

PREDICTION OF THE MOISTURE HOLDING CHARACTERISTICS OF QUEENSLAND SOILS—A PRELIMINARY STUDY

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SUMMARY

A method of predicting moisture retention characteristics from a simply measured soil property is required for the estimation of available water and potential moisture storage under fallow. In this study, the relationship between clay percentage and two important soil water potentials is studied for a range of Queensland soils.

A highly significant linear correlation is obtained between clay percentage and the 15 atmosphere moisture percentage. The accuracy of prediction of the 15 atmosphere percentage is improved if soils are divided into groups on the basis of clay mineralogy. The results also indicate that soil moisture retention is dependent on length of cultivation. A highly significant correlation is also obtained between clay percentage and the $\frac{1}{10}$ atmosphere moisture percentage, but in this case accuracy of prediction is not improved by a consideration of clay mineralogy.

The error in prediction of both 15 atmosphere percentage and $\frac{1}{10}$ atmosphere percentage from clay percentage is shown to be less than 25%.

I. INTRODUCTION

The availability of soil water to plants is of major importance to crop growth. Plant response is related more closely to soil water potential than to any other soil moisture characteristic. For purposes of estimating soil storage, irrigation requirements, etc., two measurements of matric potential have been widely used. The $\frac{1}{10}$ atmosphere moisture percentage measured using the pressure plate apparatus (Richards 1948) has been considered to represent the upper limit of retention of water usable by plants, and the 15 atmosphere moisture percentage as the lower limit of water available to plants (Richards and Weaver 1944). Water at potentials between these two points has been classed as "available water".

While it is well known that there is no theoretical justification for considering either of these points as limits of water potential suitable for plant growth, they can be used to give an approximation of soil moisture holding characteristics for soils.

Measurements of soil moisture holding characteristics have a number of uses. As mentioned above, they may be used in conjunction with soil moisture percentage to approximately determine the amount of water available for crop growth, or the potential moisture storage capacity of soils under fallow. This

information is of great value under Queensland conditions, where clay soils are predominantly used for winter cereal production and moisture storage during a fallow period is relied upon to provide moisture for crop growth.

Direct measurement of moisture-holding characteristics is time-consuming and the equipment required is expensive. For these reasons, a number of attempts have been made to relate soil moisture holding characteristics to simply measured soil properties.

Moisture is held in soils by a number of mechanisms:—

- (a) Adsorption onto the surface of inorganic and organic soil colloids.
- (b) Retention in stable pores which drain as moisture is removed from the soil.
- (c) Retention in unstable pores which contract as moisture is removed from the soil, but which do not drain over the available moisture range. The expansion and contraction of these pores is associated with the adsorption and desorption of water on the surface of soil colloids.

Fox (1964) has shown that field samples of Black Earths contain no stable voids. In this type of soil, where moisture retention is associated with the swelling of soil colloids, it is expected that moisture retention will be closely related to surface adsorption of soil colloids.

Therefore, moisture retention at a given applied tension is given by the formula:

$$y = ax + b,$$

where y = gravimetric moisture percentage, x = colloid percentage, a = a coefficient dependent on surface adsorption and retention of water in unstable pores, and b = theoretical moisture percentage at zero colloid percentage.

If the ratio organic colloid percentage: inorganic colloid percentage is low, x may be taken as the clay percentage and a may be considered as a variable dependent on clay mineralogy.

In this paper, the effect of clay percentage and clay mineralogy on soil moisture holding characteristics is examined for a range of Queensland soils.

II. MATERIALS AND METHODS

A total of 104 soil samples was used for this study. Examples of the following Great Soil Groups (Stephens 1962) were included:— Black Earths, Grey and Brown soils of heavy texture, Podzolic soils, Red-brown Earths, and Krasnozems. Surface, subsurface, virgin and cultivated samples were obtained for some soil types.

A rapid technique was used to measure clay percentage for all samples. A 25 g soil sample (50 g for soils of low clay content) was added to 200 ml of aqueous solution containing 10 ml 1.0N sodium hydroxide and 10 ml 10% "Calgon" solution. The sample was stirred mechanically for 15 min, then

transferred to a sedimentation cylinder and made up to 1 litre with distilled water. The suspension was stirred by hand for 1 min, and clay percentage was calculated from the hydrometer reading after 5 hours' settling.

The 15 atmosphere percentage was determined for 104 soil samples after equilibration in the pressure membrane apparatus for 3 days at 220 p.s.i. pressure. The $1/10$ atmosphere moisture percentage was determined for 60 soil samples after equilibration in the pressure plate apparatus at 1.5 p.s.i. pressure.

Selected samples were used for the following determinations:—

- (a) Clay mineralogy.—Soil samples were added to a 0.005N calcium chloride solution, and were disrupted by ultrasonic vibration. The resultant suspension was deposited on a frosted glass slide and air-dried. The slides were treated with ethylene glycol, and clay minerals were identified from their characteristic $d(001)$ X-ray diffraction spacings (Warshaw and Roy 1961).
- (b) Cation exchange capacity of the soil samples was determined using the method of Metson (1956).
- (c) Organic carbon content was determined using the technique of Walkley and Black (1934).

III. RESULTS

In Figure 1, the 15 atmosphere percentage is plotted against clay percentage for 104 soil samples. A number of different soil types are included in the figure, and these are represented by different symbols. In Figure 2, the $1/10$ atmosphere percentage is plotted against clay percentage for 60 soil samples. As with Figure 1, different soil types are represented by a number of symbols.

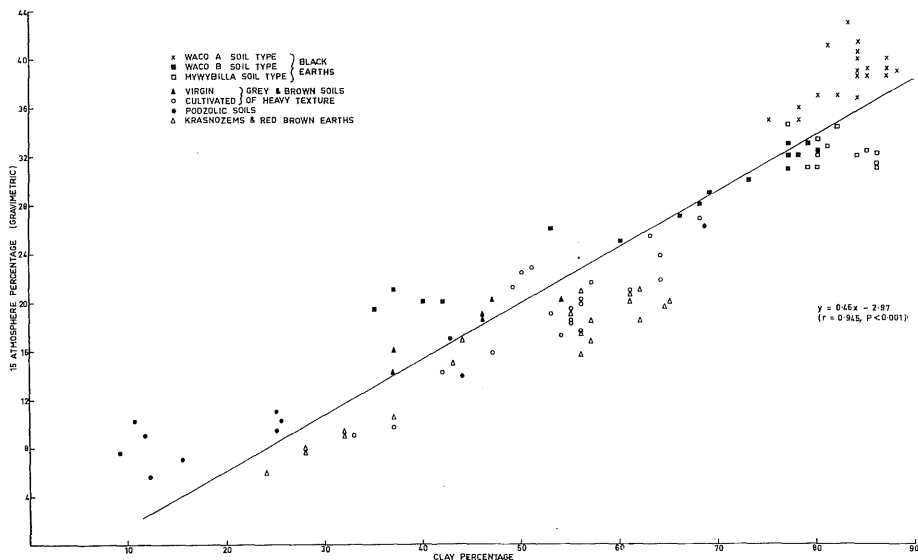


Fig. 1.—The 15 atmosphere percentage plotted against clay percentage for 104 soil samples.

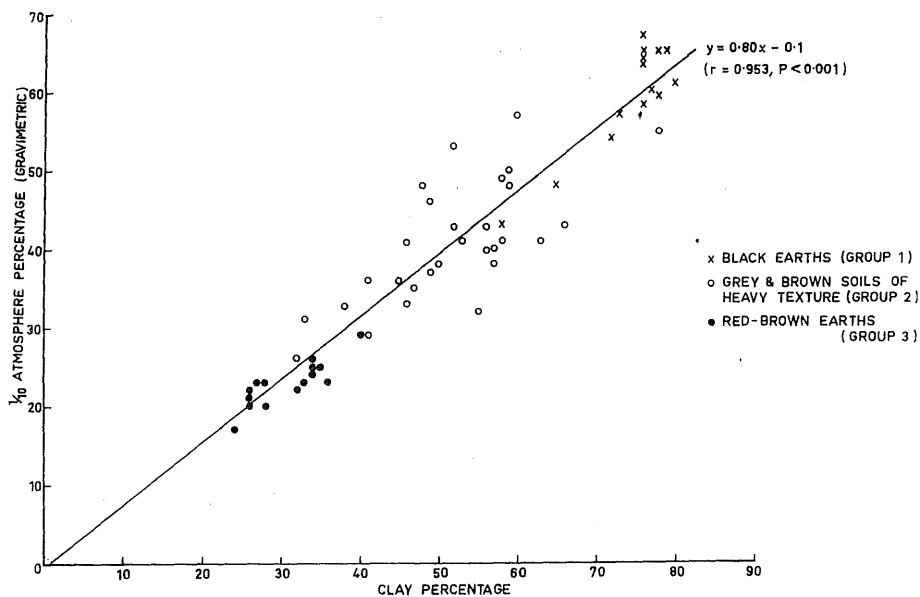


Fig. 2.—The $\frac{1}{10}$ atmosphere percentage plotted against clay percentage for 60 soil samples.

In Figure 3, X-ray diffraction traces of three representative soil types over the range $3\text{--}13^\circ$ of 2θ are shown. This range is sufficient to identify all layer-silicate clay minerals. Montmorillonite, vermiculite and kaolinite were identified in the soil samples studied. Figure 3 shows that wide variations occur in the intensity of the kaolinite peaks in these soils. Kaolinite is a mineral of low surface activity compared with montmorillonite or vermiculite, and its presence in the clay fraction would decrease the adsorption of water per centum of clay at a given applied tension.

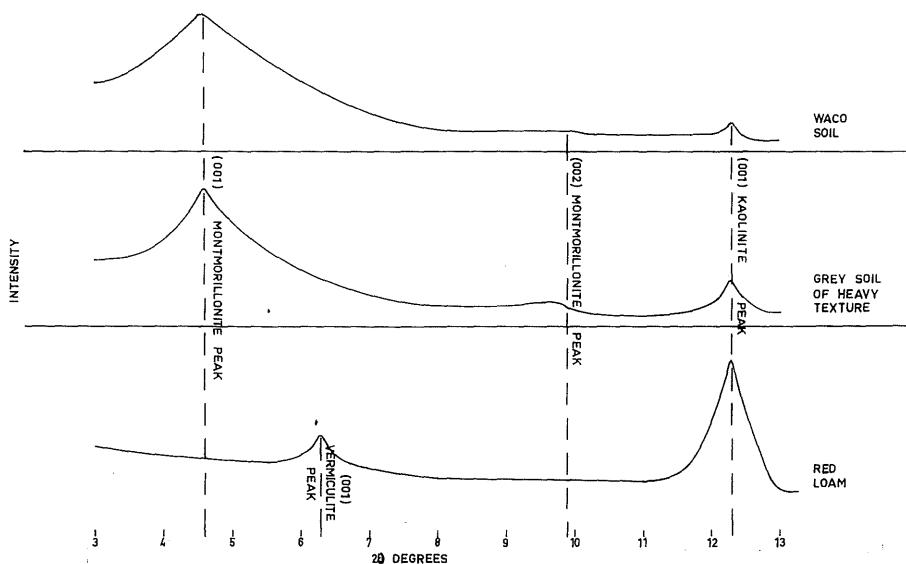


Fig. 3.—Schematic representation of X-ray diffraction traces of three soil types.

Semi-quantitative measurements of the proportion of kaolinite and other low activity clay minerals in the clay fraction are obtained by comparing the cation exchange capacity of a soil with the clay percentage. For a pure montmorillonite clay, the ratio $\frac{\text{cation exchange capacity}}{\text{clay percentage}}$ is approximately 1.0, while for a pure kaolinitic clay the ratio is less than 0.1. For field soil samples, organic matter makes a significant contribution to the measured cation exchange capacity. Assuming a cation exchange capacity of 200 m-equiv./100 g for soil organic matter, the corrected soil C.E.C. (attributable to soil minerals) may be calculated from the equation:

$$(C.E.C.)_{\text{corr}} = (C.E.C.)_{\text{meas}} - 2 (O.M.),$$

where $(C.E.C.)_{\text{corr}}$ = corrected soil cation exchange capacity
 $(C.E.C.)_{\text{meas}}$ = measured soil cation exchange capacity and $(O.M.)$ = percentage organic matter in the soil sample.

In Table 1, the ratio $\frac{(C.E.C.)_{\text{corr}}}{\text{clay percentage}}$ is shown for a number of soil types represented in this study.

TABLE 1

THE RATIO $\frac{(C.E.C.)_{\text{corr}}}{\text{clay percentage}}$ FOR A NUMBER OF SOIL TYPES

| Soil type | $\frac{C.E.C._{\text{corr}}}{\text{clay percentage}}$ |
|--|---|
| Waco A | 0.9-1.1 |
| Waco B | 0.6-0.8 |
| Mywybilla | 0.7-0.8 |
| Grey and Brown Soils of Heavy Texture .. | 0.4-0.6 |
| Podzolic Soils | 0.2-0.5 |
| Red-brown Earths | 0.2-0.4 |
| Krasnozems | <0.25 |

IV. DISCUSSION

Figure 1 shows that clay percentage is linearly related to the 15 atmosphere percentage for the soils studied. Linear regression analysis was carried out on the data, and the line of best fit and correlation coefficient for this line are shown. The correlation is highly significant ($P < 0.0001$). Despite the significance of the correlation, it is of little use for prediction purposes because of the wide variation in 15 atmosphere percentage obtained for a given clay percentage. Measured values vary from predicted values by as much as 200% for soils containing less than 20% clay, while for soils containing 20-40% clay, errors in prediction may be as high as 60%. For soils containing more than 60% clay,

errors as high as 30% are common. For this reason, an attempt was made to divide the soils into a number of groups within which closer predictions can be made. These groups were selected on the basis of clay mineralogy.

Three groups are recognized in Table 1:

Group 1 $\frac{(\text{C.E.C.})_{\text{corr}}}{\text{clay percentage}} > 0.6$ —includes soils from the Black Earth Great Soil Group.

Group 2 $\frac{(\text{C.E.C.})_{\text{corr}}}{\text{clay percentage}} = 0.4-0.6$ —includes soils from the Grey and Brown soils of heavy texture Great Soil Group, and possibly also Podzolic soils.

Group 3 $\frac{(\text{C.E.C.})_{\text{corr}}}{\text{clay percentage}} < 0.4$ —includes Red-brown earths, Krasnozems, and possibly Podzolic soils.

This grouping is justified from Figure 1, which shows that, for a given clay percentage, it generally follows that 15 atmosphere percentage is in the order: Group 1 soils > Group 2 soils > Group 3 soils.

The grouping of Podzolic soils is uncertain from the results of Figure 1 and Table 1. Most of the Podzolic samples are from the surface horizon and contain less than 25% clay. At low clay percentages, soil organic matter will have a significant effect on surface adsorption, causing the soil sample to have a higher 15 atmosphere percentage than expected from clay percentage and clay mineralogy. However, for the purposes of the present study, Podzolic soils are placed in Group 2.

The effect of organic matter on moisture retention is also seen from a comparison of the virgin and cultivated samples of the Grey and Brown soils of heavy texture. The 15 atmosphere percentage of virgin soils is consistently higher than that of cultivated soils. It may be desirable to divide soils into groups according to length of cultivation.

Linear regression analysis has been carried out for the three groups of soils mentioned above. The lines of best fit for the data and the correlation coefficients for these lines are shown in Figure 4. All correlations are highly significant ($P < 0.0001$). From these linear equations, predictions of atmosphere percentage within each group may be made from measurements of clay percentage. Within Group 3, measured values are within 20% of the predicted values for all soils, for a range of 6–21% gravimetric moisture content. Within Group 2, the error in prediction of 15 atmosphere percentage for Podzolic soils with less than 15% clay is very high, as expected from the previous discussion. For Grey and Brown soils of heavy texture, the error in prediction is less than 30%, for a range of 8–27% gravimetric moisture content, the largest error being obtained for soils of lower clay percentage. For Group 1 soils,

measured values of the 15 atmosphere percentage are within 10% of predicted values over the clay percentage range 35–75%, for a range of 20–30% gravimetric moisture content. In fact, the 15 atmosphere percentages of all soils of the Waco B type are closely predicted from the linear equation plotted in Figure 4. Above 80% clay percentage, soils of Group 1 are divided into two types: Waco A soils, which have a measured 15 atmosphere percentage higher than the predicted value, and Mywybilla soils, with a measured 15 atmosphere percentage lower than the predicted value. Table 1 shows that the ratio

$\frac{(\text{C.E.C.})_{\text{corr}}}{\text{clay percentage}}$ covers the range 0.9–1.1 for Waco A soils, while for Mywybilla soils it covers the range 0.7–0.8. This is evidence of the validity of the use of soil mineralogy to separate soils into groups.

[NOTE: The only Waco A type soils studied at this stage were from the Jondaryan area. Most Waco soils probably are included in the B type category.]

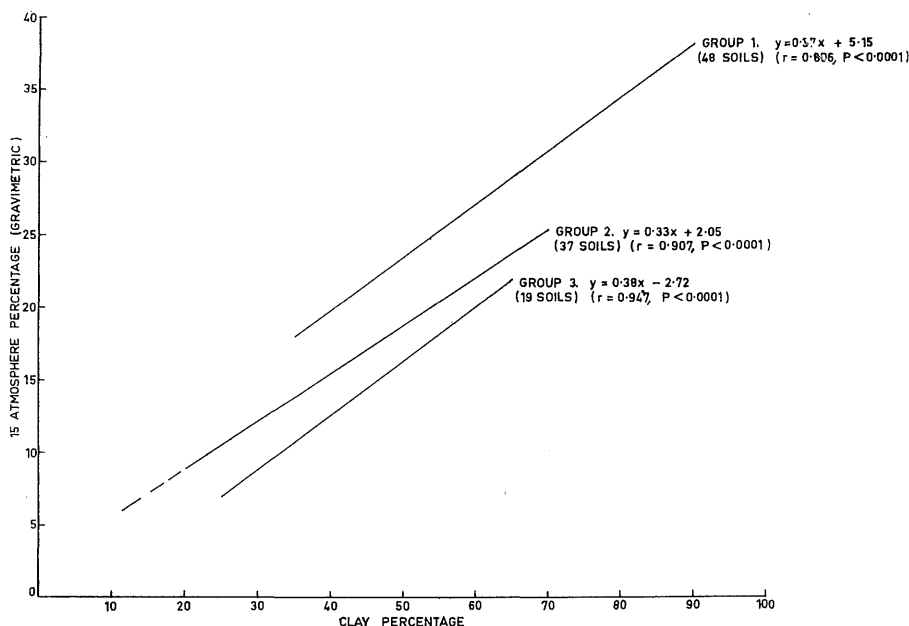


Fig. 4.—Lines of best fit for 15 atmosphere percentage data from soils in three groups.

The relationship between clay percentage and $1/10$ atmosphere percentage for 60 soil samples is shown in Figure 2. The line of best fit to the data is shown along with the correlation coefficient for linear regression. The correlation is highly significant ($P < 0.0001$). There is no justification for splitting the total sample into groups, since none of the three groups previously defined consistently fall above or below the predicted line for the whole sample. This may be explained by a consideration of the contribution of stable pores and swelling clay surfaces to soil moisture retention. At low tensions, a proportion of the

moisture retained may be held in stable pores. In soils containing a low percentage of swelling clay minerals, moisture held in these pores will tend to offset the greater surface adsorption in soils containing a higher percentage of swelling clay minerals, and consequently fewer stable pores.

Prediction of measured $1/10$ atmosphere percentage from the line of best fit is accurate for Groups 1 and 3. Measured values are within 10% of the predicted value for Group 1, and within 15% of the predicted value for Group 3. Group 2 is considerably more variable, but most measured values are within 20% of the predicted value.

The intercepts of the equations $y = a x + b$ shown in Figures 1, 2 and 4 are of interest. For a homogeneous range of soil samples, a small positive intercept is expected due to moisture retention by surface adsorption on sand, silt and organic matter, and by the capillary action of soil porosity. A negative intercept is only explained by soil heterogeneity. Negative intercepts are obtained for the total samples (Figures 1 and 2) and for Group 3 soils (Figure 4). For the total samples, it has already been shown (Table 1) that surface activity of soils per centum of clay follows the order: Group 1 > Group 2 > Group 3.

Figure 1 shows that average clay percentage follows the same order. This association of high surface activity with high clay percentage and low surface activity with low clay percentage increases the slope of the line of best fit and results in a negative intercept.

In the case of Group 3 soils, most of the high clay percentage samples are taken from subsurface layers. It appears that these samples contain a higher proportion of active clay minerals than the surface samples.

The above discussion emphasises two points:—

- (a) Negative intercepts in a correlation indicate sample heterogeneity and justify the separation of the sample into groups.
- (b) It is desirable to consider surface and subsurface samples as separate groups, particularly where the soil has a well-developed B horizon.

Accurate predictions of moisture retention may be made from measurements of clay percentage if soils are divided into groups on the basis of (a) soil type and soil mineralogy, (b) length of cultivation—organic matter content, and (c) depth of sampling or soil horizon.

Use of field texture techniques to determine clay percentage as described in the U.S.D.A. Soil Survey Manual (Soil Survey Staff 1951) is not anticipated at this stage. This method involves the kneading of a plastic soil sample by hand, and subjective judgements of clay percentage may be badly in error, particularly with soils of high clay content or containing appreciable amounts of iron oxides. However, within a narrow range of soil types, field texture techniques may be quite accurate if soil samples of known clay percentage are available for reference.

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REFERENCES

- FOX, W. E. (1964).—A study of bulk density and water in a swelling soil. *Soil Sci.* 98:307-16.
- METSON, A. J. (1956).—Methods of chemical analysis for soil survey samples. *Soil Bur. Bull. N.Z.* No. 42.
- RICHARDS, L. A. (1948).—Porous plate apparatus for measuring moisture retention and transmission by soil. *Soil Sci.* 66:105-11.
- RICHARDS, L. A., and WEAVER, L. R. (1944).—Moisture retention by some irrigated soils as related to soil-moisture tension. *J. Agric. Res.* 69:215-35.
- SOIL SURVEY STAFF, BUREAU OF PLANT INDUSTRY, SOILS, and AGRICULTURAL ENGINEERING (1951).—Soil survey manual. *Agric. Handb. U.S. Dep. Agric.* No. 18.
- STEPHENS, G. G. (1962).—"A Manual of Australian Soils". (Commonwealth Scientific and Industrial Research Organization: Melbourne).
- WALKLEY, A., and BLACK, T. A. (1934).—An examination of the Degtjareff method for soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.* 37:29-38.
- WARSHAW, C. M., and ROY, R. (1961).—Classification and a scheme for the identification of layer silicates. *Bull. Geol. Soc. Am.* 72:1455-92.

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