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Pedotransfer Functions for Predicting Three Points on the Moisture Characteristic Curve of a Zimbabwean Soil

Francis T. Mugabe
Department of Lands and Water Resources Management,
Midlands State University, P. Bag 9055, Gweru, Zimbabwe

Abstract: The moisture content of 41 soil samples taken from 14 locations in the Romwe catchment in Zimbabwe was measured at three matric potentials (-1430, -270 and –60 kPa) in a pressure chamber. Single and multiple linear regression analyses identified the relationships between soil moisture and the clay, silt, sand and organic matter content of the soils and their bulk density. The moisture content at the three suctions was significantly related to clay, sand and organic matter. At each of the three matric potentials, six sets of regression equations were used to predict the moisture content from the composition and bulk density of the soil. The predictions were improved by increasing the number of parameters used in the models.

Key words: Pedotransfer, soil moisture, soil water potential, empirical equations

INTRODUCTION

The soil moisture characteristic curve, described by many variations on the Brook and Corey[1] or van Genuchten[2] equations and the hydraulic conductivity are the two basic hydraulic properties of a soil that are used to model water movement in unsaturated soils[3]. Most of the Soil Vegetation Atmosphere Transfer Schemes (SVAT) simulation models such as PARCH (Predicting Arable Resource Capture in Hostile Environments) or SWIM (Soil Water Infiltration and Movement) require these properties as input parameters. The hydraulic properties of the soil are also important in modelling the movement of solutes in the soil.

Measuring the relationship between the matric potential and water content is costly, time consuming and difficult and is the major bottleneck in the application of SVAT simulation models. The ability to relate the moisture characteristic curve to more easily measured soil properties would lead to an improved economy of effort.

The similarity between the particle size distribution and the moisture characteristic curve was recognised when Childs[4] concluded that the nature of the soil particles is a major factor governing the curve which is essentially a pore size distribution curve influenced by both particle size distribution and soil structure[5]. Structure is important at the lower suction end of the water release curve while texture is important at very high suctions[6]. Structure is difficult to measure and in most studies it has been substituted with bulk density.

There are two general approaches that have been used to estimate the soil moisture characteristic curve from the soil composition. The first, used by Arya and Paris[5] translates the particle size distribution into pore size distribution. Then the cumulative increasing pore radii corresponding to progressively increasing pore radii are divided by the bulk volume of the sample to give volumetric contents and the pore radii are converted to the equivalent soil water pressure using the equation of capillarity[7] which can be simplified to

$$S = \frac{0.15}{r}$$

where, S is the suction in P pascals and r is the pore radius of the largest water-filled pore at that suction in meters.

The second general approach, which was employed in this study, is to use regression equations to predict moisture at given matric potentials. Although a number of workers[3,8-11] have developed pedotransfer functions based on the sand, silt, clay and organic matter content and the bulk density to predict points on the soil moisture characteristic curve it has been argued that pedotransfer functions developed elsewhere cannot be used on other soil types[12].

The only attempts to relate soil composition and bulk density to water retention in Zimbabwean soils were made by Tillett and Saunder[13] and Hall[11] and there is a need for further investigations into these aspects using datasets from other areas. The objective of this study was to develop useful relationships between the composition of the soil, specifically its clay, silt, sand and organic content, as well as its bulk density and its water content at -1430, -270 and -60 kPa and to develop pedotransfer functions for predicting the water content at these three suctions.

MATERIALS AND METHODS

Forty-one soil samples were taken from three or more horizons at each of 14 locations in the Romwe catchment (4.6 km^2) located in southern Zimbabwe, 86 km south of Masvingo and close to Ngundu. Three soil types occur in the catchment because of differences in the parent material. The first group are the fersialitic soils (III 5P) according to the Zimbabwean soil classification system[14] which are equivalent to the Ferric Lixisols in the FAO/UNESCO/ISRIC classification system. The second group are the fersialitic red clays with granular micro-structure (III 5E) derived from the more mafic pyroxene gneisses, equivalent to Chromic Lixisols. The third group of soils are the Vertisols (III 3E), which occur as the lower members of the catenal sequence in parts of the catchment.

Soil cores for the determination of bulk density and for particle size analysis were taken from three faces of a pit using a core sampler with a volume of 167.5 cm^3. The soil samples were put in soil tins and oven-dried for 24 h at 105°C and then reweighed to an accuracy of 0.1 g. The determination of particle size and organic matter was done by the Institute of Soils and Chemistry (Ministry of Agriculture, Harare).

The pressure chamber method was used to determine the gravimetric moisture content at -1430, -270 and -60 kPa according to the method by Black[15]. A saturated paste was prepared from each of the 41 samples and replicated twice in rings placed on ceramic plates. The samples were left to equilibrate until there was no significant increase in the amount of water in the burettes that were collecting the outflow. This was achieved after nine days. After equilibration, the samples were transferred into weighing aluminum foil and the wet soil plus the foil was weighed, then dried at 105°C for 24 h, and weighed again. The relationship between the composition and bulk density of the soil and its water content was determined by regression analysis.

RESULTS AND DISCUSSION

The soil samples included the following ranges of clay (mean 23% and range 4-50%), silt (mean 10%, range 3-33%) and sand (mean 76%, range 34-91%) contents. Organic matter ranged from 0.5–2% while the bulk density ranged from 1.08 to 1.64 g cm^{-3}).

The gravimetric moisture content of the 41 soil samples varied from 1.4 to 22.5% (mean = 10.2%, coefficient of variation = 0.62) at –1430 kPa, 1.8-25.5% (mean = 12.9%, Cv. = 0.58) at –270 kPa and 2.8-30.5% (mean = 15.5%, Cv. = 0.56) at –60 kPa. The means and ranges of soil moisture values increased with suction because at lower suctions most of the moisture in the macro-pores of the clay soils drains out thereby increasing the range. At higher suctions, most if not all, of the macro-pores in the sandy soils no longer drain water (Fig. 1 and Table 2).

Water content was positively correlated with the clay and organic matter content but was negatively correlated with the sand content (Fig. 1) at all the three suctions. There was no significant correlation between bulk density and soil moisture content. The relationships all at the three suctions were very similar but differed in magnitude. These findings are similar to those of Hall[11], who also found a positive and negative relationship between retained water and clay and bulk density, respectively.

Six multiple linear regressions of different combinations of soil properties and moisture contents at the three matric potentials (-1430, -270 and -60 kPa) gave significant coefficients of determination (Table 1). At -1430 kPa, a comparison of models 1 and 4, 2 and

Table 1: The six models used to predict the soil water content at matric potentials of -1430, -270 and –60 kPa in the Romwe catchment soils

Matric potential (kPa)	Model number	% Clay	% Silt	% Sand	% OM	BD	Intercept	Coefficient of determination (R^2)
-1430	1	0.36	0.38	-	-	-	-1.98	0.849
	2	-	-	-0.43	-	10.23	24.36	0.882
	3	0.43	0.44	-	-	10.08	-18.55	0.885
	4	0.40	0.42	0.04	-	-	-6.03	0.849
	5	0.33	0.35	-0.10	-	10.15	-8.87	0.885
	6	0.23	0.26	-0.11	0.92	9.72	-6.08	0.898
-270	1	0.43	0.46	-	-	-	-1.65	0.882
	2	-	-	-0.51	-	12.03	29.67	0.912
	3	0.50	0.54	-	-	11.97	-21.32	0.919
	4	0.79	0.81	0.37	-	-	-38.27	0.883
	5	0.71	0.74	0.21	-	11.84	-41.59	0.919
	6	0.63	0.66	-0.19	0.76	11.43	-39.29	0.926
-60	1	0.49	0.54	-	-	-	-0.14	0.861
	2	-	-	-0.60	-	16.87	31.61	0.910
	3	0.59	0.65	-	-	16.72	-28.89	0.915
	4	0.63	0.68	0.14	-	-	-15.77	0.862
	5	0.51	0.57	-0.08	-	16.76	-20.47	0.915
	6	0.41	0.49	-0.10	0.82	16.40	17.97	0.920

OM = organic matter, BD = bulk density

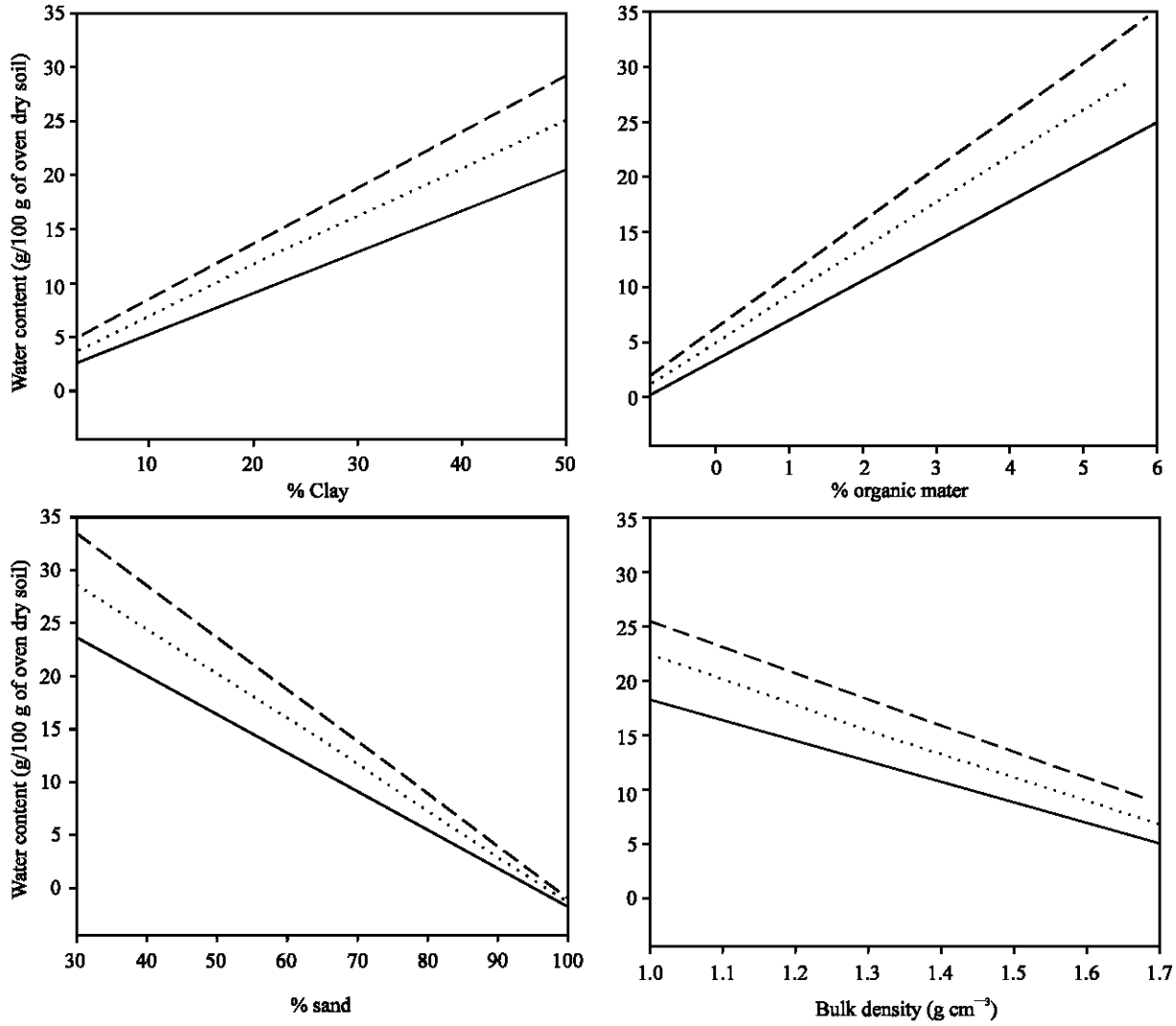

Fig. 1: The relationship between water content at –1430 (solid lines), – 270 (dotted lines) and – 60 kPa (long dash lines) and % clay, % organic matter, % sand and bulk density

Table 2: Regression equations and r^2 values of different parameters

	Matric potential (kPa)	Regression equation	r^2 value
% Clay	–1430 kPa	y = 0.383x + 1.320	0.761
	–270 kPa	y = 0.453x + 2.359	0.786
	–60 kPa	y = 0.519x + 3.279	0.763
% Organic matter	–1430 kPa	y = 3.320x + 3.330	0.728
	–270 kPa	y = 4.202x + 4.883	0.725
	–60 kPa	y = 4.817x + 6.150	0.706
% Sand	–1430 kPa	y = -0.363x + 34.400	0.846
	–270 kPa	y = -0.429x + 41.520	0.875
	–60 kPa	y = -0.493x + 48.222	0.856
Bulk density	–1430 kPa	y = -18.872x + 37.108	0.223
	–270 kPa	y = -22.365x + 44.746	0.231
	–60 kPa	y = -24.002x + 49.519	0.197

5 shows that the inclusion of sand in the empirical equation does not improve the coefficients of determination but the inclusion of sand at –270 and –60 kPa did improve them slightly.

A significant linear relationship between clay + silt and moisture content was found in Zimbabwean soils with textures varying from true sands to heavy sands[13]. Since the clay + silt content of a soil is an inexpensive and easily determined parameter (by removing the sand fraction with an 0.5 mm sieve) it is a simple way to obtain three points on the moisture characteristic curve without the need to do a proper particle size analysis in the laboratory. The addition of bulk density (model 3 in Table 1), which can be easily measured by the use of a soil corer, improved the coefficients of determination from 0.849 to 0.885, 0.882 to 0.919 and 0.861 to 0.915 at -1430, -270 and –60 kPa, respectively and the best prediction is therefore obtained when all five parameters are included in the regression equations (model 6). However, exclusion of organic matter (model 5) that is seldom determined in

most of the mechanical analyses, gives predictions that are closer to the recommended model 6. Model 6 accounted for 90, 93 and 92% of the variation in moisture content about the mean at -1430, -270 and –60 kPa, respectively and the remaining variations might be due to structure which was not included in this analysis. A very accurate prediction of the moisture in a soil, based only on its textural composition, is unlikely to be obtained unless some quantitative method of measuring the effect of structure can be found, which would enable this factor to be taken into account[9].

REFERENCES

1. Brook, R.H. and A.T. Corey, 1966. Properties of porous media affecting fluid flow. J. Irrigation and Drainage Division, America Society of Civil Engineers, 92: 61-88.
2. Van Genuchten, M.T.H., 1980. A closed-form equation for predicting hydraulic conductivity of unsaturated soils. Soil Science Society of America, 44: 822-827.
3. Gupta, S.C. and W.E. Larson, 1979. Estimating soil water retention characteristics from particle size distribution, organic matter percent and bulk density. Water Resources Res., 25: 1633-1635.
4. Childs, E.C., 1940. The use of moisture characteristics in soil studies. Soil Sci., 50: 239-252.
5. Arya, L.M. and J.F. Paris, 1981. A physicoemperical model to predict the soil moisture characteristic from particle size distribution and bulk density. Soil Sci. Soc. Am. J., 45: 1023-1030.
6. Hillel, D., 1982. Introduction to Soil Physics. Academic Press, San Diego.
7. Marshall, R.J. and J.W. Holmes, 1988. Soil Physics. Cambridge University Press, Cabridge.
8. Jameson, V.C. and E.M. Kroth, 1958. Available moisture storage capacity in relation to textural composition and organic matter content of several Missouri soils. Soil Science Society of America, 22: 189-192.
9. Salter, P.J., G. Berry and J.B. Williams, 1966. The influence of texture on the moisture characteristic curve of soils. III. Quantitative relationships between particle size, compaction and available capacity. J. Soil Sci., 17: 93-98.
10. Rawls, W.J., D.L. Brakensiek and K.E. Saxton, 1982. Estimation of soil water properties. Transactions of ASAE, 25: 1316-1320.
11. Hall, D.G.M., 1991. Relationship between moisture retention characteristics and other soil properties of Zimbabwean soils. Zimbabwe J. Agril. Res., 29: 52-63.
12. Campbell, G.S., 1974. A simple method for determining unsaturated hydraulic conductivity from moisture retention data. Soil Sci., 117: 311-314.
13. Tillett, E.R. and D.H. Saunder, 1958. Soil moisture relationships of some Zimbabwean soils. Zimbabwe J. Agri., 56: 61-64.
14. Thompson, J.G. and Purves, W.D., 1978. A Guide to the Soils of Rhodesia. Rhodesia Agriculture Journal Technical Handbook no. 3.
15. Black, C.A., 1965. Methods of soil analysis Part 1. Physical and mineralogical properties. Agronomy no. 9.