DATA RELEVANT TO THE SEVERAL SOIL TYPES.

Locality.	Latitude (Degrees South).	Mean Annual Rainfall (Inches).	Mean Annual Temperature °F.		Relative Humidity (Per Cent.).
			Maximum.	Minimum.	
Cairns	17	89	85	68	78
Russell River	17½	162	82½	65	77
Burdekin Delta	19½	41	84	64	62
Bundaberg	25	44	80	60	64

relatively dry tropics, and the last the relatively dry sub-tropics. Although the latter two localities experience frosts, there are only about five per year and their effect on the physical condition of the soil can probably be neglected. The rainfall, however, in all areas may occur with tropical intensity, a few instances of 10 inches of rain in 24 hours having been recorded for the two more southern localities and many such for the others.

Since the Lower Burdekin and Bundaberg soils are irrigated, it is clear that all the soil types under consideration are subjected to a considerable impact of water, whether as heavy rainfall alone or as rainfall and furrow-irrigation combined. In the present study the methods of investigation take cognizance of this fact, for it is of no avail to measure carefully some temporary condition of the soil if the stability of that condition to the impact of water is not also determined.

METHODS.

The methods used have been simple and in this way many more data have been collected than would have been possible using some of the involved apparatus described in the literature. Although these methods have not yet reached the highest desirable degree of precision, they have been justified by the results. The use of the original improperly prepared samples of soil previously referred to has sometimes clouded the issue when comparisons are made with the later and more carefully prepared samples; but, on the other hand, the difference in method of preparation has sometimes simply provided a comparison between a control and a dry working "treatment" and the results have been indicated accordingly (see Appendix A, where the original sample No. 2410 is in effect the dry worked treatment of No. 6355).

Reference has already been made (Cassidy, 1944) to certain of the methods used. The simple apparatus employed is shown in Plate 1.

Keen-Raczkowski Test.

This was carried out in Coutts' (1930) modified boxes, with the additional modification that the soil was passed through a 2 mm. sieve only, instead of through the 100 mesh specified, in order to avoid changes of structure due to fine sieving. Even the 2 mm. sieving was shown to have some effect on soil properties, and it was used as little as possible. After sub-samples of the soils had had any treatment involving moistening with water they were allowed to come to optimum moisture content (i.e., the best condition of friability as determined by feel) and then broken down gently with the fingers. In cases where this still resulted in a lumpy condition and prevented the surface of the box from being struck off level, a small quantity of soil was very gently ground in a mortar and used as a thin finishing-off layer. A modification was also introduced for cases where contraction of volume occurred on wetting, as for certain puddled soils, and when a soil at optimum moisture was used as original sample. This modification is given in detail below.

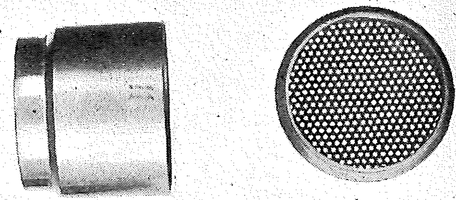
Modification for Cases where Contraction in Volume Occurs on Wetting.

Select a sample of sand which retains its original volume on wetting. A screened faction 0.5-1.0 mm. is convenient and will have negligible hygroscopicity.

1. After making weighings (a) and (b) in the usual way, immerse the dish in $\frac{1}{4}$ inch water as usual, until the soil is saturated. To obtain this state correctly, the dish must be withdrawn from the water and shaken gently to fill the gap around the walls of the dish with saturated soil and not (as would otherwise be the case) with water. Then make weighing (c) of dish + saturated soil.

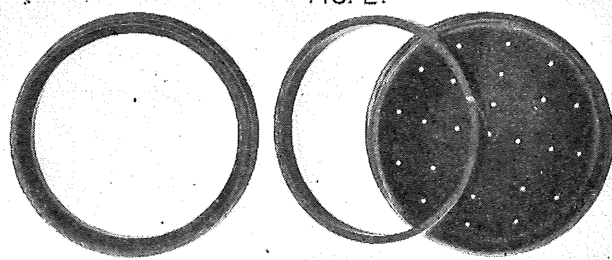
2. Pour dry sand from a small weighed beaker into the Keen-Raczkowski dish, and strike off with a spatula to remove the excess. Dry the excess (if it has come into contact with moisture) and return it to the beaker. Find by difference the weight of dry sand (Ws) used.

FIG. 1.

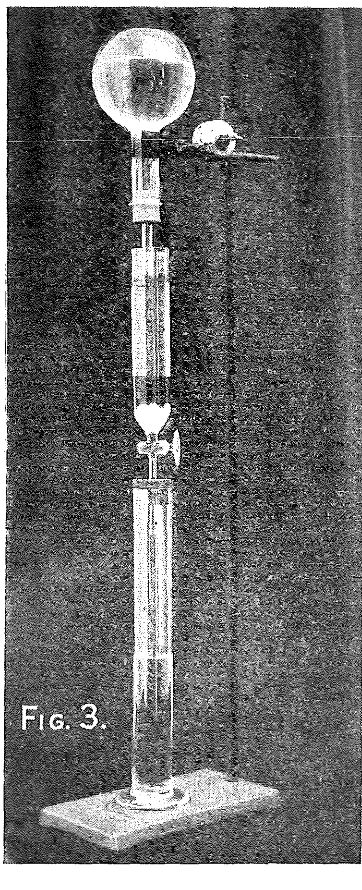


a. b.

FIG. 2.



a. b.



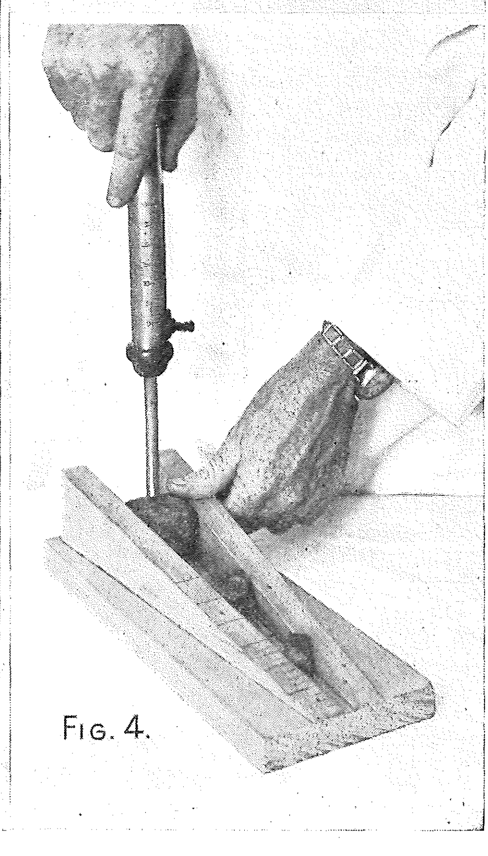


Plate 1.

3. Divide Ws by the Sp.Gr. of the sand to find its volume (Vs), and multiply Ws by the water capacity (Cs) of the sand to give the amount of water WsCs which this layer of sand can hold.

N.B. The constants of the sand are determined by making a Keen-Raczkowski test on it in the ordinary way.

4. Again immerse the dish and when the soil and sand are saturated make weighing (d). Proceed then in the usual way.

Calculations.

$$\text{Pore Space} = \frac{(c - a) - (e - a - Ws)\ 100}{V - Vs}$$

$$\text{Sp. Gr.} = \frac{e - a - Ws}{V - Vs - (d - e - WsCs)}$$

$$\text{Vol. Contraction} = \frac{Vs}{V} \times 100$$

As an indication of the reliability of Keen-Raczkowski data, Table 3 shows the difference in water capacity necessary for significance at odds of 20 : 1, when duplicate determinations are made on both the normal, air-dried soil and on the same soil after a treatment has been applied. It will be appreciated that whenever more than duplicate tests have been made, a smaller difference will be significant, depending on the actual number of replications. Thus in Appendix A Lab. No. 2412, for six tests on the normal, air-dried sample and two on any "treated" sample, the difference in water capacity required for significance will only be 4.2 per cent. as against 5.2 per cent. when but two measurements are made.

Table 3.

SIGNIFICANT DIFFERENCES IN WATER CAPACITY DETERMINED BY KEEN–RACZKOWSKI METHOD

Soil Type.	Laboratory Number.	Significant Difference (with duplicate determinations and odds 20 : 1).
		%
Burdekin alluvial ..	4825	±2·3
	6350	±5·0
Russell River alluvial	2412	±5·2
	6352	±1·7
Bundaberg red forest	2411	±3·8
	6353	±5·4
Bundaberg red volanic	6354	±4·8
	2410	±3·3
	6355	±2·2

DESCRIPTION OF PLATE 1.

Apparatus used for making tests. Fig. 1, Moisture equivalent dish, showing (*a*) general shape, and (*b*) perforated bottom. Fig. 2. Keen-Raczkowski dish, showing (*a*) filter paper disc and split ring in position, (*b*) split ring removed from dish, and view of perforated bottom. Fig. 3. Apparatus for determining relative percolation rate. Fig. 4. Hardness instrument in use.

The values of most interest are those for water capacity and pore space. It should be noted that pore space is expressed as a percentage by volume. It represents the total air space in the soil. Results are quoted without comment and no attempt is made to divide the total pore space into hypothetical capillary and non-capillary parts. The water capacity represents the maximum amount of water which the soil can retain for a brief period (there is usually no loss by drainage during the weighing operation) when the box has been standing in $\frac{1}{4}$ inch of water. The box itself is $\frac{3}{4}$ inch deep. Although this value for water-holding capacity is obviously too high for temperate climates and long drainage periods, there is much to recommend its use in place of lower values of the order of the moisture equivalent when heavy rain or furrow irrigation is the means by which the soil receives its moisture, and when high evaporation and high transpiration tend to prevent conditions of slow percolation from being established in the soil.

Relative Percolation Rate.

This simple test of permeability of the soil to water was devised not as a measure of absolute values but as an indication of their relative order. The original procedure (Cassidy, 1944) has been modified by using a Mariotte bottle to maintain the head of water at constant level, and by adding the soil sample to the leaching funnel so that it falls gently at the junction of the funnel and the water surface, when there is a depth of 10 cm. of water in the funnel. The cotton-wool plug and tap funnel are as previously described. By means of these standardizations of procedure better replications of results were obtained, and it is only with very high percolation rates that large differences between replications are likely to be obtained. Duly and Domingo (1944), using a somewhat similar technique, showed that a change of temperature of 30 deg. F. did not significantly affect the results. The method is clearly one for measuring saturated flow and using soil which has been disturbed from its natural state. The latter condition is necessitated by the nature of the investigations reported in this paper, and the former is the only one applicable to the climatic and field conditions concerned. The data are expressed in millilitres per minute and records were continued in some cases up to three hours after commencement. As a rule the 30 to 60 minute period proved satisfactory in providing a relative percolation rate characteristic of the soil and its particular condition at the time of the experiment. By taking this time period zero errors were eliminated; moreover, the normal decrease in rate due to washing out of soluble salts had not usually commenced.

Christiansen (1944) has shown that high initial permeability, decreasing with time, is characteristic of a de-aerated soil; whilst low initial permeability, increasing for several days, is characteristic of soil containing entrapped air. In the present paper, low values in a series of replicates are therefore more likely to be suspect than are the high ones, and it is felt that the removal of air when adding the soil sample through a water layer may yet be made more complete by further modification of the present technique.

Table 4.

HARDNESS OF SOIL CRUSTS ENCOUNTERED IN A CONTINUOUS SEQUENCE OF TREATMENTS.

No. of Test in Sequence.	Sub-irrigated to Saturation, and Drained 10-15 Minutes, between Tests.		No. of Series.	Burdekin alluvial.	Russell River alluvial.	Bundaberg red forest.	Bundaberg red volcanic.	Total Units of Hardness.
	Mechanical Treatment (given prior to drying).	Method of Removing Water.						
1	Nil	Centrifuged at 100 g; then dried in oven	1	2	1	< 1	2	5·5
	Nil		2	$2\frac{1}{2}$	$1\frac{1}{4}$	< 1	$1\frac{1}{2}$	6
	Nil		3	3	$1\frac{1}{2}$	< 1	$1\frac{1}{2}$	6·7
2	Nil	Dried in air, then in oven	1	$1\frac{1}{3}$	< 1	< 1	< 1	3·3
	Nil		2	2	< 1	< 1	< 1	4
	Nil		3	2	< 1	< 1	< 1	4
3	Nil	Centrifuged at 1,000 g; then dried in oven	1	$2\frac{1}{2}$	1	< 1	< 1	5
	Nil		2	2	1	< 1	< 1	4·5
	Nil		3	2	1	< 1	< 1	4·5
4	Nil	Centrifuged at 1,000 g; dried in air ($2\frac{1}{2}$ days), then in oven	1	2	1	< 1	< 1	4·5
	Pressed lightly		2	6	$2\frac{1}{2}$	3	4	15·5
	Pressed heavily		3	12	7	8	7	34
5	Nil	Centrifuged at 500 g; then dried in oven	1	$1\frac{1}{4}$	< 1	< 1	< 1	3·5
	Nil		2	4	2	1	< 1	7·7
	Nil		3	9	4	$2\frac{1}{3}$	1	16·3
6	Pressed heavily	Centrifuged at 500 g; then dried in oven	1	14	7	9	3	33
	Pressed lightly		2	11	6	3	3	23
	Nil		3	7	2	1	1	11
7	Nil	Dried in air and sun ..	1	9	4	$2\frac{3}{4}$	1	16·5
	Nil	Dried in air ($2\frac{1}{2}$ days), then in oven	2	$7\frac{1}{2}$	5	2	1	15·2
	Nil		3	6	2	1	1	9·7
	All dishes emptied out, and the dry, lumpy soil returned to the respective dishes and sub-irrigated. The wet soil was shaken till it subsided to an even surface.							
8	Wet soil shaken to an even surface	Centrifuged at 250 g; then dried in oven	1	5·5	4·7	3	1	13·9
			2	4	3·4	1·7	1	9·8
			3	2	3	1	1	6·7
9	As above ..	As above ..	1	4·4	3	1·5	1	9·6
			2	5	2·4	1·2	1	9·3
			3	3·7	2	1	1	7·4

Table 4—*continued.*

HARDNESS OF SOIL CRUSTS ENCOUNTERED IN A CONTINUOUS SEQUENCE OF TREATMENTS—*continued.*

No. of Test in Sequence.	Sub-irrigated to Saturation, and Drained 10-15 Minutes, between Tests. Mechanical Treatment (given prior to drying).	Sub-irrigated to Saturation, and Drained 10-15 Minutes, between Tests. Method of Removing Water.	No. of Series.	Burdekin alluvial.	Russell River alluvial.	Bundaberg red forest.	Bundaberg red volcanic.	Total Units of Hardness.
10	Pressed heavily with turning motion	Centrifuged at 250 g; soils tipped out, then returned to dishes and worked with rubber stopper down to level surface again (*see* "Treatment"). Dried in oven	1	c 30	13·6	21	21	>86
			2	>30	13	20	20·6	>84
			3	>30	14·2	19·4	19·8	>83
11	Nil	Dried in air, then in sun and oven	1	14	7	5	9	35
	Nil	Dried in sun, then in oven	2	22	7	$3\frac{3}{4}$	$10\frac{1}{2}$	$43\frac{1}{4}$
	Nil	Dried in oven	3	$15\frac{1}{2}$	5	3	2	$25\frac{1}{2}$
12	Wet soil shaken to an even surface	Dried in air, then in sun and oven	1	13	9	$5\frac{1}{2}$	8	36
		Dried in sun, then in oven	2	16	9	6	6	37
		Dried in oven	3	17	10	$6\frac{1}{2}$	2	36

Note: g = acceleration due to gravity.

Hardness Test.

This test, which has also been previously described (Cassidy, 1944) was further developed to shorten the necessary drying time. In order to do this the subirrigated samples of soil were centrifuged in their containers as for an ordinary moisture equivalent determination. (If required, the determination of moisture equivalent was completed by making the necessary weighings in the original dishes, applying a correction for the water held by the filter paper disc). Table 4 gives a continuous record, in chronological order, of the treatments applied to a series of soils and of the hardness of the soil surface after treatment. The numerical values are mean readings on the hardness instrument, four or more individual readings usually being obtained before the breaking up of the soil cake prevented any more readings being taken.

The results show clearly that:—

1. The hardness test indicates changes produced by the various soil treatments given.
2. Centrifuging and oven drying are permissible expedients. (This is later modified for certain Burdekin soils).
3. Pressing the moist soil increased the hardness according to the amount of pressure applied.
4. Wetting and drying alone will cause the recovery of a crusted soil, but in severe cases several repetitions of the treatment are required.

The hardness test thus evolved was used to determine the effect of other treatments upon the soil. It was then found that for certain Burdekin soils conclusion 2 above does not apply. The action of centrifuging the wet soil is sufficient to give a considerably higher value for the resultant hardness when cultivated Burdekin soil, and especially soil that is partially sodium-saturated, is used. The results shown in Table 4 were obtained with virgin Burdekin soil.

In Table 5 are shown segregated the effect due to draining the centrifuge dishes and that due to the action of centrifuging. It will be seen that it is immaterial whether or not a 10-15 minute drainage period is allowed before

Table 5.

SHOWING HOW CENTRIFUGING (BUT NOT DRAINING) AFFECTS THE HARDNESS VALUE RECORDED FOR CERTAIN BURDEKIN SOILS.

Lab. No.	Phase of Burdekin Alluvial Soil.	Drained Only.	Centrifuged Only.	Drained and Centrifuged.
4825	Virgin soil. Clods very lightly crushed	3·9	4·2	4·0
1229	Cultivated soil	5·0	13·3	12·9
4826	Cultivated soil	1·5	11·6	13·2
1219	Cultivated soil	9·4	10·1	17·5
3635	Cultivated soil	10·4	14·7	14·0
3637	Cultivated soil	8·6	13·8	12·7
Average value for the Cultivated soils		7·0	12·7	14·1

centrifuging, but the action of the centrifuge does cause a higher hardness value to be registered; presumably this is due to the working suffered by the soil sample as it settles under the centrifugal force. Table 6 shows the influence of centrifuging at a force of 250 times gravity and then at 1,000 times gravity. The difference between the centrifuged and the non-centrifuged samples is greater in the latter case than in the former, further indicating that, for these soils, the act of centrifuging constitutes a "treatment." It is interesting to note that in this phase of the work, where the same samples in the same dishes were used, being centrifuged first at 250g and then at 1,000g, the

Table 6.

Showing the Increases in Hardness due to two different rates of Centrifuging of certain Burdekin Soils.

Lab. No.	Phase of Burkedin Alluvial.	Sub-irrigated and Drained.					
		Centrifuged at 50 g.	Not Centrifuged.	Increase Due to Centrifuging.	Centrifuged at 1000 g.	Not Centrifuged.	Increase Due to Centrifuging.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
4825	Virgin soil. Clods crushed	6·8	6·9	—0·1	4·4	1·9	2·5
1223	Cultivated soil..	5·0	4·1	0·9	3·7	1·0	2·7
1229	Cultivated soil..	9·7	7·2	2·5	10·0	2·2	7·8
6229	Cultivated soil..	5·7	4·5	1·2	2·1	<1	—
..	Cultivated soil..	11·3	10·4	0·9	8·8	3·8	5·0
Average for all soils ..		7·7	6·6	1·1	5·8	1·8	4·0

absolute values are lower in columns 5 and 6 than in columns 2 and 3 because of the intervening wetting and drying which has taken place. The Burdekin soils which showed increased values of hardness after being centrifuged were those soils which owing to partial sodium-saturation or bad management, or both, readily gave high values under other methods of handling. It is a moot point whether, in determining the hardness values of such soils, the tendency of the normal conditions of the experiment to produce high values in some soils should not be allowed to take its course, since the super-sensitiveness of these soils will give rise to this result very readily under field conditions. Occasionally soil types other than the Burdekin alluvial gave increased hardness values after centrifuging, but the increases were of a lower order than with the Burdekin soils.

Calibration of Hardness Scale.

It is of interest to know the actual pressures exerted by the hardness instrument. By pressing with the point of the instrument on one scale pan of a balance in order to equalize various weights loaded on to the other pan, the curve shown in Figure 1 was obtained. An instrument reading of 26 divisions corresponds to a pressure by the needle of about 1,000 atmospheres, or 15,000 lb., per square inch. Up to this reading the relationship is linear. The calibration curve did not change during 12 months' usage. The limit of the instrument was about one and a-half times this pressure, the curve showing rapid increases of pressure for small increases in readings at the end of the range.

In preliminary experiments on the hardness developed in soils upon being mishandled it was found that wet working by kneading the soil with the fingers often produced a condition on drying that was impenetrable to the soil penetrometer. As it is desirable to be able to distinguish between one soil condition and another (however bad they may be), and also to work somewhat nearer to the treatment experienced by the soil in the field, another

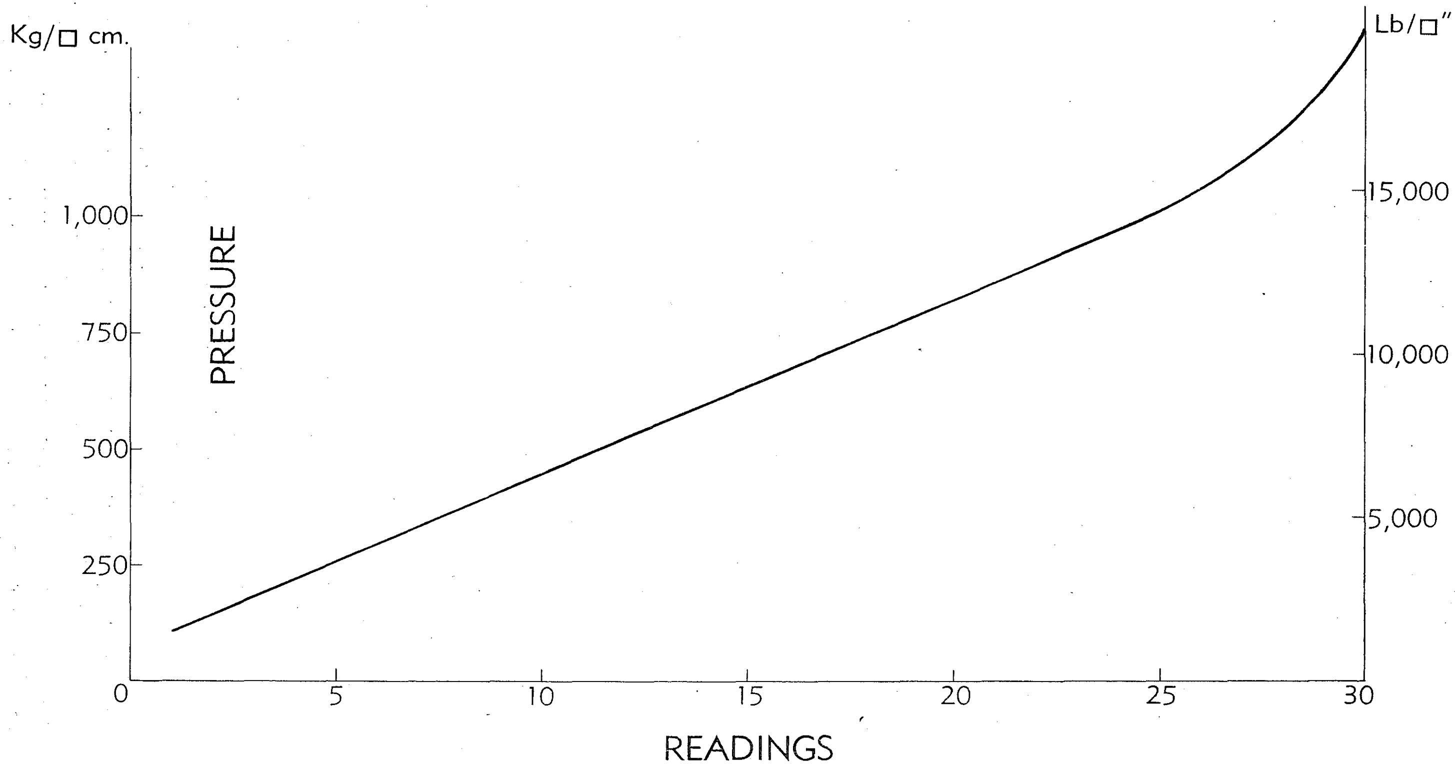


Figure 1.

Showing calibration curve of hardness instrument.

method of mishandling the soil was adopted, bringing the hardness values within the range of the instrument. This treatment consisted in centrifuging the samples exactly as for a moisture equivalent determination, and then subjecting them whilst at this moisture content to pressure, with a slight turning motion, applied through a rubber stopper. The stopper just fitted the moisture equivalent cup containing the soil, but allowed freedom for turning. In applying the test one of a pair of cups was placed on each pan of a heavy duty balance of the type known as "druggist's scales." To one side was added the requisite weight of approximately 5 kilograms. Pressure was then applied manually to one soil surface through the medium of the rubber stopper until the balance just assumed the equilibrium position; at the same time the stopper was turned through a right angle. This procedure was carried out five times. The whole treatment will hereafter be described in this paper by the terms "pressed heavily" or "heavy pressure." The pressure exerted on the soil by this heavy pressure treatment is 500 g. per sq. cm. or approximately 7 lb. per sq. inch. The wheel pressures of a number of crawler-type tractors were found from specifications to be 5-6 lb. per square inch, whilst the air pressure in rubber-tyred tractors is commonly 10-15 lb. per square inch. It is therefore clear that the heavy pressure treatment given in these laboratory experiments is of the same kind and of the same order as that experienced by the soil when, say, a rubber-tyred tractor turns on a headland. It is of interest to note that such heavy pressure on a soil which is in particularly bad physical condition may induce in the final dried surface a hard crust which requires 2,000 times the original pressure to break through it.

A second treatment, described by the terms "light pressure" and "pressed lightly," was also made use of and this was simply one-tenth of the heavy pressure value. It was used in those cases where the particular laboratory treatment given to the soil left it in a lumpy condition unsuitable for the application of the penetrometer test. Appendix C shows that this light pressure, applied even at the relatively high-water content of the moisture equivalent, does not unduly increase the hardness readings. In fact, where the original untreated values were high, the additional wetting and drying involved in subjecting the samples to "light pressure" treatment was sufficient to cause an actual reduction in the readings. It may be noted in passing that this method of working the soil is restricted to the small amounts held in the centrifuge cups and is therefore not suitable for the treatment of large samples.

For the preparation of such samples another, more empirical and less reproducible method, had to be used. It consisted in weighing 700-800 g. air-dry soil into a 9-inch diameter crystallizing dish, adding gradually from a burette enough distilled water to bring the total to the moisture equivalent, meanwhile incorporating the water with the soil by stirring with a 9-inch steel-bladed spatula. When the soil had assumed a uniform colour it was worked with 100 strokes of the spatula, moving the blade with a sliding motion across the soil lying under it. The blade was scoured clean between strokes, with a smaller spatula, as required. When smaller samples of worked soil were needed the number of strokes was reduced somewhat proportionately to the weight of soil, with a minimum of 20 strokes for a 20 g. sample. This treatment is referred to in the tables as "worked at moisture equivalent," "worked at 30 per cent. moisture," etc. It will be realized that the effects produced on different sized samples thus treated will be the same in kind rather than in degree.

Dispersion of Silt and Clay.

The remaining physical property of the soil measured in these studies was the dispersion of the silt and clay particles. The ordinary mechanical analysis of the soil, with complete dispersion, was carried out according to the International Method (Robinson, 1933). The soil was then subjected to the same pipette method of analysis, but without any pretreatment with hydrogen peroxide and hydrochloric acid. In other words, the distribution of clay, silt, and sands was determined without altering the state of dispersion existing in the particular sample on hand. This, of course, constitutes an inverse aggregate analysis in which the attention is fixed on the small particles and not, as is usual, on the large aggregates. The percentage dispersion was then calculated by dividing the actual silt and clay present in the particular sample by the total silt and clay in the completely dispersed soil. This determination was made because of the prevalent idea in the literature of soil science that a soil in bad physical condition is simply a soil with its clay dispersed. In this paper it is shown that, although saturation with sodium will cause poor physical condition associated with dispersion of the clay, mechanical working of a soil at an unfavourable moisture content may cause little change in its dispersion whilst degrading its physical structure in no uncertain manner as shown by, say, its percolation rate or its hardness value. It therefore becomes clear that dispersion (and especially dispersion of the clay alone) is not in itself a sufficient explanation of poor physical condition in soils. If percentage dispersion had been defined in terms of clay only, instead of silt plus clay, partial sodium-saturation would have been the only treatment which produced any considerable amount of dispersion; and the identification of all cases of poor physical condition with a high degree of dispersion of the clay would appear still more erroneous.

TREATMENTS.

The treatments used in this work were (*a*) dry working; (*b*) wet working; (*c*) partial sodium-saturation; (*d*) cropping to beans; and (*e*) some combinations of these.

Dry Working.

This treatment merely consisted in grinding the air-dry soil in a porcelain mortar, using no more pressure than was readily applied by a "pencil grip" on the pestle instead of the customary fist grip. Some idea of the fineness of the soil resulting from this treatment may be gained by referring to the fourth column in Table 7.

Wet Working.

The methods of wet working have been explained, *inter alia,* on pages 102-103.

Partial Sodium-saturation.

The partially sodium-saturated soils of a previous investigation (Cassidy, 1944) were used in this work. These soils contained no soluble salts, the latter having been removed during the preparation of the soils.

Cropping to Beans.

Three of the soil types—the Burdekin alluvial, the Russell River alluvial and the Bundaberg red forest soil—were cropped to beans in order to determine the effect of root growth on the soil. At the same time the effect of dry working these soils was combined with the straight-out influence of the legume. Five-inch or 6-inch unglazed pots, painted grey on the outside to reduce evaporation and maintain soil temperature, were used. Sufficient air-dry soil of numbers 4825, 2411, and 2412 to give a kilogram of soil at optimum moisture was employed. The requisite amount of moisture was gently incorporated with the normal air-dry soil in one case and with the dry-worked soil in the other. The moistened soils were transferred to tared pots and the pots were weighed. These weights were used when adding water to restore loss by evaporation, and when transpiration became important a correction was made for it. Six seeds of the Brown Beauty variety of French beans were planted in each pot. The seeds were planted at a depth of $\frac{3}{4}$ inch and none failed to germinate. The experiment was continued for nine weeks after planting, and at that time, although germination and growth had been very slow owing to the cool weather prevailing, the most advanced plants were bearing young beans. During the trial the soils were never allowed to approach the wilting point for very long before water was added; in this way the surface layer suffered wetting and drying about 35 times during the course of the experiment, and this may have had some effect on the "pot" soil samples as a whole, but, of course, not as between the members of a pair. Water was always added gently to the normal soils, but without care to the dry ground ones.

Owing to an error the moisture content of the Bundaberg red forest soils was kept too low in the early part of the experiment, and this delayed growth in these two pots very considerably. As the cotyledons emerged the date was noted, and later unwanted plants were removed, leaving two average-sized plants growing in each pot. Towards harvest a small quantity of nutrient solution was added, but as the total addition of ions was less than 15 milli-equivalents per pot, and as each one of a pair received equal amounts, the added salts should have no effect on comparisons of structure. At harvest the plants were washed free of soil, and both green and dry weights of the plants and of the plant roots were obtained. The soils were removed from the pots, mixed, and air dried for testing. Table 7 gives the relevant data.

Table 7.

POT EXPERIMENT DATA.

Soil Type.	Treatment.	Pot No.	Soil Fineness (% less than 1 mm.).	Emergence of Plants.		Green Weights (Grams).		
				Total No.	Time (Days).	Tops.	Roots.	Roots as Percentage of Total.
Burdekin alluvial	Normal, air dried	1	40	6	30	5·80	0·75	11
	Dry ground ..	2	90	4	52	6·42	0·58	8
Bundaberg red forest	Normal, air dried	3	72	5	58	3·34	1·70	34
	Dry ground ..	4	90	5	58	4·27	1·88	31
Russell River alluvial	Normal, air dried	5	51	6	23	13·65	4·62	25
	Dry ground ..	6	80	5	42	7·13	1·83	20

It will be seen that dry grinding prevented the emergence of some of the seedlings and greatly added to the time necessary for the last seedling to come through. In no case was germination at fault, but the cotyledons were held down in the soils of bad structure and in some cases they either snapped off in the hypocotyl region or otherwise failed to break through the soil crust. The proportion of roots to total plant was higher for the normal soil in each case, but

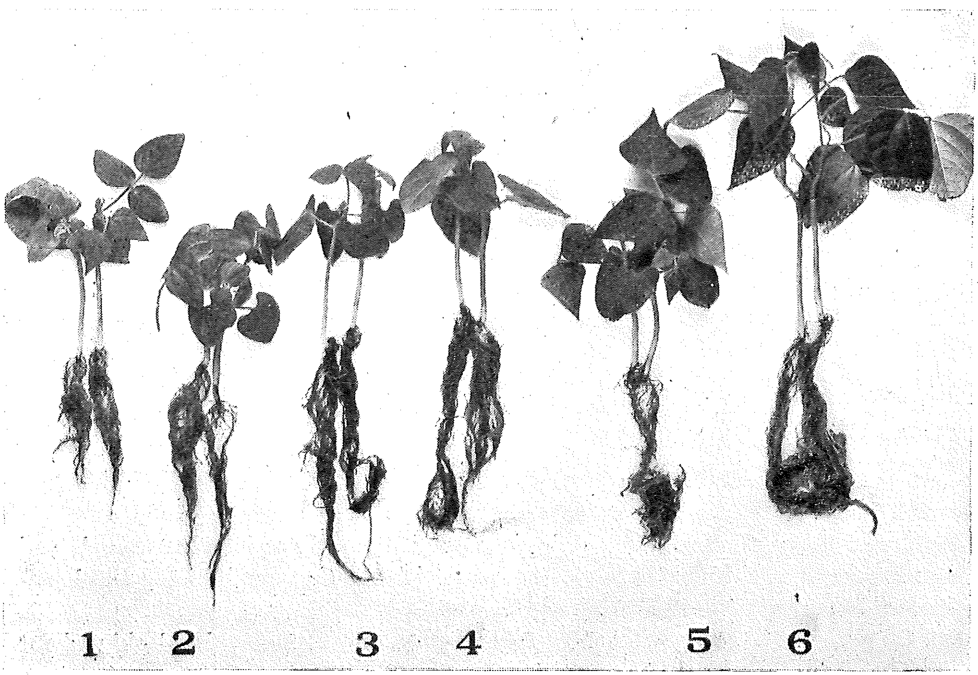


Plate 2.

Bean plants grown on soils subjected to various treatments. (1) Burdekin alluvial; normal, air dried; (2) Burdekin alluvial; dry ground; (3) Bundaberg red forest soil; normal, air dried; (4) Bundaberg red forest soil; dry ground; (5) Russell River alluvial; dry ground; (6) Russell River alluvial; normal, air dried. Note that the order for Pots 5 and 6 has been reversed.

no test of the significance of this was possible in the absence of replicates. The low absolute value of this ratio for the Burdekin soil indicates its inferior physical status, for its plant nutrient content is as high as that of either of the other soil types. Plate 2 shows the plants from the respective pots at harvest.

REFERENCE STANDARD OF STRUCTURE.

One of the conclusions reached in this paper is that, at least in the present state of our knowledge, each soil type needs to be treated as a particular case. It is therefore desirable to adopt a definite condition of the soil as a standard of reference and it is natural to fix on the air-dried state as the one to be so chosen. The normal condition is, then, that which results when the soil has been wetted and then thoroughly air dried. It is, of course, assumed that there is no immediate past history of gross mishandling in any way. That this norm is a good selection is supported by the data in Table 4, which shows that wetting and drying will expunge the effects of any prior treatment that is not too severe, at least as far as the hardness of surface crusts is a criterion. McGeorge (1937) adopted the dispersion in the air-dry state as his zero correction, when expressing dispersion in any other condition as a "degree of puddling." The air-dry state has been adopted in Table 9, which summarizes by plus and minus symbols the effect of various physical treatments on the several properties dealt with in this paper.

FIELD INFORMATION.

Clods.

It is clear from the nature of this investigation that very little of the data can be garnered in the field. For example, it is not practicable to have a field just at the moisture equivalent when it is to be worked, and then to have it dry out completely and be re-worked in the dry state. Still less can these conditions be realized at will in a series of soils, and the samples be brought to a central laboratory without change. It is for this reason that treatments such as dry grinding in a porcelain mortar have been used, though they are not replicas of field operations. They do, however, represent types of mishandling, and it is hoped that better laboratory treatments will be devised in the future. Some field samples have, however, been obtained, including samples of clods formed in three fractious soils. Hardness determinations made directly on the dry clods showed that whilst 3-inch clods tended to be harder than 2-inch and these harder than 1-inch, there was no appreciable difference between the hardness inside and outside the larger clods, except where an implement had left a smooth, glazed surface. In that case there was an extremely hard skin about a quarter-of-an-inch thick, below which the hardness values were somewhat less. Table 8 shows some of the results.

Each figure for the dry clods represents an average of 10 or more readings. It was found advantageous to use a hollow, wooden wedge to hold the clod steady when making these readings (see Plate 1). Measurements recorded in the other columns were made by the standard procedure using moisture equivalent cups.

Table 8.

HARDNESS READINGS ON FIELD CLODS.

Lab. No.	Soil.	Dry Clods. Max. Dimension.			Clods Crushed.	Clods Slaked.	Clods Crushed and Ground.	Clods Slaked; Centrifuged, and Pressed Heavily.
		1″	2″	3″				
4825	Burdekin alluvial	11	18	..	2·0	9·0	4·8	9·2
6331	Burdekin alluvial	..	28	28	12·6	7·3	26·4	13·6
..	Burdekin alluvial	22	28	28	12·8	9·2	17	22·5

In this case preparation by merely crushing the clods before subirrigating and drying the sample in the standard manner appears to be the best procedure to adopt in assessing the relative hardness of the soils.

Evidence of Field Officers and Farmers.

In order to test the conclusions to which these laboratory experiments have led, a questionnaire was submitted to extension officers, who gave (by collaborating with practical farmers) the experience and the opinions of those closely associated with the cultivation of the several soil types regarding the behaviour of the soils in the field. As a result of the questionnaire the Burdekin alluvial and to some extent the Cairns red schist soil were rated as "sensitive to handle" and the others as more tolerant, indicating no serious conflict between the laboratory findings and practical experience in the field. Some properties, such as water capacity and pore space, cannot of course be evaluated by simple field observations.

RESULTS.

The measurements on each of the soil properties studied are recorded in the Appendixes. These should be consulted for all details, but for convenience Table 9 has been drawn up to provide a survey of the whole field. It should be noted that this table merely provides a resume of the main findings and is approximate only. It is not a simple compression of the data.

DISCUSSION.

The first fact that emerges from a review of the data is that all soil types reacted in some way to any treatment which was used in these experiments. In many cases more than one of the properties measured was found to have undergone a change, and the changes were often of considerable magnitude. The increase in the percolation rate of the Bundaberg red volcanic soil type, due to working at or slightly above the moisture equivalent, was spectacular; for by this mechanical means the normal high percolation rate of the subtropical red loam was increased fourfold, to the equivalent of a light gravel. The treatments to which the soils were subjected were admittedly rigorous in some cases, and they may not reflect very well the action of field operations. It is well known that the effect on the soil of a wooden mouldboard is different

Table 9.

Summary of Results.

Soil and Treatment.	Water Capacity	Pore Space.	Dispersion.	Percolation Rate.	Hardness.	Remarks.
Basis of Evaluation.	Change in Normal Value.				Actual Reading of Instrument.	
Legend. (Negative Signs show corresponding decreases).	+ = 5% ++ = 10% +++ = 20% ++++ = 40%		+ = 25% ++ = 50% +++ = 100%	+ = ×2 ++ = ×4 +++ = ×8		
Burdekin alluvial—						
Normal values	62	56	40	4	4	
Dry ground in a mortar ..	−−−	−−	0	−−	10	
Worked at the moisture equivalent	0	+	0	−−	7	Moisture equivalent = 22%
Worked at the sticky point..	0	0	+++	−−−−	28	Sticky point = 30%
Cropped to beans in pot experiment	−−	0	−	0	1	
Partially sodium-saturated..	−−	0	++	−−−	16	
Ditto; and cropped to cane for 40 years	−−−	−−		0	16	
Ditto; and dry ground ..	−−−		+++	−	26	
Ditto; and wet worked ..	−−		+++	−−−−	Impenetrable	
Russell River alluvial—						
Normal values	60	54	24	7	1	
Dry ground in a mortar ..	{ ++ { −	+	+	−	3	See comments in Appendix A.
Worked at the moisture equivalent	+++			+	4	Moisture equivalent = 28%
Worked at the sticky point..	+++	+++	+++	−−−	13	Sticky point = 44%
Cropped to beans in pot experiment	+++	++	−	+	2	
Partially sodium-saturated ..	++	++	++	−	1	
Bundaberg red forest—						
Normal values	37	45	18	8	<1	
Dry ground in a mortar ..	−−	−	++	−	3	
Worked at the moisture equivalent	++	+		++	2	Moisture equivalent = 12%
Worked at the sticky point..	+++	+++	++++	−−	7	Sticky point = 22%
Cropped to beans in pot experiment	++++	+++	−−	++	1	
Partially sodium-saturated ..	+++	+	++	0	<1	
Bundaberg red volcanic—						
Normal values	60	56	9	8	1	
Dry ground in a mortar ..	−−−	−	+++	−	8	
Worked at the moisture equivalent	++	+	++	++	1	Moisture equivalent = 26%
Worked at the sticky point..	+++	++		−	7	Sticky point = 36%
Cropped to cane for 40 years	−−	0	0	−−	1	
Cairns red schist—						
Normal values	45	50	13	9	1	
Dry ground in a mortar ..	0	0	+	−	6	
Worked at the moisture equivalent	++	+	++	0	3	Moisture equivalent = 15%
Worked at the sticky point..	0		0		21	Sticky point = 34%

from that of a steel one, whilst in these experiments porcelain, glass, rubber, and steel surfaces were all used at different times. Nevertheless, the experiments have further demonstrated the essential dynamic nature of soil in the physical sense. The changing nature of the physical condition of a soil has long been recognized in respect of the dispersion of the fine particles (usually the clay is specified) and also in respect of the hardness of the soil clods. It is also well known that the absorption of sodium ions by the soil results in decrease of permeability to water and in increased hardness of the soil clods. That the physical manipulation of the soil in any way may effect these properties has been given much less consideration, and measurements of such effects appear to be very few.

It is believed that the dynamic nature of the maximum water-holding capacity of a soil has not previously been fully recognized and quantitatively reported. v. Nostitz (1932) recognized the dependence of water capacity upon the particular structure of the soil existing at the moment. He showed the determining influence on water capacity of the actual process of sieving during preparation of the sample; and he found also that pulverizing the soil to reduce the particles to less than 1 mm. (prevailing soil moisture not stated) increased the water capacity considerably. However, his only conclusion from this work was that water capacity was of no use as a "single value" constant for the appraisal of soils. The water capacity or field capacity of a soil has always been regarded as a fixed quantity, the absolute value for a given soil depending only on the particular method of measurement, provided the chemical composition of the soil remains unchanged, as for example in regard to total organic matter. Shaw and Swezey (1937) stated: "Each soil has a definite capacity for moisture which is inherent in the physical structure and chemical nature of that soil and does not change with season nor with the plant species grown therein." Veihmeyer and Hendrickson (1943), summarizing the known facts, stated the following:—"Structure is the manner in which the soil particles are arranged. It has little effect on the field capacity (for water) but may influence the permeability of the soil to water." Table 9 shows clearly that the static concept of a soil's moisture-holding capacity must be abandoned in favour of a dynamic view which allows of very considerable fluctuations, either positive or negative, from the normal mean value. Table 9 shows how the water capacity, as measured by the Keen-Raczkowski test, may change by either a positive or a negative quantity, and the absolute amount of change may be such as to be of great practical importance. For a complete prosecution of this aspect it would be necessary to determine if physical manipulation of the soil affects that portion of the soil moisture which is not available to the plant—i.e., below the wilting point.

In general the changes of total pore space are similar to those of water capacity but of lesser magnitude. It may well be that these two factors—primarily, water capacity, and, secondarily, aeration—are the ones directly affecting the plant when "a favourable state of aggregation" of the soil is reported.

It will be seen also that the dispersion is increased by many of the treatments, but that the growing of beans caused a definite aggregation of the soil particles.

Percolation rate was decreased by practically all treatments. The phenomenal effect of wet working upon the Bundaberg red volcanic soil is referred to in the comments on Appendix B.

The second outstanding conclusion to be drawn from Table 9 is that the various soil types have responded differently to the same treatments, although the two Bundaberg soils behaved very much alike. This means that, until such time as it is shown that some complete concept is applicable to all soils, each and every soil must be regarded as a separate problem in itself. Certain treatments are shown by Table 9 to have both good and bad effects on the same soil. For example, the water-holding capacity has in many cases shown a very favourable increase due to wet working—a treatment which invariably causes some increase in the hardness of the soil clods. If the latter effect is not very serious, it may become a sound method of management to carry out cultivation at a higher moisture content than would have been countenanced in the past. Clearly there is now a need to test the laboratory findings by field trials in order to work out the best cultural practice for each soil type. Other field treatments of proven value, such as the application of large amounts of molasses to cane lands, should be capable of more accurate assessment by means of the methods described in this paper. One such assessment, for example, has been made on samples from two similar blocks of Burdekin alluvial land, one of which had had an application of molasses in 1942 and the other in 1943. Hardness tests, without centrifuging, were made on these samples, which were originally in poor physical condition, and showed the following values:—

Molasses Applied.	Hardness Determined in 1944.
8 tons per acre in 1942	13.4
5 tons per acre in 1943	5.5

It is clear that a recent application of 5 tons per acre of readily decomposable organic matter is better in its action than 8 tons applied a year previously.

In the discussion of the method for determining the hardness of soil crusts it was shown that wetting and drying is the best corrective for an unduly hard soil crust. In terms of field practice, especially in cases where spray irrigation is used, a procedure is thus indicated for the amelioration of land which has formed hard clods or a crusted surface.

Evidence from other countries shows that now is the time to take stock of the prevailing theories of soil cultivation and to test the value of the methods at present recommended. The former theory that continual cultivation, by maintaining a dust mulch, preserved moisture under hot conditions has been discarded by scientific workers, at least for conditions normally met with.

Other ideas based largely on tradition will need to be closely examined also. Bennett and Allison (1928) after describing the remarkable Matanzas loam of Cuba, which can be cultivated without ill effect at very high moisture content, had this to say of the Bayams type of dense intractable clay:—"Fields were found where knifing and cross knifing to depths of more than 2 feet with subsequent deep plowing and harrowing, at large expense, $60 per acre in one instance, was followed by a flowing together of the disturbed clay into its original state of unfavourable density with the first saturating rains." The possible futility of some operations is also indicated by the conclusions of Cole (1939) who found that "the wetting of the soil, both by winter rains and by irrigation water, brings about changes in the size distribution of aggregates that are often as great as changes brought about by tillage implements." Nor is the unorthodox to be feared, as is shown in the success attributed by Wadham and Wood (1939, p. 180) to a method evolved specifically for dealing with a particular intractable soil in Victoria—i.e., wet ploughing using a skeleton mouldboard.

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APPENDIX A.

KEEN–RACZKOWSKI DATA.

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity	Pore Space.	True Sp. Gr.	Vol. Exp.	No. of Tests.	Remarks.
		% (weight)	% (volume)		%		
Burdekin alluvial—							
Lab. No. 4825—							
Original moist sample	1·04	62·7	55·8	2·21	1·1	6	
Air dried, remoistened, sieved and dried	1·00	60·6	56·4	2·16	2·0	3	
Dry ground lightly	1·10	54·3	56·2	2·20	2·1	2	
Dry ground more severely	1·18	48·2	51·0	2·22	6·6	11	
Worked at sticky point*	0·99	62·4	58·2	2·24	4·1	4	Sticky point = 30%
Worked at sticky point, then dry ground	1·22	46·3	51·6	2·32	6·3	2	
Dry ground, then worked at sticky point	0·98	63·9	58·8	2·23	4·6	2	
Dry ground, then worked at 24% moisture	1·00	62·4	58·8	2·30	4·7	2	
Cropped to beans	1·06	55·3	54·8	2·24	4·2	3	Pot. No. 1
Dry ground; cropped to beans	1·05	(58·1)	56·9	2·25	3·5	3	Pot. No. 2
Partially sodium-saturated—							
Soil E (8·3% Na)	1·01	64·1	59·0	2·34	3·3	2	
Soil C (12·0% Na)	1·04	59·7	56·7	2·28	4·4	2	
Soil B1 (15·8% Na)	1·04	58·7	55·9	2·24	4·6	2	
Soil D (16·5% Na)	1·11	54·9	53·4	2·26	6·0	2	
Soil A (16·8% Na)	1·08	52·1	(53·0)	(2·22)	−ve	2	
Soil B2 (21·4% Na)	1·07	53·5	54·6	2·28	2·0	1	
Soil F (84·9% Na)	1·17	52·5	52·9	2·47	−2·6	2	
Soil E Dry ground	1·15	49·5	53·8	2·40	2·6	1	
Worked at 28% moisture	1·04	55·7	56·7	2·29	1·7	1	Lateral movement of water almost nil
Soil A Dry ground	1·18	50·6	53·2	2·26	9·9	1	
Worked near sticky point	0·99	54·3	..	..	−ve	1	
Soil B2 Dry ground	1·17	46·8	53·1	2·41	1·3	1	
Worked near sticky point	1·07	..	..	..	−ve	1	
Lab. No. 1219 (14·4% Na)—							Field sample
Normal, air dried	1·09	55·1	54·3	2·17	8·0	2	
Dry ground	1·00	57·8	57·0	2·20	..	4	
Worked near sticky point	1·02	52·8	53·7	2·14	−ve	2	
Field sample	1·13	48·2	50·0	2·17	−ve	2	12·9% Na. Cultivated for cane, 40 years
Lab. No. 6350—							
Original moist sample	0·88	52·3	53·4	2·16	−22·6	4	11% moisture
Normal, air dried	1·11	52·4	52·3	2·20	7·5	10	
Air dried; cloddy sample	1·16	48·8	51·2	2·24	5·3	4	Small clods were gently crushed
Dry ground	1·16	49·1	50·2	2·20	5·6	2	
Worked at moisture equivalent	0·88	54·8	51·2	1·96	−19·1	4	Moisture equivalent = 21·4%
Russell River alluvial—							
Lab. No. 2412—							
Normal, air dried	1·09	55·5	53·0	2·16	8·4	6	
Dry ground	0·98	61·6	55·5	2·14	2·7	5	
Worked at sticky point	0·91	71·2	62·0	2·22	3·0	2	Sticky point = 40%
Dry ground, then worked at sticky point	0·94	64·1	58·5	2·25	2·0	3	
Worked at sticky point, then dry ground	0·95	58·6	55·1	2·12	−ve	3	
Partially sodium-saturated (18%)	0·94	66·2	57·7	2·14	4·4	2	
Cropped to beans	0·89	70·0	59·3	2·12	1·5	1	Pot. No. 5
Dry ground; cropped to beans	0·89	70·6	59·2	2·11	2·3	1	Pot. No. 6

* Sticky Point indicates point of maximum stickiness.

APPENDIX A—continued.

KEEN–RACZKOWSKI DATA—*continued.*

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity	Pore Space.	True Sp. Gr.	Vol. Exp.	No. of Tests.	Remarks.
		% (weight)	% (volume)		%		
Lab. No. 6352—							
Normal, air dried	1·03	61·3	56·0	2·10	6·0	10	
Dry ground	0·94	58·8	57·8	2·16	−4·6	2	
Worked at moisture equivalent	0·84	72·1	61·6	2·19	−20·8	2	Moisture equivalent = 28·6%
Worked at moisture equivalent, then air dried	0·94	67·1	57·3	2·06	8·9	2	
Bundaberg red forest—							
Lab. No. 2411—							
Normal, air dried	1·31	35·0	43·9	2·25	4·2	2	
Dry ground	1·37	32·2	42·6	2·32	2·9	3	
Worked at sticky point	1·12	45·4	51·8	2·28	−ve	2	Sticky point = 20%
Worked at sticky point, then dry ground	1·37	34·3	44·0	2·35	4·2	2	
Dry ground, then worked at sticky point	1·06	49·3	54·4	2·25	Nil	3	
Partially sodium-saturated (15%)	1·28	40·9	47·0	2·30	5·6	2	
Cropped to beans	1·10	47·6	51·8	2·30	0·4	2	Pot. No. 3
Dry ground; cropped to beans	1·06	51·0	52·6	2·22	1·3	3	Pot. No. 4
Lab. No. 6353—							
Normal, air dried	1·24	38·7	46·0	2·24	1·0	2	
Dry ground	1·31	35·3	43·0	2·26	−1·0	2	
Worked at moisture equivalent {	0·91	(43·6)	48·4	2·17	−23·4	2	Stored 2 weeks
	1·12	44·7	46·8	2·05	4·8	2	Stored 10 weeks
Worked at moisture equivalent, then air dried	1·16	42·8	48·5	2·25	2·2	2	
Bundaberg red volcanic—							
Lab. No. 2410—							
Normal, air dried	1·24	46·5	51·8	2·36	8·2	2	
Dry ground	1·24	44·7	52·6	2·46	5·0	2	
Worked at moisture equivalent	0·93	61·7	58·4	2·38	−20·7	5	Moisture equivalent = 25·0%
Worked at moisture equivalent, then air dried	1·02	60·7	58·2	2·30	3·6	6	
Worked at sticky point, then air dried	0·97	64·7	59·9	2·28	3·1	3	Sticky point = 35%
Worked at sticky point, then dry ground	1·16	48·2	55·8	2·48	2·8	2	
Dry ground, then worked at sticky point	0·95	66·0	59·9	2·25	2·7	3	
Lab. No. 6355—							
Normal, air dried	1·12	60·7	56·2	2·20	6·0	4	Cultivated for cane for 40 years. (Cf. 6354, virgin phase of this soil)
Crushed, dry	1·22	46·8	54·7	2·32	5·6	2	
Worked at moisture equivalent	0·84	68·8	60·3	2·36	−22·9	7	Moisture equivalent = 27·1%
Worked at moisture equivalent, then air dried	0·94	67·5	59·8	2·22	3·8	6	

APPENDIX A—continued.

KEEN–RACZKOWSKI DATA—*continued.*

Soil and Treatment.	App. Sp. Gr.	Maximum Water-holding Capacity	Pore Space.	True Sp. Gr.	Vol. Exp.	No. of Tests.	Remarks.
		% (weight)	% (volume)		%		
Lab. No. 6354—							
Normal, air dried	1·10	67·3	56·4	2·00	16·5	4	Virgin soil. (Cf. Lab. 6355 for same soil cultivated for 40 years)
Crushed, dry	1·14	65·9	56·9	2·12	17·3	2	
Worked at moisture equivalent..	0·94	79·8	64·0	2·27	−8·2	2	
Worked at moisture equivalent, then air dried	0·97	73·5	60·4	2·07	16·8	2	
Dry ground	1·07	71·0	59·6	2·25	11·4	2	
Cairns red schist—							
Lab. No. 6351—							
Normal, air dried	1·23	44·6	49·6	2·30	6·6	2	
Worked at moisture equivalent..	0·85	48·9	53·2	2·35	−29·0	2	
Worked at moisture equivalent, then air dried	1·06	53·3	53·0	2·23	2·0	2	
Worked at sticky point	1·16	45·4	(52·0)	2·29	5·0	2	Dried and remoistened
Dry ground	1·24	43·4	49·6	2·35	6·0	2	

COMMENTS.

Burdekin alluvial.

Dry grinding caused a considerable decrease in water capacity, the amount of change being proportional to the severity of the treatment. Pore space was affected to a smaller extent. Wet working had no significant effect on water capacity. When dry grinding and wet working were applied successively the last treatment used expunged the effects of the former treatment. Increasing sodium-saturation gave progressive lowering of the water capacity and, to a lesser extent, of the pore space. Partial sodium-saturation also prevented the attainment of enhanced values by wet working. The treatment of cropping to beans in a pot experiment failed to improve the soil, and the final result was a lower water capacity than before.

Russell River alluvial.

There is a discrepancy between the responses of the two samples to dry grinding. This may be due to the dissimilarity in properties shown in Table 1. Wet working, cropping to beans, and even partial sodium-saturation had favourable effects on the water capacity and pore space.

Bundaberg red forest.

Dry grinding was the only unfavourable treatment as regards water capacity and pore space. Wet working, cropping to beans and partial sodium-saturation each produced substantial increases; whilst in the case of alternate dry grinding and wet working it was the effect of the last treatment to be applied which persisted in the soil.

Bundaberg red volcanic.

Wet working was favourable and dry grinding unfavourable to the achievement of high water capacity and pore space. As with other soil types, the latter treatment expunged the effects of the former.

Cairns red schist.

Wet working at the moisture equivalent (but not at the sticky point) caused an increase in water capacity and pore space. Dry grinding was without effect.

In all soil types except the Burdekin alluvial, wet working enhanced the water capacity and the pore space. Dry grinding had the opposite effect on most of the soils used. The favourable result recorded in some cases of partial sodium-saturation may be a secondary effect from wet handling during the process.

APPENDIX B.

Relative Percolation Rates.

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
	%	%	%	%	%	%	
Burdekin alluvial—							
Lab. No. 4825—							
Normal, air dried	4·4	..	..	..	..	..	
Remoistened and sieved ..	0·8	..	..	..	..	..	
Partially sodium-saturated—							
Soil E (8·3 % Na)	3·6	..	..	..	..	..	
Soil C (12·0% Na)	5·8	..	..	..	..	..	
Soil A (16·8% Na)	0·5	..	..	..	..	..	
Soil D (16·5% Na)	0·2	..	..	..	..	..	
Soil B2 (21·4%)	0·0	..	..	..	..	..	
Soil F (84·9% Na)	0·0	..	..	..	..	..	
Soil C Dry ground	1·6	..	..	..	..	..	
Cropped to beans	6·3	..	..	..	..	..	Pot. No. 1
Cropped to beans ; remoistened and sieved	0·7	..	..	..	..	..	Pot. No. 1
Dry ground ; cropped to beans	5·2	..	..	..	..	..	Pot. No. 2
Dry ground ; cropped to beans ; worked at sticky point	0·1	..	..	..	..	..	Pot. No. 2
Lab. No. 6350—							
Normal, air dried	4·3	4·1	4·0	3·8	..	..	
	3·2	2·5	2·8	2·2	..	..	
Original moist sample ..	2·5	1·8	1·5	1·2	1·4 (2½–3½ Hour)		
	2·6	1·9	1·6	1·4	1·7 (2½–3½ Hour)		
Original moist sample ; stored 6 months	24·6	22·6	22·1	..	..	..	Soil micro-flora active
	35·7	33·2	31·5	..	..	..	
	26·5	22·8	20·5	20·6	..	..	
Original moist sample ; stored 6 months, then worked at 11% moisture	0·8	0·9	..	..	..	..	
	0·9	0·6	..	..	..	..	
Moistened to optimum moisture	1·7	1·6	1·6	1·3	1·4	1·2	Optimum moisture = 15%
	1·1	0·9	0·7	0·7	0·6	0·5	
Worked at optimum moisture	1·6	3·0	5·7	5·2	..	..	
	1·2	1·0	0·9	0·8	..	..	
	2·4	2·1	1·9	..	..	..	
	2·5	2·1	1·9	..	..	..	
Worked at moisture equivalent	0·6	0·4	0·4	0·3	..	..	Moisture equivalent = 21·4%
	0·5	0·4	0·3	0·3	..	..	
Worked at moisture equivalent, then air dried	3·5	3·0	..	..	..	..	
	8·8	8·3	..	..	..	..	
	5·7	4·4	4·1	3·7	..	..	
	9·9	8·6	8·5	8·1	..	..	
	4·8	4·4	4·3	4·0	..	..	
	5·0	4·7	4·5	3·8	..	..	
Dry ground	2·4	..	..	..	..	..	
	2·4	2·2	2·0	..	..	..	
Other Burdekin alluvials—							
Lab. No. 1219 (14·4% Na)—							
Normal, air dried	1·0	..	..	..	..	..	
Dry ground	0·4	..	..	..	..	..	
Lab. No. 4826 (12·9% Na)—							
Normal, air dried	3·5	..	..	..	..	..	
	2·7	..	..	..	..	..	
	4·2	..	..	..	..	..	
Worked at 18% moisture ..	<0·1	..	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
	%	%	%	%	%	%	
Lab. No. 6476—							
Normal, air dried	1·6	1·2	..	..	..	..	8 tons per acre molasses in 1942
Lab. No. 6477—							
Normal, air dried	4·7	3·9	..	..	..	..	5 tons per acre molasses in 1943
Russell River alluvial—							
Lab. No. 2412—							
Normal, air dried	11·2	..	..	..	..	..	Early trials
	4·5	..	..	..	..	..	
	6·6	..	..	..	..	..	
	4·6	..	..	..	..	..	
	4·6	3·9	3·5	3·2	2·8	..	
	6·0	4·0	3·5	3·1	2·9	..	
	8·9	..	..	..	..	..	
	5·8	..	..	..	..	..	
Dry ground	3·1	..	..	..	..	..	
Partially sodium-saturated (18% Na)	2·9	..	..	..	..	..	
Remoistened to 20% moisture, then sieved	3·3	..	..	..	..	..	
Worked at 20% moisture ..	5·9	..	..	..	..	..	
Worked at moisture equivalent, then air dried	6·0	5·0	4·3	..	..	..	Moisture equivalent = 23·8%
	7·0	5·9	5·6	..	..	..	
Worked at 40% moisture ..	0·6	..	..	..	..	..	Sticky point = 43%
Cropped to beans	10·1	..	..	..	..	..	Pot. No. 5
	14·7	13·6	12·9	..	..	..	
	7·9	6·3	5·5	..	..	..	
	11·3	10·4	10·2	..	..	..	
	13·0	12·1	11·6	..	..	..	
	11·9	10·9	10·8	..	..	..	
Dry ground; cropped to beans	5·2	..	..	..	..	..	Pot. No. 6
	10·2	9·7	9·1	..	..	..	
	9·5	8·6	8·5	..	..	..	
	6·1	5·1	4·2	..	..	..	
	10·2	10·2	8·5	..	..	..	
	13·6	13·0	12·7	..	..	..	
Lab. No. 6352—							
Normal, air dried	7·2	5·8	5·0	4·1	..	..	
	6·5	5·1	4·4	3·8	..	..	
Dry ground	1·9	1·8	1·7	1·6	..	..	
Worked at moisture equivalent	14·3	11·7	10·6	..	..	..	Moisture equivalent = 28·6%
	18·2	15·8	14·3	..	..	..	
	23·7	21·4	20·3	..	..	..	
Worked at moisture equivalent and air dried	8·0	6·5	6·0	..	..	..	
	8·2	6·4	5·9	..	..	..	
Bundaberg red forest—							
Lab. No. 2411—							
Normal, air dried	3·7	..	..	..	..	..	
	4·5	..	..	..	..	..	
	3·8	3·1	2·8	2·4	1·6	..	
	4·1	3·3	2·9	2·4	2·3	..	
Dry ground	2·3	..	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute. ½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	Remarks.
	%	%	%	%	%	%	
Partially sodium-saturated (15% Na)	4·0	..	..	..	..	..	
Remoistened to 10% moisture, then sieved	2·6	..	..	..	..	..	
Worked at 10% moisture ..	6·3	..	..	..	..	..	Optimum moisture = 13%
Worked at moisture equivalent, then air dried	6·7	5·0	4·0	..	..	..	Moisture equivalent = 13·5%
	5·6	4·1	3·3	..	..	..	
Worked at 20% moisture ..	1·0	..	..	..	..	..	Sticky point = 21%
Cropped to beans	8·2	6·2	5·0	..	..	..	Pot. No. 3
	14·8	11·0	..	..	..	..	
	9·2	6·8	5·6	..	..	..	
	8·5	7·0	4·7	..	..	..	
	8·3	6·2	5·4	..	..	..	
Dry ground ; cropped to beans	4·7	3·2	2·7	..	..	..	Pot. No. 4
	8·2	7·3	6·9	..	..	..	
	10·3	8·7	8·0	..	..	..	
	9·0	..	..	..	..	..	
	12·5	9·4	8·2	..	..	..	
Lab. No. 6353—							
Normal, air dried	9·8	6·7	5·5	..	..	..	
	11·8	9·5	9·7	..	..	..	
	15·2	10·7	7·0	..	..	..	
	9·3	6·6	5·9	..	..	..	
	11·9	8·8	8·6	6·2	..	..	
Dry ground	3·8	3·3	3·0	2·7	..	..	
Worked at moisture equivalent	31·3	25·4	21·2	..	..	..	Moisture equivalent = 11·3%
	27·9	20·2	16·5	..	..	..	
	36·0	..	..	..	..	..	
	37·2	..	..	..	..	..	
Worked at moisture equivalent, then air dried	7·4	4·9	3·6	..	..	..	
	11·3	8·9	8·4	..	..	..	
	10·5	7·8	6·6	..	..	..	
	15·8	8·6	10·0	..	..	..	
	14·0	11·2	9·2	..	..	..	
	14·7	11·5	9·9	..	..	..	
	15·4	12·5	10·7	..	..	..	
	15·6	12·0	9·6	..	..	..	
Bundaberg red volcanic— Lab. No. 2410—							
Normal, air dried	5·8	..	..	..	..	..	
	6·6	..	..	..	..	..	
	6·5	..	..	..	..	..	
	5·4	..	..	..	..	..	
	6·9	..	..	..	..	..	
Dry ground	2·4	..	..	..	..	..	
Remoistened to 20% moisture	8·8	..	..	..	..	..	
Remoistened to 20% moisture, then sieved	4·3	..	..	..	..	..	2 mm. sieve used
Worked at 20% moisture ..	8·7	..	..	..	..	..	
	6·8	..	..	..	..	..	

APPENDIX B—continued.

Relative Percolation Rates—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute. ½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	Remarks.
	%	%	%	%	%	%	
Worked at 22% moisture ..	7·8	..	..	..	..	..	
Worked at moisture equivalent	37·3	..	..	..	..	..	Moisture equivalent = 25%
	26·7	..	..	..	..	..	
	34·5	..	..	..	..	..	
	>50	..	..	..	..	..	
	30·0	17·3	15·0	10·2	9·8	..	
	35·0	18·5	11·2	7·0	6·5	..	
Worked at 27% moisture ..	23·3	..	..	..	..	..	
Worked at 30% moisture ..	11·7	..	..	..	..	..	
Worked at 35% moisture ..	2·9	..	..	..	..	..	
Worked at 38% moisture ..	2·0	..	..	..	..	..	
Worked at 40% moisture ..	2·1	..	..	..	..	..	
Worked at moisture equivalent, then air dried	8·0	..	..	..	..	..	
	8·4	..	..	..	..	..	
Lab. No. 6355—							Cultivated for cane for 40 years. (Cf. 6354, virgin phase of this soil)
Normal, air dried	6·9	..	..	..	..	..	
	9·1	..	..	..	..	..	
	7·4	..	..	..	..	..	
	6·3	5·5	4·2	..	..	..	
	6·8	4·8	4·1	3·3	..	..	
Crushed lumps	3·8	2·9	3·1	2·2	..	..	
Dry ground	2·4	2·1	1·8	1·7	..	..	
	2·8	2·4	2·2	2·0	..	..	
Worked at moisture equivalent	38·7	22·8	13·5	9·2	8·2	..	
	37·5	24·7	22·5	15·5	15·8	..	
	30·2	23·3	19·7	..	..	..	
Worked at moisture equivalent, then air dried	16·2	10·8	10·1	8·3	9·0 (2½–3½ Hour)		
	12·0	8·5	8·2	6·8	6·4	..	
	11·8	8·6	8·6	7·8	8·9	..	
	14·4	11·8	10·7	..	..	..	
	16·9	14·3	12·1	..	..	..	
Lab. No. 6354—							Virgin soil:
Normal, air dried	27·7	20·8	..	..	..	..	Not passed through sieve
	22·9	18·1	15·7	14·5	..	..	
	23·8	21·5	22·0	19·3	..	..	Passed through 2 mm. sieve
	57·7	52·0	..	..	..	..	
Crushed lumps	2·4	1·7	1·8	1·5	1·6	..	
	2·3	1·6	1·6	1·3	1·3	..	
Worked at moisture equivalent	27·2	18·0	31·8	11·3	11·0 (2½–3½ Hour)		Moisture equivalent = 31·5%
	48·7	32·0	26·3	16·3	17·1 (2½–3½ Hour)		
	23·3	14·7	12·4	9·5	8·2	6·9	
	51·3	31·0	24·1	16·6	11·3	8·3	
	47·6	33·3	25·8	..	..	..	
	26·8	21·0	18·8	..	..	..	
Worked at moisture equivalent, then air dried	114·0	92·0	..	..	..	..	
	97·0	72·0	..	..	..	..	

APPENDIX B—continued.

RELATIVE PERCOLATION RATES—*continued.*

Soil and Treatment.	Percolation Rate ml. per Minute.						Remarks.
	½–1 Hour.	1–1½ Hour.	1½–2 Hour.	2–2½ Hour.	2½–3 Hour.	3–3½ Hour.	
Cairns red schist— Lab. No. 6351—							
Normal, air dried	9·8	6·7	6·4	6·7			
	9·5	6·8	7·0	7·6			
	9·3	6·9	7·0	7·6			
	8·8	6·2	6·9	7·4			
	10·2	8·4	8·4	7·3	8·0	6·3	
	11·6	9·2	8·8	7·9	7·5	6·2	
Dry ground	6·3	6·0	5·6	..	..	..	
Worked at moisture equivalent	14·1	10·3	9·3	10·4			
	10·9	6·2	4·8	4·8			
	15·8	11·7	9·9	8·3	..	..	
Worked at moisture equivalent, then air dried	6·1	3·7	3·1	..	..	..	
	9·3	7·7	8·4	7·4	7·9	..	
	8·9	7·1	7·4	7·3	6·4	..	
Worked at sticky point ..	17·2	13·2	10·4	8·5	..	..	Dried partially and remoistened to optimum moisture
	11·9	10·7	9·8	9·5	..	..	

COMMENTS.

Working at the moisture equivalent produced an increase in the percolation rate for all soil types except the Burdekin alluvial. In the case of the two Bundaberg soils this increase was remarkable; but the red volcanic soil was the only one to retain a greatly augmented rate after final air drying.

The Burdekin alluvial appeared to be improved by wetting and drying and by cropping to beans.

The percolation rate of all soils was decreased by dry grinding.

APPENDIX C.

Hardness Data.

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Burdekin alluvial—			
Lab. No. 4825—			
In original lumpy condition	..	1	
Lumps crushed	3·9* ; 4·2	..	*Sample not centrifuged
Dry ground	..	4·0	
Cropped to beans—			
Pot No. 1. Normal, air dried	1·0 ; 1·5	1·2	
Pot No. 1. Dry ground	5* ; 8	..	*Sample not centrifuged
Pot No. 1. Worked at moisture equivalent	..	8·0	
Pot No. 1. Pressed heavily at 24% moisture	..	20·8	
Pot No. 1. Worked at sticky point ..	..	28·5	
Dry ground ; cropped to beans—			
Pot No. 2. Normal	..	2·0	
Pot No. 2. Dry ground	9* ; 15·0 ; 17·4 ..	..	*Sample not centrifuged
Pot No. 2. Pressed heavily at 24% moisture	..	20·6	
Partially sodium-saturated—			
Soil E (8·3% Na). Normal, air dried ..	7* ; 15	..	*Sample not centrifuged
Soil D (16·5% Na)	17*	..	*Sample not centrifuged
Soil A (16·8% Na)	20* ; 24	..	*Sample not centrifuged
Soil B2 (21·4% Na)	Almost impenetrable	..	
Partially sodium-saturated, then mishandled—			
Soil E. Dry ground	..	17·8	
Worked at 15% moisture	..	30	
Worked at 20% moisture	..	Imp.	
Soil D. Dry ground	..	25	
Worked at 25% moisture	..	Imp.	
Soil A. Dry ground	..	29	
Worked at 25% moisture	..	Imp.	
Lab. No. 6350—			
Original moist sample	6·7 ; 7·3 ; 7·0 ..	7·0	
Normal, air dried	..	4·0	
Re-wetted, centrifuged, then dried	..	4·0	
Re-wetted, then air and oven dried	5·5 ; 6·5	6·0	
Dry ground	10·2	..	
Worked at optimum moisture (15%)	..	1·5	Pressed lightly
Worked at moisture equivalent	7 ; 7 ; 7 ; 8 ..	7·2	Sub-irrigated, centrifuged, pressed lightly
Pressed heavily at moisture equivalent ..	{ ..	10·5	Normal, air dry sample
	..	16·3	Original moist sample used
Pressed heavily at sticky point	Impenetrable ..	..	
Other Burdekin alluvials—			
Lab. No. 1229 (5% Na)—			
Normal, air dried	5·0 ; 7·2 ; 5·4 ; 5·8 ;	5·8*	*Sample not centrifuged
	11·4 ; 14·0 ; 17·8 ; 12·7 ; 13·6 ; 11·8	13·6	
Dry ground	..	24·4* / 25·7	* Sample not centrifuged
Remoistened only to optimum moisture ..	..	3·9	Sample not centrifuged
Worked at optimum moisture	Just penetrable ..	..	

APPENDIX C—continued.

HARDNESS DATA—*continued.*

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Other Burdekin alluvials—*continued.*			
Lab. No. 4205 (10% Na)—			
Normal, air dried	..	4·0*; 10·5	*Sample not centrifuged
Pressed heavily at moisture equivalent	..	24·1	
Lab. No. 4824 (21% Na)—			
Normal, air dried	25·0; 17·6; 22·3; 18·4; 18·0	20·3	
Remoistened only to optimum moisture	..	18·4	
Dry ground	..	30	
Worked at optimum moisture	Just penetrable	..	
Russell River alluvial—			
Lab. No. 2412—			
Normal, air dried	1; 2	1·5	
Dry ground	4·0; 1·5; 3·9	3·1	
Worked at moisture equivalent	..	5·0	Sub-irrigated and centrifuged
Worked at sticky point	..	4·8; 14·0	Pressed lightly; Sub-irrigated and centrifuged
Partially sodium-saturated (18%)	..	1·0	
Cropped to beans in pot experiment	3; 1·5; 1·5; 1·5	1·9	
Lab. No. 6352—			
Normal, air dried	..	1·1	
Dry ground	11·0; 4·0; 6·9	7·3	
Pressed lightly at moisture equivalent	..	2·0	Moisture equivalent = 28·6%
Pressed heavily at moisture equivalent	3·0; 4·2	3·6	
Worked at moisture equivalent	..	4·0	Sub-irrigated, centrifuged, pressed lightly
Pressed heavily at 36% moisture	..	16·1	
Worked at sticky point	..	12·5	Pressed lightly
Bundaberg red forest—			
Lab. No. 2411—			
Normal, air dried	..	< 1	
Dry ground	1·0; 4·0; 3·2	2·7	
Worked at moisture equivalent	..	4·5	Sub-irrigated and centrifuged
Worked at sticky point	..	7·0; 18·0	Pressed lightly; Sub-irrigated and centrifuged
Partially sodium-saturated (15%)	..	< 1	
Cropped to beans in pot experiment	1·5; 1; 1; 1	1·1	
Lab. No. 6353—			
Normal, air dried	..	< 1; < 1	Not centrifuged; Centrifuged
Dry ground	..	3·0	
Worked at moisture equivalent	..	1·9; 4·8	Centrifuged and pressed lightly; Pressed heavily
Pressed heavily at 14% moisture	..	4·6	
Worked at sticky point	5·8; 7·8	6·8	Pressed lightly

APPENDIX C—continued.

HARDNESS DATA—*continued.*

Soil and Treatment.	Hardness Readings.	Mean Value.	Remarks.
Bundaberg red volcanic—			
Lab. No. 2410—			
Normal, air dried	..	< 1	
Dry ground	..	5·6	
Worked at moisture equivalent	..	1	Pressed lightly
		1	Sub-irrigated and drained
		3·2	Sub-irrigated and centrifuged
Lab. No. 6355—			
Normal, air dried	..	< 1	Sub-irrigated and drained
		2·8	Sub-irrigated and centrifuged
Dry ground	10·8	..	
Worked at moisture equivalent	..	< 1	Pressed lightly
		1·5	Centrifuged and pressed lightly
		2·0	Sub-irrigated and drained
		4·6	Sub-irrigated and centrifuged
Pressed heavily at moisture equivalent ..	..	5·7	Moisture equivalent = 27·1%
Pressed heavily at 30% moisture	9·1 ; 9·3	9·2	
Worked at sticky point	..	8·2	Pressed lightly. Sticky point 38%
Lab. No. 6354—			
Normal, air dried	..	< 1	Virgin soil
		3·4	Sub-irrigated and centrifuged
Crushed gently and sieved	4·6 ; 4·8	4·7	
Dry ground	9·0	..	
Pressed heavily at moisture equivalent ..	6·7 ; 8·8	7·8	Moisture equivalent = 31·5%
Worked at sticky point	6·0 ; 7·0	6·5	Pressed lightly. Sticky point = 54%
Cairns red schist—			
Lab. No. 6351—			
Normal, air dried	..	1·0	
Dry ground	6·1 ; 3·0	..	
Worked at moisture equivalent	..	3·4	Pressed lightly
Pressed lightly at moisture equivalent ..	..	1·0	Moisture equivalent = 15·2%
Pressed heavily at moisture equivalent ..	2·4 ; 6·5	..	
Pressed heavily at 28% moisture	..	21·7	
Worked at sticky point	19·0 ; 22·5	..	Pressed lightly. Sticky point = 35%

APPENDIX D.

$$\text{Percentage Dispersion} = \frac{(\text{Silt} + \text{Clay}) \text{ in sample}}{(\text{Silt} + \text{Clay}) \text{ at complete dispersion.}} \times 100$$

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Burdekin alluvial—						
Lab. No. 4825—						
Completely dispersed	13·9	40·6	20·9	24·6	100·0	
Normal, air dried	14·7	67·0	16·9	1·4	40·2	
Dry ground	17·5	63·5	16·7	2·3	41·8	
Worked at optimum	29·8	53·9	13·8	2·5	35·8	Optimum moisture = 15%
Worked at moisture equivalent	16·8	62·0	19·1	2·1	46·6	Moisture equivalent = 22·5%
Worked at moisture equivalent, then dry ground	18·1	54·0	24·6	3·3	61·3	
Worked at sticky point ..	15·6	50·8	26·1	7·5	73·8	Sticky point = 30%
Cropped to beans	23·1	63·6	12·3	1·0	29·2	
Partially sodium-saturated—						
Soil E (8·3% Na)	16·8	62·7	18·6	1·9	45·1	
Soil D (16·5% Na)	14·6	52·7	27·1	5·6	71·9	
Soil A (16·8% Na)	15·7	55·9	25·0	3·4	62·4	
Soil B2 (21·4% Na)	13·2	46·3	28·0	12·5	89·0	
Soil F (84·9% Na)	14·2	44·2	22·9	18·7	91·4	
Partially sodium-saturated, then mishandled—						
Soil D. Dry ground.	11·7	52·8	29·0	6·5	78·0	
Worked at 33% moisture	13·2	42·4	25·8	18·6	97·6	
Soil A. Dry ground.	11·3	51·8	29·4	7·5	81·1	
Worked at 30% moisture	12·5	42·0	24·2	21·3	100·0	
Soil E. Worked at 15% moisture	17·1	60·0	19·4	3·5	50·3	
Lab. No. 6350—						
Completely dispersed	2·6	54·0	19·7	23·7	100·0	
Normal, air dried	12·1	70·8	15·6	1·5	39·4	
Dry ground	7·9	72·0	18·0	2·1	46·2	
Original moist sample	15·9	63·2	17·3	3·6	48·1	
Worked at moisture equivalent	6·5	75·6	15·7	2·2	41·2	Moisture equivalent = 21·4%
Worked at moisture equivalent, then dry ground	5·9	71·6	20·3	2·2	51·8	
Dry ground, then worked at moisture equivalent	5·7	71·6	19·6	3·1	52·2	
Other Burdekin alluvials—						
Lab. No. 1220—						
Completely dispersed	4·2	23·1	41·2	31·5	100·0	
Normal, air dried	12·7	67·9	17·3	2·1	26·7	
Lab. No. 1221—						
Completely dispersed	9·6	26·8	31·0	32·6	100·0	
Normal, air dried	16·7	65·9	15·3	2·1	27·4	
Lab. No. 1222—						
Completely dispersed	8·6	38·0	34·9	18·5	100·0	
Normal, air dried	10·3	74·5	13·3	1·9	28·5	
Lab. No. 1223—						
Completely dispersed	28·7	39·0	5·0	27·3	100·0	
Normal, air dried	20·6	67·8	10·4	1·2	35·9	

APPENDIX D—continued.

PERCENTAGE DISPERSION = $\frac{\text{(Silt + Clay) in sample}}{\text{(Silt + Clay) at Complete Dispersion}}$ × 100—*continued.*

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Lab. No. 1224—						
Completely dispersed	1·9	46·3	24·8	27·0	100·0	
Normal, air dried	3·5	80·0	13·8	2·7	31·9	
Lab. No. 1225—						
Completely dispersed	8·6	55·7	15·6	20·1	100·0	
Normal, air dried	4·3	83·8	10·5	1·4	20·1	
Lab. No. 6331 (Clod Sample)—						
Clods completely dispersed ..	5·2	33·1	29·9	31·8	100·0	
Clods slaked	28·0	50·1	19·5	2·4	35·5	
Clods crushed	4·2	57·4	32·2	6·2	62·2	
Russell River alluvial—						
Lab. No. 2412—						
Completely dispersed	8·0	37·6	23·9	30·5	100·0	
Normal, air dried	8·0	76·6	14·3	1·1	28·3	
Dry ground	9·4	71·5	16·9	2·2	35·1	
Dry ground, then worked at sticky point	5·1	69·5	22·2	3·2	46·7	Sticky point = 43%
Worked at sticky point, then dry ground	6·2	63·9	24·8	5·1	55·0	
Cropped to beans	19·8	67·7	11·7	0·8	23·0	
Partially sodium-saturated (18% Na) ..	8·1	68·2	20·8	2·9	43·6	
Lab. No. 6352—						
Completely dispersed	10·1	20·5	31·1	38·3	100·0	
Normal, air dried	30·9	54·8	12·7	1·6	20·6	
Worked at sticky point ..	38·8	33·3	22·9	5·0	40·2	Sticky point = 52%
Bundaberg red forest—						
Lab. No. 2411—						
Completely dispersed	31·6	24·2	14·1	30·1	100·0	
Normal, air dried	39·1	51·1	8·6	1·2	22·2	
Dry ground	36·8	49·3	12·1	1·8	31·4	
Dry ground, then worked at sticky point	37·5	55·8	5·9	0·8	15·2	Sticky point = 21%
Worked at sticky point, then dry ground	35·2	46·7	15·6	2·5	40·9	
Cropped to beans	44·4	50·1	5·1	0·4	12·4	
Partially sodium-saturated (15% Na)	38·5	47·9	12·2	1·4	30·8	
Lab. No. 6353—						
Completely dispersed	46·4	23·8	6·2	23·6	100·0	
Normal, air dried	57·0	38·6	3·9	0·5	14·8	
Worked at sticky point ..	54·3	32·4	10·6	2·7	44·6	Sticky point = 23%
Bundaberg red volcanic—						
Lab. No. 2410—						
Completely dispersed	14·6	10·2	15·7	59·5	100·0	
Normal, air dried	58·1	34·6	5·9	1·4	9·7	
Dry ground	43·3	40·6	13·6	2·5	21·4	
Worked at moisture equivalent	64·9	23·6	7·4	4·1	15·3	Moisture equivalent = 25%
Dry ground, then worked at sticky point	31·8	58·8	8·4	1·0	12·5	Sticky point = 35%
Worked at sticky point, then dry ground	30·7	45·9	20·5	2·9	31·1	

APPENDIX D—continued.

PERCENTAGE DISPERSION = $\frac{\text{(Silt + Clay) in sample}}{\text{(Silt + Clay) at complete dispersion}}$ × 100—*continued.*

Soil and Treatment.	Coarse Sand.	Fine Sand.	Silt.	Clay.	Percentage Dispersion.	Remarks.
	%	%	%	%	%	
Lab. No. 6355—						Cultivated for cane for 40 years.
Completely dispersed	12·8	8·6	18·4	60·2	100·0	(Cf. No. 6354, virgin phase
Normal, air dried	48·8	45·3	4·7	1·2	7·5	of same soil)
Worked at moisture equivalent	57·9	30·9	7·2	4·0	14·2	Moisture equivalent = 27%
Lab. No. 6354—						
Completely dispersed	22·6	9·5	23·8	44·1	100·0	Virgin soil
Normal, air dried	72·3	22·0	4·5	1·2	8·4	
Cairns red schist—						
Lab. No. 6351—						
Completely dispersed	7·7	50·5	16·4	25·4	100·0	
Normal, air dried	17·0	77·6	5·1	0·3	12·9	
Worked at moisture equivalent	18·5	72·9	7·9	0·7	20·6	Moisture equivalent = 15·2%
Worked at sticky point ..	11·5	83·5	4·6	0·4	12·0	Sticky point = 35%
Dry ground	15·0	78·1	6·6	0·3	16·5	

COMMENTS.

Burdekin alluvial.

Neither dry grinding nor working at the moisture equivalent caused a very great increase in the dispersion. These treatments, applied successively, gave a cumulative result which was the same regardless of the order in which the treatments were given.

Wet working at the sticky point caused a much increased dispersion.

Partial sodium-saturation caused a large increase in dispersion and when this was followed by dry grinding or wet working the results appeared more than additive. A 15 per cent. sodium-saturation followed by working at the sticky point was sufficient to cause complete dispersion.

The original moist field sample was improved by air drying; and cropping to beans was the only treatment which showed an improvement above the normal air dry condition. Other Burdekin samples varied in normal dispersion from 20 per cent. to 35 per cent. Hard clods slaked down to a normal value but if crushed they retained a high dispersion.

Russell River alluvial.

Dry grinding increased the dispersion, as also did partial sodium-saturation. Dry grinding followed by working at the sticky point caused a 50 per cent. increase in the dispersion and the same treatment in reverse order was even more effective. Cropping to beans definitely assisted granulation of the particles.

Bundaberg red forest.

Dry grinding and partial sodium-saturation both increased the dispersion. Dry grinding followed by working at the sticky point produced a lower dispersion than the original normal value; but the same treatments in reverse order left a much more dispersed soil. Cropping to beans produced a very definite improvement in the amount of dispersion.

Bundaberg red volcanic.

Dry grinding was very effective in increasing the original (low) value of the dispersion. Whilst dry grinding followed by working at the sticky point produced some increase, the reverse process was particularly effective. Working at the moisture equivalent (= optimum) was also dispersive in its action. Cropping to sugar cane over 40 years had caused no significant increase in the normal dispersion of this soil type.

In soil types of low normal dispersion, working either wet or dry readily produced high proportional increases; and the opposite was true of types with high normal dispersion. Nevertheless, the absolute values attained by the two Bundaberg soils (types with low original values) never exceeded the normal air-dry value of the Burdekin alluvial. Cropping to beans in pots, was, for all types tried, an aggregate-forming treatment.
