"SINGLE VALUE" SOIL PROPERTIES: A STUDY OF THE SIGNIFICANCE OF CERTAIN SOIL CONSTANTS.

VII. THE MOISTURE EQUIVALENT AND SOME RELATED QUANTITIES.

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(With Two Text-figures.)

In the work described in Papers I (9) and II (4) of this series the moisture equivalent was excluded from the series of soil properties examined, partly on account of the difficulty in obtaining the necessary apparatus, and partly because it was considered unlikely that the method would be available in cases such as those arising in a soil survey, where it was hoped that the "Single Value" measurements would be of most use. More recently, however, Bouyoucos (3) has developed a method requiring only simple apparatus, which leads to results comparable with the moisture equivalent. The writer, having an opportunity of using the Rothamsted moisture equivalent centrifuge, considered that it would be useful to find what information could be derived from this method in addition to that gained by the earlier methods, and to examine the relationship between the moisture equivalent and some of these other soil properties.

For this work there were available 64 of the 66 Natal soil samples, concerning which a considerable number of data had been discussed in Paper II. In addition, several new samples were examined, and the results derived from these will be discussed later in this paper. It has been pointed out earlier (in Paper II) that, while the Natal samples show a wide range of physical properties, they were collected from a comparatively restricted area, chiefly in the midlands of Natal, with fairly uniform climatological conditions: and this must be borne in mind in interpreting the results obtained, or in comparing them with those obtained under widely different conditions of climate or soil composition.

Experimental.

The centrifuge was the standard Briggs-McLane model, giving a centripetal force of 1000 gm. dynes for a speed of 2440 R.P.M. Various workers have investigated the features of experimental technique requiring particular attention and their results have recently been summarised by Keen (8). In the present work, the routine method adopted was to run the centrifuge for 40 min. at the standard rate. But since it was necessary to economise the rather small samples available, it was not possible to use this standard amount of 30 gm. of soil for each determination; a slight modification of the method used by Joseph (7) for clay fractions was therefore employed. A wooden block was cut to fit into the ordinary centrifuge box, and its lower face was shaped to fit the curvature of the circumference of the centrifuge bowl. A hole, $\frac{5}{8}$ in. diameter, was bored through the centre of the block, and the soil samples placed in the hole. By trial with several different soils, with moisture equivalents ranging from 12 to 25 per cent., it was found that under these conditions 3·8 gm. of soil gave the same results as 30 gm. of soil under standard conditions. The blocks were coated with paraffin wax, which gave a smooth surface in contact with the soil (and also simplified the cleaning of the apparatus after a run). This method was found convenient for measurements of the moisture equivalent, but could not be used when the xylene equivalent was under examination, since the xylene attacked the wax. In this latter case, brass tubes ($\frac{5}{8}$ in. diameter) were inserted in the wooden blocks. A test experiment showed that the same results (within the limits of experimental error) were obtained for the moisture equivalent with apparatus of either form.

The experimental procedure, therefore, was as follows. The numbered wooden blocks were fitted into the boxes over filter paper, and 3·8 gm. of soil added. The boxes were placed with their bases in water, and the soil wetted from below. The boxes were left in the water for at least 4 hours, and were then transferred to a saturated atmosphere and left overnight. Next morning, the lids were fitted to the boxes, and they were "centrifuged" for 40 min. The soil samples were transferred to weighing bottles, and the loss in weight determined on drying for 24 hours at 105° in a Hearson oven. All measurements were made in duplicate, and results expressed as a percentage of the oven-dried soil.

As a check on the constancy of the running of the centrifuge, a large sample of soil was thoroughly mixed, and its moisture equivalent determined in duplicate on 30 gm. samples during each set of measurements. The moisture equivalent of this control soil, found as the mean of 26 duplicate experiments extending over several months, was $22{\cdot}69 \pm 0{\cdot}18$; and its xylene equivalent, the mean of 14 duplicates, was $12{\cdot}39 \pm 0{\cdot}06$. The results for the Natal soils are summarised in Table I.

Table I. *Moisture equivalent and xylene equivalent of Natal soils.*

No.	Moisture equivalent	Xylene equivalent	No.	Moisture equivalent	Xylene equivalent
1	16·7	6·5	33	24·0	12·7
2	17·0	7·6	34	27·0	12·1
3	15·1	7·8	35	30·3	13·7
4	16·9	8·1	36	26·8	14·5
5	20·6	8·8	37	26·4	18·2
6	19·7	9·8	38	31·8	15·0
7	16·5	7·5	39	30·6	16·9
8	13·4	6·7	40	31·3	13·2
9	8·0	3·7	41	34·7	16·6
10	8·0	4·1	42	32·3	17·2
11	14·4	5·9	43	32·9	13·4
12	12·3	5·7	44	29·2	14·4
13	30·6	15·5	45	28·0	14·0
14	19·9	9·9	46	23·8	11·9
15	18·6	9·3	48	26·4	12·9
16	21·3	8·2	49	44·2	21·0
17	16·4	8·3	50	41·5	20·6
18	14·7	9·1	52	44·2	20·9
19	13·7	6·9	53	35·0	16·4
20	17·0	7·7	54	31·4	16·2
21	17·9	8·7	55	28·8	17·1
22	16·1	6·4	56	36·5	17·3
23	18·8	9·7	57	35·8	17·2
24	17·3	7·2	58	34·0	16·6
25	12·4	5·8	59	27·5	12·4
26	28·3	14·3	60	42·2	22·0
27	27·4	13·1	61	36·3	18·0
28	24·8	10·5	62	27·7	13·6
29	19·5	8·9	63	24·6	14·4
30	23·1	10·4	64	23·9	14·5
31	20·6	10·1	65	34·1	16·0
32	20·2	12·5	66	11·6	6·0

The moisture equivalents in the table are for air-dried soils; the moisture equivalents of oven-dried soils at 105° were also measured, and were in most cases slightly lower than those given in the table. The xylene equivalents are for oven-dried soils.

DISCUSSION.

The moisture equivalents of the 64 Natal soils show high correlations with certain of the soil properties discussed in Paper II. Examples are given in Table II.

Table II. *Correlation coefficients between moisture equivalent and sticky point* (S), *hemihygric coefficient* (R), *loss on ignition* (I) *and clay* (C).

S	R	I	C
0·911	0·928	0·924	0·832

For purposes of general classification within a group such as that formed by these samples there appears to be little advantage in the use of the moisture equivalent as compared with some of these other quantities, which can be more easily obtained.

The water held by the soils after centrifuging comprises that held in the smaller capillaries and that held by the soil colloids. Many attempts have been made to express the moisture equivalent in terms of the mechanical composition of the soil and its organic matter content. For the present data, the results are adequately represented by the following equation (found by the method of partial regression):

$$M = 1{\cdot}015\, I + 0{\cdot}373\, F_1 + 0{\cdot}218\, F_2 + 0{\cdot}69 \pm 1{\cdot}54, \quad \ldots\ldots(1)$$

where M = moisture equivalent; I = loss on ignition; F_1 = "silt" (*i.e.* silt + fine silt I)[1]; and F_2 = "clay" (*i.e.* fine silt II + clay)[1].

Table III shows the difference between observed and calculated values of the moisture equivalent (Mo and Mc respectively):

Table III. *Observed and calculated values of moisture equivalent.*

$Mo \sim Mc$	<1	<2	<3	<4	<5	<6	<7	>7
	23	20	12	4	3	1	1	0

The numerical coefficients in equation (1) are of interest. In equations expressing the moisture equivalent in terms of the mechanical composition only (and not containing explicitly a term including the colloids) the highest numerical coefficient is asociated with the clay term. The reason why the coefficient of F_2 is the lowest occurring in equation (1) is that the influence of the clay colloids is already accounted for in the term involving I. It appears that, for equal masses, more water can be held at a tension of 1000 gm. (by capillarity) by the silt, F_1, than by the clay F_2. The coefficient of I shows that when the soil contains the amount of water corresponding to the moisture equivalent the ignitable matter contributes a mass of water slightly greater than its own. There is reason to believe that at saturation the soil colloids can retain roughly three times their own weight of water, so that even allowing for the fact that a considerable proportion of the ignitable matter is probably combined water, the result is in accordance with the view that the soil colloids are not completely saturated at the moisture equivalent. This is to be expected, since the moisture equivalent is much lower than the sticky point, when the soil colloids presumably are saturated.

While the correlation coefficient between the moisture equivalent and the sticky point has been quoted in Table II, it must be pointed out that the correlation method is not a suitable one for the examination of the

[1] On the Agricultural Education Association 1926(1) basis.

relationship between the two quantities, since the scatter diagram (Fig. 1) suggests that the points fall into two groups, the lighter soils tending to give relatively higher sticky points. This difference can be accounted for by supposing that in these lighter soils a larger proportion of the total sticky point water is held in the wider pores which are emptied under a stress of 1000 gm.

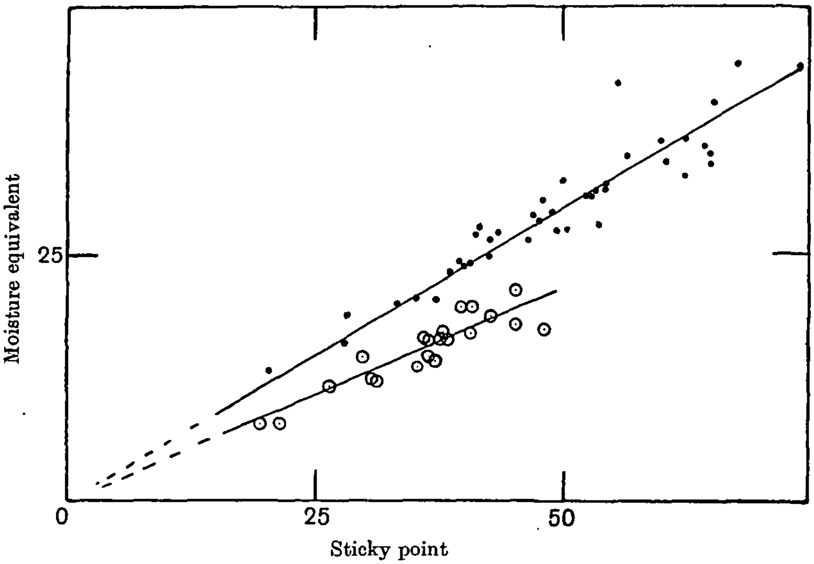

Fig. 1. Relationships between moisture equivalent and sticky point of Natal soils.

The moisture equivalent of some alkaline and saline soils.

Moisture equivalents have been measured on a series of Sind soils from the arid region to be irrigated from the new Lloyd barrage. These soils do not, on the whole, contain such high proportions of clay as the Natal soils, but, from the field point of view, they are in certain cases difficult to work on account of the deflocculation and loss of crumb structure due to their alkaline and saline nature. These soils, and the most convenient methods for their examination, are to be discussed in the near future in a paper from Rothamsted, but note may be taken here of their properties as represented by their moisture equivalents. For soils of almost equal clay content the moisture equivalents of the Sind soils are higher than those of the Natal soils (except when the latter contain very large amounts of ignitable matter). Examples appear in Table IV and illustrate the greater "field heaviness" of the Sind soils.

Table IV. *The moisture equivalents of Natal soils (series 20) compared with those of Sind soils (series 21) of approximately equal clay* content.*

Series 20				Series 21			
No.	*I*	*C*	Moisture equivalent	No.	*I*	*C*	Moisture equivalent
15	10·1	15	18·6	7	8·3	13	25·1
18	7·8	24	14·7	9	8·2	24	25·0
22	5·5	18	16·1	11	9·0	17	22·6
34	16·5	31	27·0	8	9·3	31·5	36·0†‡
49	24·9	30	44·2	5	10·1	30	31·1†
60	21·0	32	42·2	4	8·3	31	30·1†

* Since the clays for the Sind soils were determined as ignited fractions with a settling velocity corresponding to the international method (2), the values for the Natal soils have been adjusted to the same basis by means of summation curves. The actual values of the clay fractions in Table IV are, therefore, not directly comparable with those used elsewhere in this paper.

† Samples waterlogged or sticky after centrifuging.

‡ Slow wetting of samples.

Further, the Sind soils show various qualitative effects (noted in Table IV) with regard to their behaviour in the centrifuge, and these provide valuable information as to their physical condition. In these respects, they resemble the alkaline Sudan soils for which the moisture equivalent method has proved suitable. While there is a moderate correlation between sticky point and moisture equivalent for these samples, the former quantity is less useful, since there is in this case nothing analogous to the useful qualitative observations made during the moisture equivalent determination. Snow (11) and other Sudan workers have also found that the sticky point is of little value with their soils, on account of the wide difference in the nature of the clay associated with varying SiO_2/Al_2O_3 ratios.

The xylene equivalent.

The xylene equivalent was measured by the method described earlier in this paper. The results agree well with those calculated from the equation

$$X = 0{\cdot}339\, I + 0{\cdot}273\, F_1 + 0{\cdot}173\, F_2 - 0{\cdot}59 \pm 1{\cdot}16, \quad \ldots\ldots(2)$$

where the symbols have the same significance as equation (1). The discrepancies are analysed in Table V.

Table V. *Observed and calculated values of xylene equivalent.*

$Xo \sim Xc$	<1	<2	<3	<4	<5	>5
	34	17	8	4	1	0

It is interesting to compare the coefficients in equations (1) and (2). In the former the relative liquid-retaining efficiencies of F_2, F_1 and I are as 1 : 1·72 : 4·66; in the latter the corresponding ratios are as 1 : 1·58 : 1·96. The purpose in view in measuring the xylene equivalent was to calculate the imbibitional water (6), which is the difference between the moisture equivalent and the xylene equivalent, expressed on a volume basis; the assumption being made that no xylene is adsorbed by the soil. It will be noticed that for the fractions F_1 and F_2, the relative efficiencies are about the same for the two liquids[1], but the relative efficiency for the ignitable material is less than half as great for the case of xylene as compared with that of water. This lowering of the efficiency is to be expected, but the fact that it remains high requires explanation if we accept the non-adsorption of xylene theory; an independent verification of this hypothesis is provided by unpublished investigations (10) on the specific gravities of soils as determined in water and in various organic liquids. The most plausible explanation is that part of the ignitable material—probably the structured organic matter—is highly porous, and that either liquid can be retained in these micropores. The significance of the imbibitional water is to be discussed in a later paper.

NOTE ON THE SPECIFIC GRAVITIES OF THE NATAL SOILS.

In order to find the moisture equivalents and xylene equivalents on a volume basis, it is necessary to know the specific gravities of the soils. These have been measured by the technique developed by E. W. Russell (10), using paraffin as the displacing liquid. The results are shown in Fig. 2. It will be noticed that the specific gravity decreases as the loss on ignition increases; that the subsoils give relatively high specific gravities, presumably on account of the absence of appreciable quantities of organic matter and of a crumb structure; and that the value for the surface soils fall into two groups, corresponding to the Table Mountain sandstone and to the Shale and Dolerite soils.

A study of partial correlation coefficients, calculating from 32 surface soils derived from shales and dolerites, shows that:

$$r_{\rho p.I} = -0·172, \quad r_{cp.I} = 0·173, \quad r_{\rho I.c} = -0·704,$$

where ρ = specific gravity and p = pore space determined by the modified Keen-Raczkowski method (5). These results are in accordance with the view that the low values of the specific gravities are due to the

[1] The absolute efficiencies are also nearly equal when expressed on a volume basis.

presence of organic matter and other ignitable material of comparatively low specific gravity, rather than to accidental trapping of air bubbles.

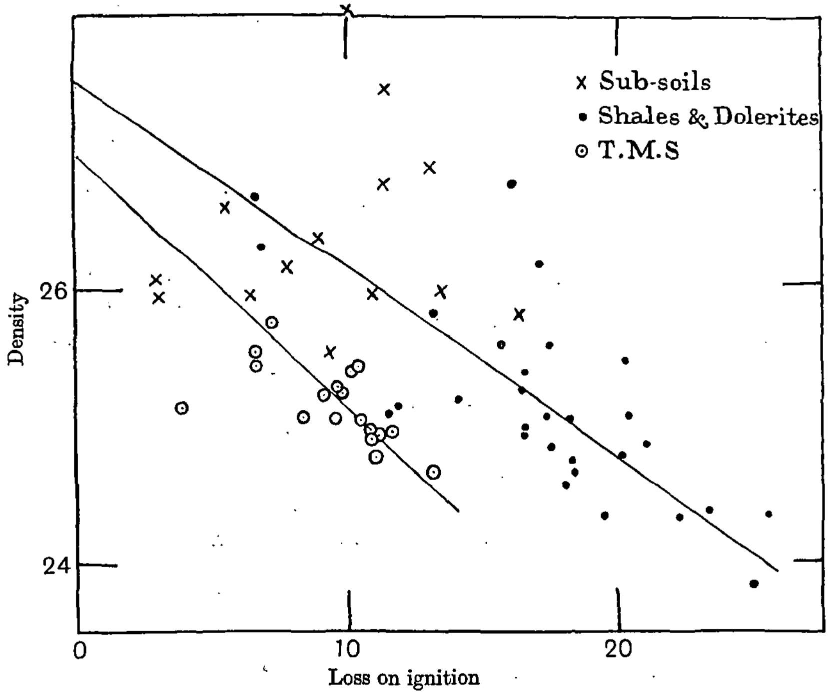

Fig. 2. Relationships between density and loss on ignition of Natal soils.

Summary.

The moisture equivalent has been measured (by a technique requiring only small quantities of soil) for a number of samples comprising Natal and Sind soils. It is concluded that while with the latter (alkaline and saline) soils the moisture equivalent gives valuable information, it adds little to the data obtained by other methods for the Natal soils. The xylene equivalent of the Natal soils has also been measured; from the moisture equivalent and the xylene equivalent, the imbibitional water can be calculated if the specific gravity of the soil is known.

Equations expressing the moisture equivalent and the xylene equivalent of the Natal soils in terms of their loss on ignition and mechanical composition are obtained, and the significance of the relative values of the numerical coefficients in these equations is discussed.

ACKNOWLEDGMENTS.

The work described in this paper was carried out during a period of leave spent at Rothamsted. The writer acknowledges gratefully the facilities placed at his disposal, the assistance obtained from Dr R. K. Schofield and the staff of the Soil Physics Department, and the advice given by Dr A. F. Joseph from his experience with the moisture equivalent method.

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(*Received July* 13*th*, 1931.)