DETERMINATION OF TOTAL AVAILABLE MOISTURE IN SOILS*

by J. N. S. HILL

Abstract

In this paper, moisture characteristics of nine Natal soils are presented. From the field capacities determined directly in the field, and from 15-bar moisture percentages obtained on undisturbed soil cores, the total available moisture property has been evaluated for each soil. It has been shown that bulk density influences moisture content over the entire range of matric suction 0.1 to 15.0 bars. Furthermore, it has been demonstrated that bulk density exerts a similar effect on the wilting point determined by the sunflower technique. It has been concluded that undisturbed soil cores are essential for reliable determinations of the wilting point, and corresponding total available moisture evaluations.

Introduction

The plant-available moisture range in agricultural soils is popularly believed to be that water held between the upper limit or field capacity and the lower limit or permanent wilting percentage.

Today, with more information on the water requirements and consumptive use of plants, it is generally accepted that gravitational water moving through the root zone is available to and is taken up by plants. However, the field capacity is still considered to be the upper limit of most importance since the contribution by gravitational water to the total seasonal water requirement of a crop is small. At the lower end of the range, two factors come into play. Firstly, in this tension range (normally designated as being between 10 and 20 bars, matric potential) moisture content changes in most soits are slight with changes in tension. Secondly, a plant factor must come in here, owing to variation in osmotic relations of different plants, which probably accounts for the width of the range. It is usual to accept the 15-bar percentage as an indication of the lower limit of available moisture in soils.

Total available moisture is, therefore, that water held between the field capacity and the 15-bar percentage. Field capacity is either determined directly in the field (from drainage release curves) or is estimated from soil moisture retention data obtained in the laboratory, employing some fractional value of 1-bar matric suction (0.05 to 0.33 bars).

Information on the moisture holding properties of soils is considered to be important in irrigation planning. Together with a knowledge of the rooting characteristics of the crop, moisture holding characteristics of the soils enable water duties to be calculated, bearing in mind the peak-period consumptive use. To date, there exists very little published information regarding the moisture characteristics and total available moisture per foot, for the various soil series occurring in the sugarbelt of Natal. With increasing interest being shown in overhead irrigation, such information is urgently required. Thus a study has been made at Tongaat of the procedure for determining total available moisture in local soils and results are detailed below.

*Post-graduate material by the writer for the Department of Soil Science, University of Natal.

Materials and Methods

(*a*) *Materials*

For this study topsoil samples of nine major soil series occurring at Tongaat were collected. In Table I, a brief description of each soil is given, together with the mechanical analysis† and dominant clay minerals.‡ Respective soil numbers appear in the figures presented in the text.

(*b*) *Methods*

Field capacity moisture content of the various soils was determined in the field by daily sampling for gravimetric moisture determinations. An area of about 100 square feet was thoroughly soaked with water each day for one week, after which evaporation was prevented by means of plastic sheeting, and sampling commenced.

For moisture retention data, the 1-bar ceramic plate extractor, 15-bar ceramic plate extractor and pressure membrane apparatus were used. Ten undisturbed cores (1½ inches diameter and 1 inch deep) were collected for each of eight equilibrium pressure determinations, at the same site as used for direct measurement of the field capacity. Sufficient undisturbed soil for investigating the influence of bulk density on moisture retention was also collected. The procedure involved with the use of this equipment has been given by Richards (1954).

Finally, a comparison of permanent wilting percentages between loose and compacted soil by the laboratory technique and the sunflower method (adapted from Salter and Haworth, 1961) was carried out.

Results and Discussion

Moisture characteristics determined on undisturbed soil cores are presented in Figure 1, in which the field capacity is indicated. Natural field capacities have been obtained from the drainage curves depicted in Figure 2. As can be seen, field capacity is not a standard tension but varies between 0.1 bar for the sands, to about 0.33 bar for the heavier soils.

Total available moisture contents have been calculated by expressing soil moisture on the volume basis. The measured bulk densities of the undisturbed cores were used for this purpose, and in Table 2 field

†determined by the hydrometer method.
‡identified by means of X-ray diffraction and DTA in the Soil Science Laboratories, University of Natal.

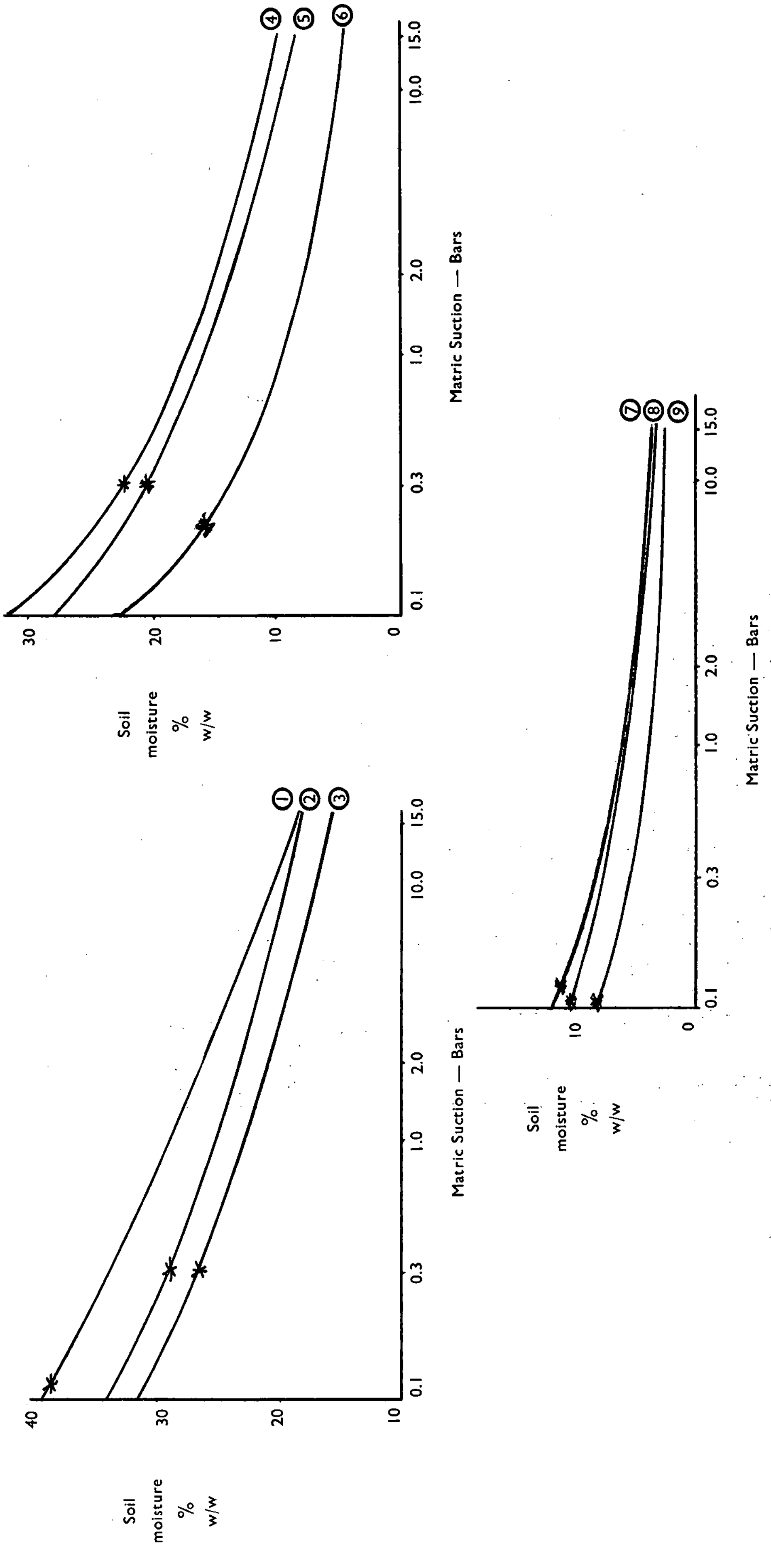

FIGURE 1 : Moisture characteristics of some Natal soils: field capacity indicated*

capacities, 15-bar percentages, average bulk densities, and total available moisture in inches per foot are shown for the different soils. As can be seen, total available moisture varies only from 0.99 to 2.29 inches per foot for the Fernwood sand and Rydalvale clay loam respectively. The order of difference is not as great as expected, and it will be seen that bulk density of the sample accounts for this anomaly.

Comparisons were made of moisture retention at each of the selected tensions, between loose soil dumped into the container rings and similar soil compacted in the retainer rings to different bulk densities. The influence of compaction on the matric potential or moisture retention at low tensions has been investigated by Box (1961) and Jamison (1956). These workers found that increasing the bulk density of a soil increased either the matric potential at constant moisture content, or vice-versa. The writer has extended these investigations into the high tension range, and has found the effect still to be operative at the 15-bar percentage. It thus occurred to him that the phenomenon could markedly affect total available moisture determinations. In Table 3, correlation (r) and regression (m) coefficients between bulk density and moisture content (percentage by weight) for matric suction values 0.1, 0.3, 1.0, 2.0, 10.0, 15.0 bars are given for the different soils. It is of interest to note that whilst the effect diminishes with increasing tension in the case of the sandy soils, it persists and even increases in some cases, with the heavy soils. This phenomenon is perhaps best illustrated by means of 3-dimensional diagrams. In Figure 3, the x, y and z ordinates are represented by matric suction (bars sub-divided on log scale), moisture content percen- (weight by weight) and bulk density (g./cc.) respect tively. From this figure it can be seen that the use of the disturbed soil sample in the determination of the 15-bar percentage results in the case of clay soils, in too-low values for the wilting point, whilst the same effect is visible at the field capacity. At the upper limit of available water, however, this effect is more pronounced in the sandy soils, but vanishes towards the wilting point.

Before any conclusions regarding the effect of this phenomenon on calculates of available soil moisture were drawn, however, a check was made using *Helianthus anuus* plants growing in loose and compacted soils. Results of the permanent wilting percentage obtained by this method are shown in Table 4, together with corresponding 15-bar percentage moisture contents. As can be seen, the same principle applies, viz. the higher the bulk density, the higher the wilting point, whilst in most cases the 15-bar percentage compares favourably with the wilting point obtained using sunflower plants.

Conclusions

The effect of bulk density on moisture retention at constant matric potential is an interesting one. It influences both the field capacity and the 15-bar percentage moisture contents of the soil. In the case of sands, the effect decreases with increasing tension, becoming negligible after most of the available moisture has been withdrawn. In clays, however, the effect persists, sometimes increasing, with increase in matric suction. In the latter instance, the phenomenon has a marked effect on calculates of total available moisture. A check against the standard physiological method for determining the permanent wilting point show that the same principle applies.

It is concluded, therefore, that undistributed soil cores are essential for reliable and value estimates of total available moisture in soils. It is also of interest to note that, in the case of clay soils, total available moisture calculations should be based *either* on disturbed samples throughout, *or* on undisturbed cores for both field capacity and 15-bar percentages.

References

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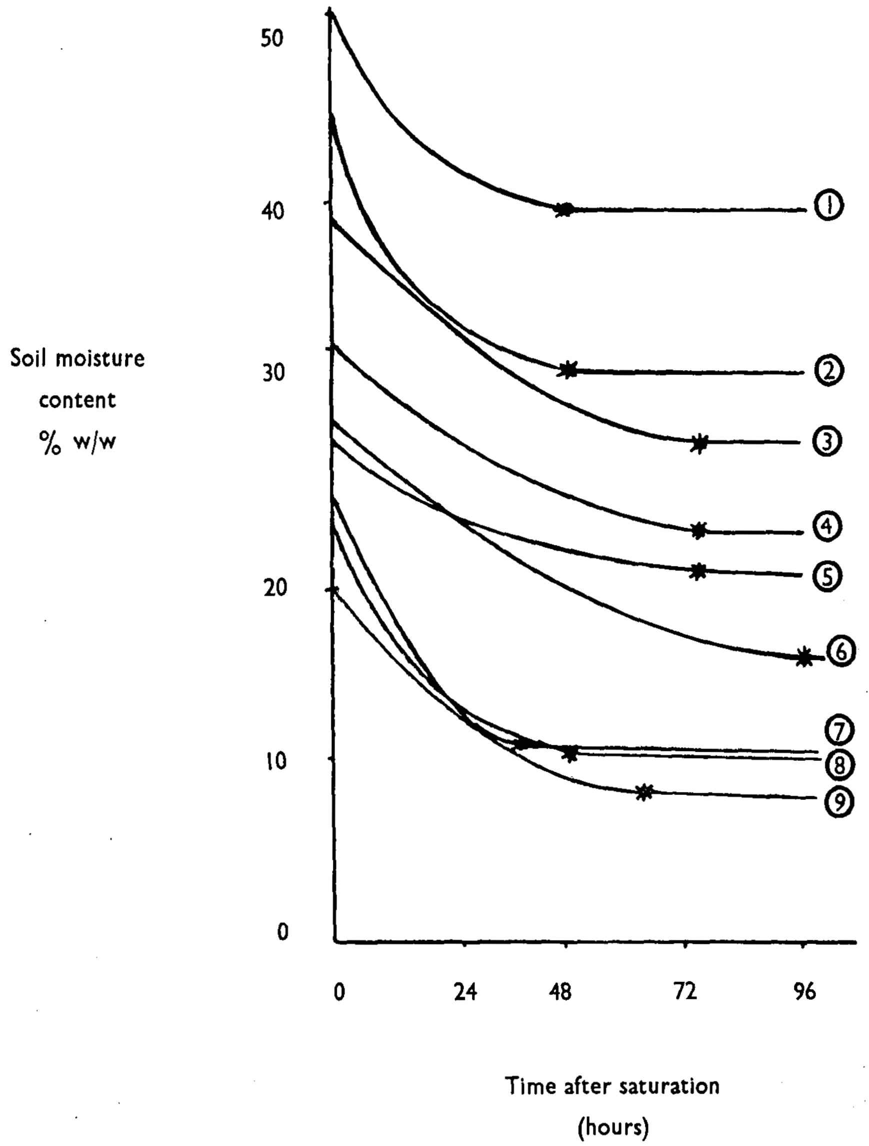


FIGURE 2 : Drainage curves of some Natal soils: field capacity indicated*

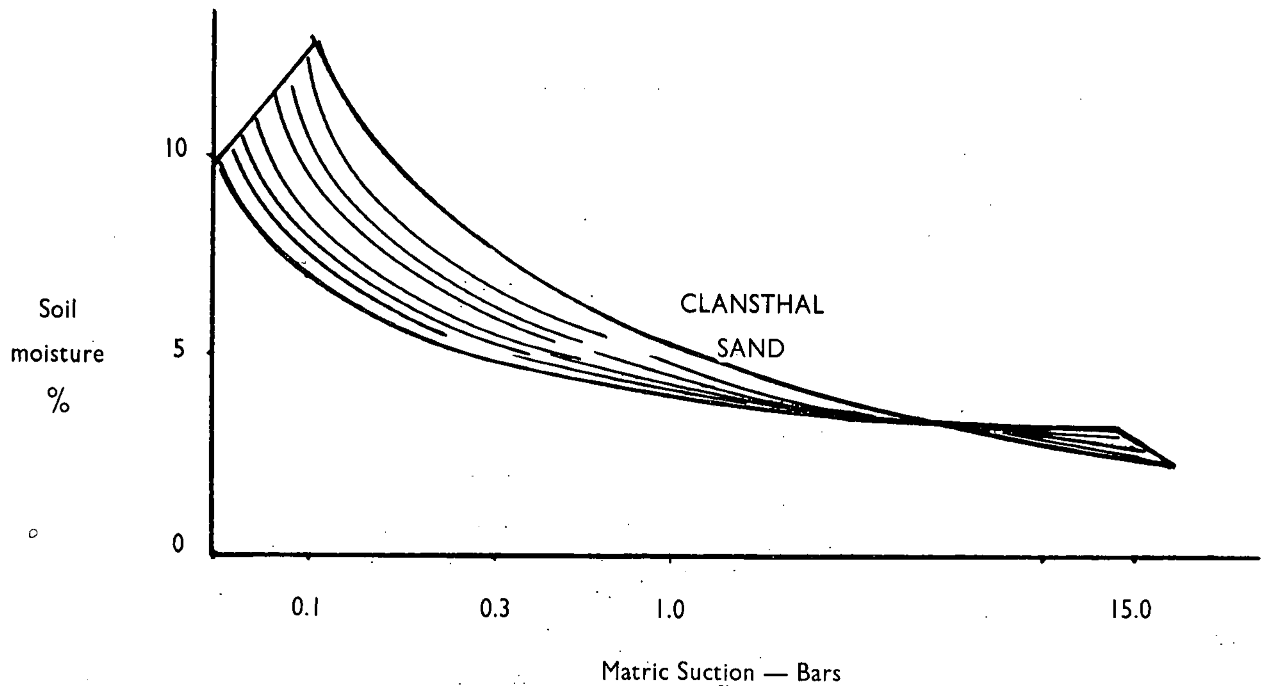
TABLE 1.—Some chemical and physical properties of nine Natal soils

Soil Series		Description of Soil in the Natural State	Mechanical Composition % Sand	Silt	Clay	Dominant Clay Minerals
CARTREF . .	(7)	Pinkish-grey loamy coarse sand — loose	89.4	3.6	7.0	KI
WILLIAMSON.	(5)	Grey-brown sandy loam — compact	74.7	8.4	16.9	MI
WALDENE. .	(4)	Dark grey-brown sandy loam — compact . . .	53.2	22.5	24.4	KIM
WINDERMERE	(3)	Dark grey clay loam — compact	48.3	17.0	35.4	MI
AVOCA . . .	(6)	Grey-brown loamy sand — very compact . . .	75.4	16.8	8.0	KI
SHORTLANDS	(2)	Red loamy clay — friable	29.3	12.7	58.2	K
RYDALVALE .	(1)	Black clay loam — friable	31.9	20.8	47.2	MK
CLANSTHAL .	(8)	Red sand— loose	89.3	2.9	7.2	K
FERNWOOD .	(9)	Grey sand — loose	94.4	2.2	3.6	K

K = kaolinite I = illite M = montmorillouite

TABLE 2.—Field capacities, 15-bar percentages, natural bulk densities and total available moisture data for some Natal soils.

Soil Series	Field Capacity Moisture Content % w/w	15-Bar Moisture Content % w/w	Natural Bulk Density g./cc.	Total Available Soil Moisture inches/foot
CARTREF	11.3	3.3	1.48	1.42
WILLIAMSON	21.0	9.1	1.27	1.81
WALDENE.	22.4	9.5	1.32	2.04
WINDERMERE	27.6	15.2	1.15	1.71
AVOCA	15.0	5.3	1.50	1.75
SHORTLANDS	29.8	18.8	1.16	1.53
RYDALVALE	39.4	21.4	1.06	2.29
CLANSTHAL	10.0	3.0	1.55	1.30
FERNWOOD	8.0	2.8	1.58	0.99



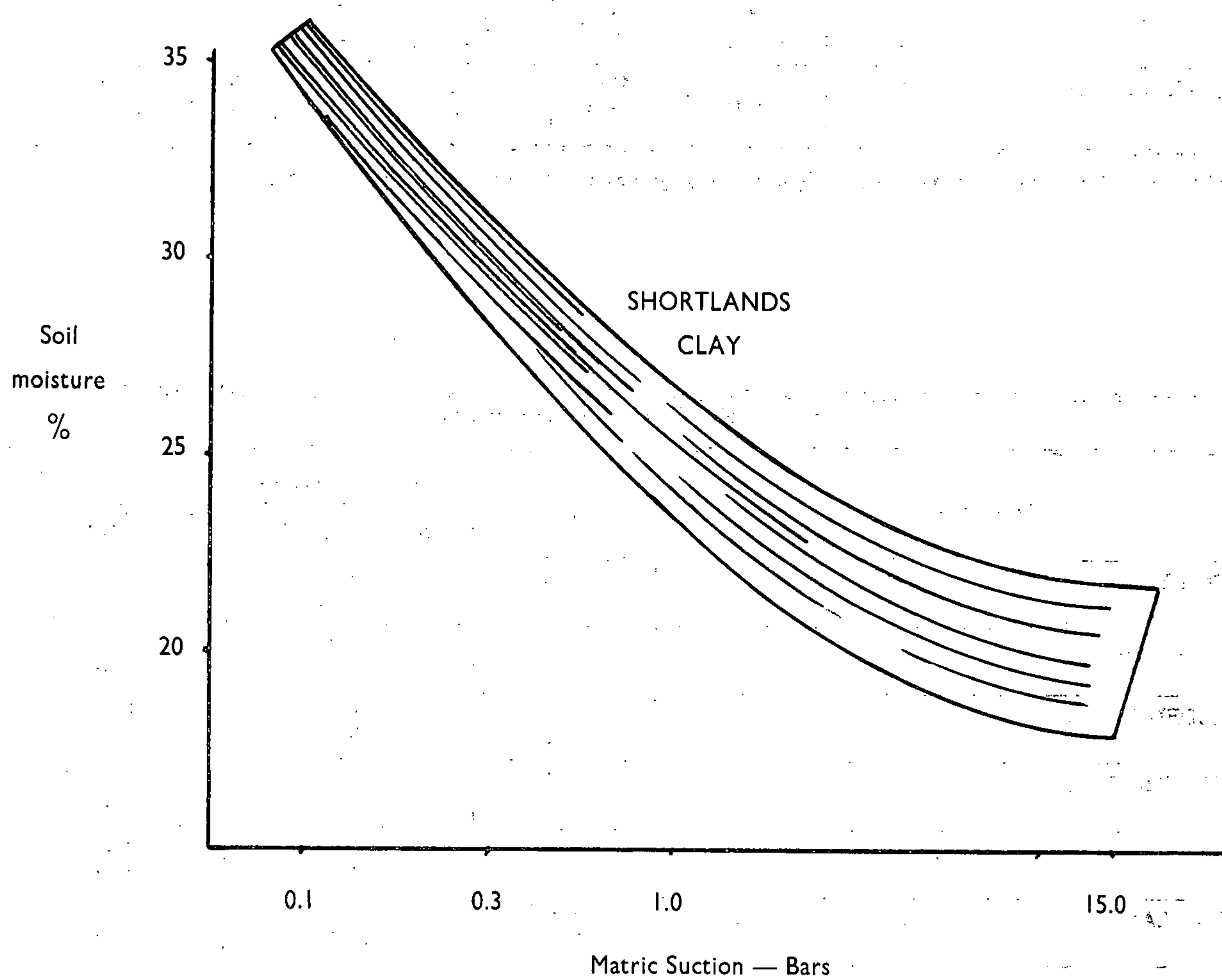


FIGURE 3 : Interrelationship between soil bulk density, moisture retention, and matric potential.

TABLE 3.—Correlation (r) and regression (m) coefficients showing the influence of soil bulk density on moisture retention for the range of matric potential 0.1 to 15.0 bars.

Soil Series		Matric Potential — Bars					
	Coefficient†	0.1	0.3	1.0	2.0	10.0	15.0
CARTREF	r	0.5236‡	0.6955‡	0.4846‡	0.9475‡	0.6550‡	0.4737*
	m	6.7630	4.9730	3.2600	0.9332	0.6780	1.3683
WILLIAMSON	r	0.5663‡	0.2352	0.3952*		0.8730‡	0.7884‡
	m	5.5868	3.2101	3.0577	ND	3.7914	3.5726
WALDENE	r	0.5563‡		0.3736	0.9257‡	0.9443‡	0.5601‡
	m	1.0431	ND	4.1031	3.0970	7.0027	3.6365
WINDERMERE	r	0.3471	0.7000‡	0.7449‡		0.7468‡	0.5978‡
	m	2.2898	4.5881	4.6004	ND	5.5900	9.8802
AVOCA	r	0.6712‡		0.6059‡		0.5872‡	
	m	4.7912	ND	8.5660	ND	1.5530	ND
SHORTLANDS	r	0.7909‡	0.6914	0.8143‡	0.6536‡	0.7653‡	0.8715‡
	m	4.0244	4.9600	5.5300	4.2200	12.8948	14.3931
RYDALVALE	r	0.3285	0.6944‡	0.8504‡		0.8929‡	0.5851‡
	m	2.6964	4.3232	5.1003	DN	8.9730	10.3454
CLANSTHAL	r	0.9548‡	0.7372‡	0.5990‡	0.8861‡	0.9548‡	-0.3237
	m	5.0111	4.5910	3.0300	1.1488	0.8992	-1.6300
FERNWOOD	r	0.9160‡	0.5312‡	0.1591		0.1591	0.0012
	m	6.9874	2.9800	0.1786	ND	0.1786	0.0010

†25 degrees of freedom. *significant at 5% level. ‡significant at 1% level. ND not determined.

TABLE 4.—Comparison between permanent wilting points obtained by the sunflower method, and 15-bar moisture contents nine Natal soils at various bulk densities.

Soil Series	Bulk Density g./cc.	Permanent Wilting Point by Sunflower Method, % w/w	15-Bar Moisture Contents % w/w
CARTREF	1.44	2.50	3.00
	1.60	3.11	3.12
WILLIAMSON	1.32	6.83	7.04
	1.57	8.61	8.16
WALDENE	1.22	8.92	8.09
	1.48	9.76	11.17
WINDERMERE	1.12	14.18	13.41
	1.48	16.29	18.27
AVOCA	1.34	4.19	5.47
	1.52	6.00	6.34
SHORTLANDS	0.97	18.86	17.69
	1.33	20.12	20.60
RYDALVALE	0.98	16.64	16.24
	1.28	21.75	21.71
CLANSTHAL	1.45	2.36	3.26
	1.70	3.52	2.89
FERN OOD	1.44	2.28	3.04
	1.67	2.45	2.97

Mr. R. A. Wood: There are some wide variations in field capacity retention values. Is this due to differences in clay minerals? The Rydalvale series contains both montmorillonite and kaolinite whereas the Shortlands soil is predominantly kaolinitic.

We find that the bulk density figure for Dwyka soils is usually between 1.6 and 1.8 g/cc. on undisturbed cores. Mr. Hill's figure is much lower.

Mr. Hill: The total available moisture values presented in this paper were determined on samples of a particular soil series from a particular site, the chemical and physical properties presented thus represent these particular samples only. I do not claim that these values represent the condition of the series throughout the sugar belt. Here, the method involved in determining total available moisture is important, rather than the figures.

The lower tension at which field capacity is represented in the Rydalvale series is indirectly related to the high montmorillonite content of this soil. In the Rydalvale series the montmorillonite clay is responsible for the formation of many small but stable peds. Thus, in bulk, there is a fair proportion of non-capillary and large pores between these peds — resulting in a lower tension at field capacity moisture content.

Clay mineral types can be tied in with moisture retention studies. Dr. Maud, for instance, has shown an extremely good correlation between the silt plus clay fraction of kaolinitic soils and their moisture retention at various suctions. I have also noticed this relationship. However, Dr. Maud expressed a relationship between total available moisture and textural analysis which I have not obtained. I think that much of the error in Dr. Maud's figures arises from, firstly, the general acceptance of 0.3 bars as the field capacity suction — whereas, in fact, it varies between soils; secondly, anomalous values of bulk density in some soils, and, also, I believe, that the bulk density effect demonstrated in this paper contributed towards his errors.

Regarding the bulk density values for Williamson and Waldene series, I have never encountered as high a figure as Mr. Wood suggests. However, it is possible that Mr. Wood's sample is more sandy or compact than the soil used in this experiment. My figure is the average of eighty undisturbed cores taken at approximately the mid-point of the A-horizon.

Dr. Dodds: Will Mr. Hill please elaborate on the sun-flower method for determining the permanent wilting point?

Mr. Hill: A single sunflower seed is planted in a can of soil having a specific volume — in this case it was 630 ccs. The soil was compacted to the bulk densities shown. The plant is watered until it has grown about four pairs of leaves. The can is then soaked with water after which evaporation is prevented by sealing the soil surface with a plastic material which is tied round the stem of the plant and the mouth of the can. The plant is placed out in the open where it transpires readily until the first symptoms of wilt occur. All leaves, with the exception of the uppermost pair, are then removed. The plant and can are placed in a dark, saturated atmosphere for 24 hours to see if it recovers turgor. If it does, it is brought out into the sunshine again. The process is repeated until the plant does not recover from wilt in a dark, saturated atmosphere. This, then, is taken as the point where the plant has extracted all the available moisture from the soil — and is called the permanent wilting point. At the permanent wilting point the plant will die, even in a saturated atmosphere, if water is not added to the soil.

The permanent wilting percentage is not a constant tension; it varies widely between about 10 and 20 bars. This is because in many soils moisture content changes between 10 and 20 bars are slight with changes in tension, and also the osmotic relations of different plants vary. Nevertheless, a fairly close agreement has been obtained by many workers between the 15-bar percentage and the permanent wilting point.

Mr. Wilson (in the chair): Mr. Hill mentions dealing with eighty samples for each soil series. How was the sampling done?

Mr. Hill: A 1½ inch diameter 1 inch deep core sampler was used. Bulk density values obtained with this size of sample were not significantly different from those found using the 4 inch sampler.

Mr. G. D. Thompson: It would appear from Mr. Hill's data that the way the wilting point is determined has an important effect on the value of total available moisture, apart from the effective rooting depth.

Mr. von der Meden: We have also found that total available moisture increases as the clay content of a soil increases but only up to a certain point. After this, an increase in clay content seems to result in a decrease in total available moisture although the moisture contents at wilting point and field capacity are both higher.

Our bulk densities are based on 4 inch cores and, consequently, give an average value over a greater depth. The smaller cores Mr. Hill is using give a point value for a much smaller area. Samples of Waldene soils from Chaka's Kraal have had an average bulk density of 1.5 g./cc., but in the top eight inches it has gone as high as 1.9 g./cc. This, again, was with the larger core. With the smaller core, one would presumably find a fair amount of variation.

Mr. Hill: The fact that increasing clay content beyond a certain level seems to decrease the total available moisture in a sample is explicable in terms of bulk density effects. Bulk densities tend to decrease with increasing clay content and also the effect of bulk density on moisture retention at high matric suctions has been shown in this paper to be important in the case of clayey soils. Thus, in the first case, although field capacity and wilting point moisture content increase with increasing clay content of a sample, the bulk density decreases and, consequently, total available moisture per unit depth of soil varies with bulk density. This can be seen from the equation used for determining total available moisture.

Mr. Gosnell: In Figure 2 the field capacity varies from 48 to 96 hours in the various soil types. At the median point of 72 hours on every one of the soil types we would be very close to the finally determined field capacity.

Mr. Hill: I agree.

Mr. von der Meden: In soils like Waldene, which are very badly drained, would it not take longer than 72 hours for the second foot to come to equilibrium?

Mr. Hill: The drainage time does increase the deeper one goes into the soil but the effective rooting depth in many of our soils is fairly close to the surface, especially in the compact soils. And, of course, the plant takes up gravitational water, so that any water over and above field capacity after 72 hours would probably be used by the plant.

Mr. Landsberg: Have you attempted to calculate the variations between your samples?

Mr. Hill: This was done prior to deciding on a certain number of samples. I think one should take ten samples for gravimetric determination of field capacity.

It is interesting to note the very low standard error of the wilting point determined by the sunflower technique. It was lower than the standard error determined for the laboratory technique.