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PREDICTION OF THE WATER CONTENT AT FIELD CAPACITY FROM DISTURBED SOIL SAMPLES

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Abstract

In many soil databases, water content at -10 kPa was measured on disturbed soil samples. Meanwhile water content at -10 kPa is heavily influenced by soil structure, pore size distribution and bulk density. In this paper a model is developed to predict water content at field capacity given data obtained from disturbed soil samples. The linear model predicts the reduction in water content at field capacity with increasing bulk density and sand content. The model has a good fit and was validated against an independent dataset.

Keywords: pedotransfer functions, available water capacity, soil hydraulic properties, water retention curve, bulk density

Introduction

Characterisation of water content at field capacity (FC) and wilting point is important for assessing soil's available water capacity. Water content at field capacity is usually measured in laboratory at a potential of -10 or -33 kPa. Water content at field capacity is affected by macroporosity and structure (Sharma and Uehara, 1968), and therefore measurement is recommended using natural soil clods. Meanwhile water content at wilting point or -1500 kPa is not much affected by structure, as most water is held with adsorptive forces, thus it can be measured using disturbed soil samples (Aina and Periaswamy, 1985).

In the absence of laboratory or field measurement, water content at field capacity is usually predicted using pedotransfer functions from soil's particle size distribution (Huang *et al.*, 2006), and bulk density (Minasny and McBratney, 2002) or soil structural information (Pachepsky *et al.*, 2006). However in many soil databases, especially in developing countries (Bell and van Keulen, 1996), water content at -10 or -33 kPa was measured on disturbed samples. This is because the samples collected from soil survey were mainly for mapping and classification purposes, and usually bulk density and soil clods were not collected. Furthermore it remains difficult to analyse water retention of clod samples.

Various authors have found the discrepancy in water content at -10 or -33 kPa when measured using soil core or clods and using disturbed (sieved) samples (Young and Dixon, 1966; Unger, 1975; Aina and Periaswamy, 1985). Unger (1975) found for water content at -33 kPa, that cores retained more water than sieved soil when the water content was below 11%. Reeve *et al.* (1973) found that in A horizons, water content at field capacity tend to increase with bulk density except in silty soils. Meanwhile in B and C horizons the water content decreases with increasing bulk density.

Bell and van Keulen (1996) warned against the use of field capacity data derived from disturbed samples. Field capacity from disturbed soil samples overestimates in-situ field capacity for all soils except for the coarser textured soil. Pidgeon (1972) derived a formula to predict in situ water content at field capacity from disturbed ferralitic soil samples from Uganda. Twonlow (1994) also showed a formula to predict in situ field capacity from disturbed samples from ferralitic soil from Zimbabwe.

Field capacity measured on disturbed samples represents what we usually called matrix water content, the water content that can be held by the soil's matrix. It usually underestimates water content for top soils because it doesn't account for structure. And it also can overestimate water content for sub soils with high bulk density. To obtain volumetric water content at -10 kPa (θ_{10}) , the gravimetric water content (w_{10}) is multiplied by its bulk density (BD):

$$\theta_{10} = w_{10} \times BD \quad (1)$$

An increase in soil bulk density due to compaction or overburden pressure will affect the pore size distribution and consequently water retention. An increase in bulk density will decrease water retention, however if we use w_{10} of disturbed samples and Eq (1), we will get an increase in water retention with increasing bulk density. So we need to modify w_{10} of disturbed samples to represent the likely water content at a given bulk density.

We should be able to use field capacity data obtained from disturbed soil samples to obtain the representation of water content at a given bulk density. Assouline (2006) derived models that predict the effect of an increase in soil bulk density on the water retention curve. However the models require water retention curve for an initial or reference bulk density as inputs. Not many soil databases have such information, and we do not have information about the bulk density of the disturbed samples.

This paper will derive simple empirical models to predict water content at field capacity (of soil clods) given measurement using disturbed soil samples.

Data

The soil characterization and profile data from the US National Soil Characterization database (Soil Survey Staff, 1997) was used for analysis. A subset of the data of 301 samples, that contain water content at -10 kPa measured both using natural clods and on disturbed samples, was selected. From this subset, 274 samples were selected for building the model and the rest (27 samples) was used as validation data. The data are from 141 profiles, and the samples come from A,B and C horizons from various depths (0-2 m).

Table 1 shows the statistics of the basic properties, where w_{10} clod is the gravimetric percent water retained at suction of 10 kPa, which was measured on natural fabric (clods), and reported on a <2 mm base. w_{10} disturbed is the gravimetric water content of air dry <2 mm samples, after equilibration at 10 kPa suction. BD is the bulk density (g cm^{-3}) of the <2 mm fraction, with volume being measured after equilibration at -33 kPa. We used stepwise linear regression to obtain w_{10} clod from w_{10} disturbed plus other basic soil properties.

Table 1. Statistics of the 301 soil samples used in this study.

	Units	Mean	Std. dev	Median	Min	Max
W_{10} clod	% weight	24.97	10.12	24.30	1.8	52.0
W_{10} disturbed	% weight	22.70	8.80	22.60	2.5	51.4
Bulk density	g cm^{-3}	1.44	0.22	1.48	0.88	1.97
Sand	% weight	38.50	30.71	29.10	0.0	98.30
Clay	% weight	28.51	18.36	27.60	0.0	76.70

Results and Discussion

There is a linear relationship between w_{10} clod and w_{10} disturbed, and can be expressed by a relationship:

w_{10} clod = 4.51 + 0.93 w_{10} disturbed (R^2 = 0.68, RMSE = 5.82) (2)

where RMSE = root mean squared error. The equation predicted an increase in water content of the clod, however there is a lot of uncertainty associated with this as it doesn't take into account bulk density. Most data above the regression line indicated low bulk density (0.8 – 1.2 g cm^{-3}) and data below the regression line has bulk density between 1.4 and 2.0 g cm^{-3} (Fig. 1).

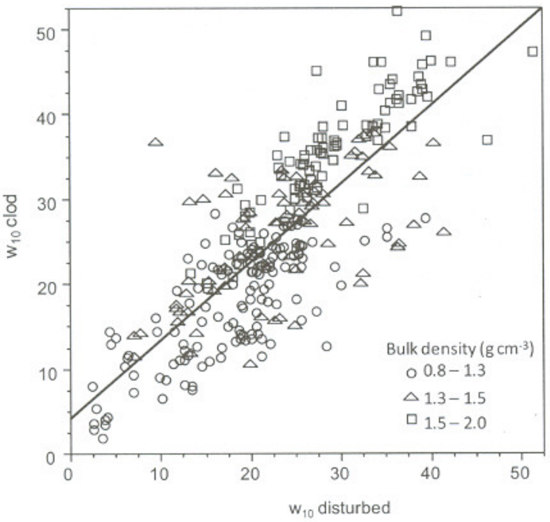

Fig. 1. The relationship between water content at -10 kPa from soil clods and disturbed soil samples. The line represents a linear model.

This relationship can be improved by including bulk density (BD) as another predictor :

w_{10} clod = 40.71 + 0.67 w_{10} disturbed – 21.36 BD (R^2 = 0.81, RMSE = 4.45) (3)

This model describes the reduction of water content with increasing bulk density. A further improvement of the model can be obtained by including sand content in the model (Fig. 2):

w_{10} clod = 51.12 + 0.40 w_{10} disturbed – 21. 41 * BD – 0.117 sand (R^2 = 0.88, RMSE = 3.58) (4)

This model describes the reduction of water content with increasing bulk density and sand content.

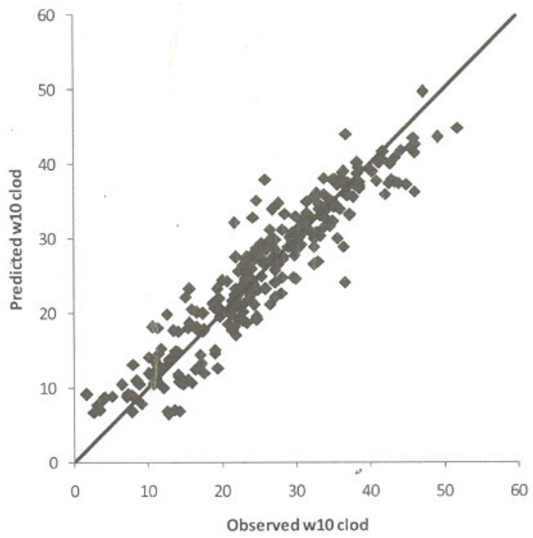

Fig. 2. Observed water content at -10 kPa from soil clods and predicted water content using disturbed soil samples.

We validated the models (Equations 5 and 6) on 27 soil samples in the database that are not being used for deriving the models. The validation data are for gravimetric water content at -6 kPa and -10 kPa.

The water content of clod at -6 kPa is predicted from disturbed samples data. Eq (2) gives an R^2 = 0.69, while eq. (3) gives an R^2 = 0.73 (Fig. 3). For water content of clod at -10 kPa, eq (2) gives an R^2 = 0.73, while eq. (3) gives an R^2 = 0.75 (Fig. 3). It can be seen that our models predict very well the likely water retention at -6 and -10 kPa of clod samples given data obtained from disturbed soil samples.

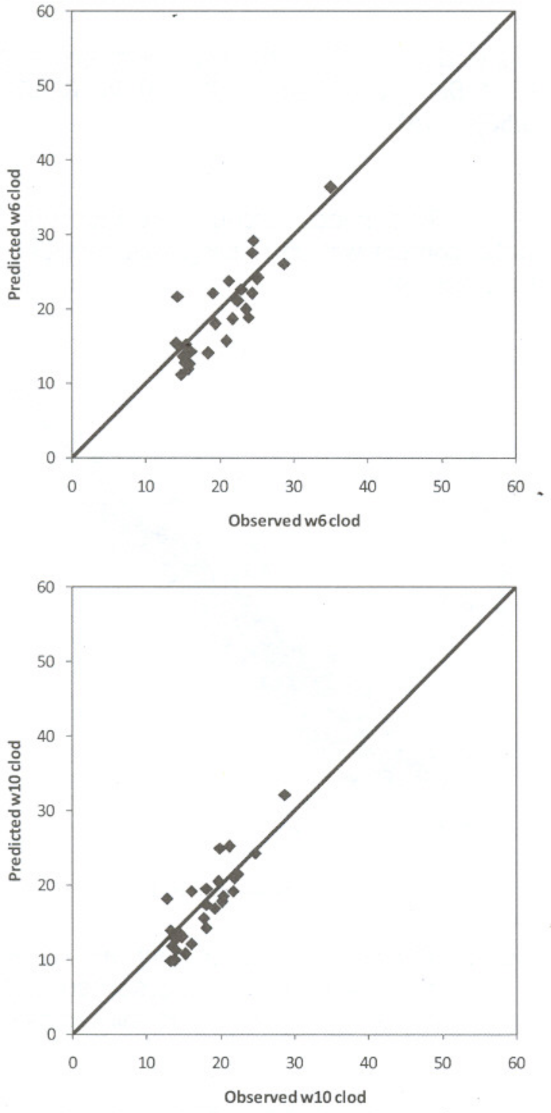

Fig. 3. Observed water content at -6 kPa and -10 kPa from soil clods and predicted water content using disturbed soil samples.

We now show that using this model, the prediction of volumetric water content at field capacity is more reasonable compared to if we use directly the values from disturbed soil samples. Young and Dixon (1966) assessed the accuracy of measurement on sieved samples by comparing the calculated volumetric water content at -33 kPa to the total porosity of the soil. If the volume of water held at -33 kPa is greater than its total soil porosity, then the value using sieved samples overestimates field capacity.

Table 2 shows prediction of volumetric water content at -10 kPa using disturbed soil samples, clod samples, and predicted clod samples (Eq. 4). We can see that if we use disturbed soil samples, the distribution is slightly skewed towards the lower end and has some impossible values volumetric water content >70% (Fig. 4). If we used Eq. (4), the result shows more reasonable values, with a maximum of 53%. We also looked at the percentage of the volumetric water content data which is less than its total porosity, calculated from bulk density. Using disturbed samples, 20% of the data are greater than its porosity. Using the correction formula, only 6% of the data overestimates field capacity. However, even using data from clod, there is an inherent 6% overestimation in the data.

Table 2. Estimation of volumetric water content at 10 kPa from disturbed samples, clod samples, and prediction model.

	Units	n	Mean	Std. dev.	Median	Min	Max	Percent data < porosity
W_{10} disturbed x BD	% volume	540	30.91	13.02	31.51	3.36	93.28	20%
w_{10} clod x BD	% volume	301	34.35	10.72	36.09	2.70	56.70	6%
Predicted w_{10} clod x BD	% volume	540	30.04	10.96	30.07	8.77	53.31	6%

Finally, if we wish to predict water content at -33 kPa instead of -10 kPa, we can use an empirical relationship. We found a good linear relationship:

w_{33} clod = -0.64 + 0.938 w_{10} clod (R^2 = 0.97, RMSE = 1.73) (7)

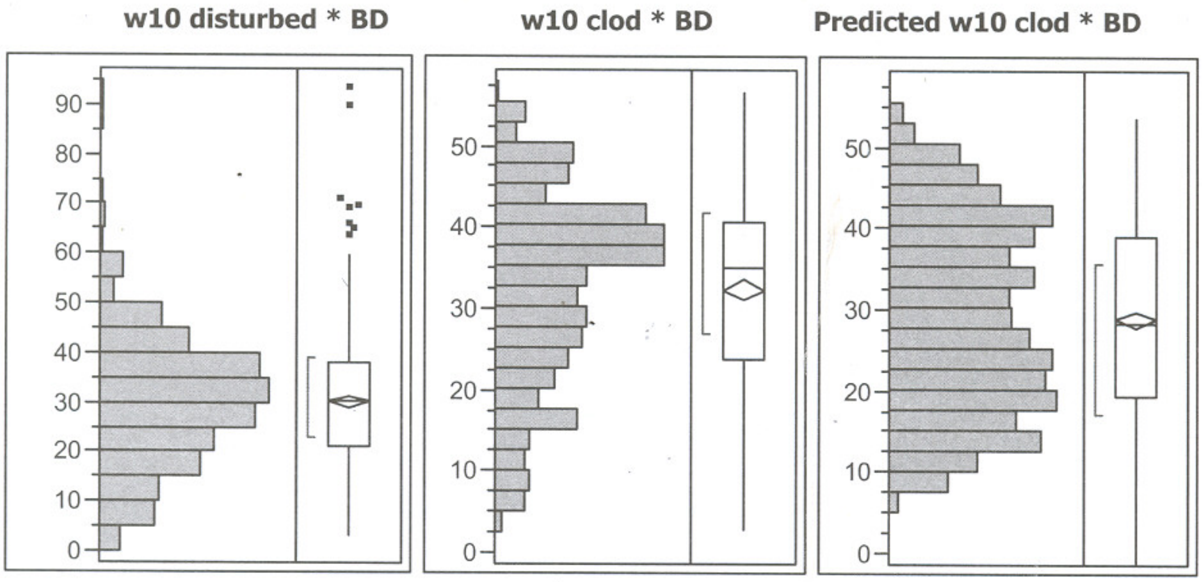

Fig. 4. Histogram of the distribution of volumetric water content at -10 kPa using disturbed samples, clod sample, and predicted clod samples.

Conclusions

In conclusion, we can predict water content at field capacity given measurement from disturbed soil samples. The simple linear model describes the reduction of water content with increasing bulk density and sand content. The model can be used to predict water content at field capacity in soil databases. Since the model is calibrated from a database from US, we should warn the applicability of the model is within the limit of the training data (Table 1).

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