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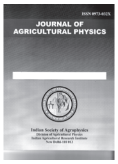

Research Article

Derivation and Validation of Pedotransfer Functions for Point Estimation of Soil Moisture in Sandy to Clayey Soil Texture

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ABSTRACT

Soil water retention at field capacity and permanent wilting point are important for recognizing plant available water potential and plant water stress in specific soil type. Using the relations between soil moisture contents, soil particles and bulk density, the pedotransfer functions (PTFs) were developed and simulated for soil moisture estimation at 0.033 and 1.5 MPa pressure head in fifty nine soil samples. Based on t-test, the developed PTFs were screened. Performance of the screened PTFs was evaluated by testing through R^2 – statistics, residual error values, coefficient of residual mass and model efficiency estimate. These established PTFs provides useful alternative to simulate point soil moisture content values from easily measurable relevant soil parameters.

Key words: Soil water retention, Field capacity, Permanent wilting point, Pedotransfer functions

Introduction

Knowledge on soil moisture content is essential to determine the plant type to be grown, study plant water stress, infiltration, irrigation practices and other assorted hydrophysical processes. Among the soil water retention characteristics, water retained at 0.033 MPa suction noted as Field Capacity (FC) and 1.5 MPa, called as Permanent Wilting Point (PWP) are vital as they represent the maximum and minimum values of plant available moisture range in soil (Hillel, 1982). In most soils, favourable plant growth occurs when the soil water is kept at or near the field capacity at most of the time during the entire growth period of the plant. Maintaining soil – water at or near to field capacity is therefore always preferable under irrigation water management. Water is becoming valued day by day, measurement of these two are thus prerequisite for efficient soil and water management practices. Determination of soil moisture at different suctions requires cost intensive soil – moisture equipments, which are rarely available at field level laboratories. However, these water retention characteristics are not exclusive soil properties, since they depends on soil textural make-up, soil structure and the nature of water. An alternative to measurement is to estimate the properties from easily measurable logical soil parameters.

Pedotransfer functions (PTFs) for estimating soil moisture using particle size distribution, particle density, bulk density, porosity, pore size distribution etc have already been derived for different soil types and at different places (Arya and Paris, 1981; Saxton *et al*., 1986; Zhuang *et al*., 2001). These PTFs are often developed from empirical observations, their applicability may be restricted to the datasets used to formulate the model (Wosten *et al*., 1999). It is therefore difficult for the users to select appropriate PTFs

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for their application (Acutis and Donatelli, 2003). The point pedotransfer function such as estimating soil moisture at certain pressure head based on linear and non-linear regressions could be used in most conditions. Several studies have been done on point PTFs and their application at various situations (Giri *et al*., 2004; Fooladmand *et al*., 2004; Vaz *et al*., 2005). The objective of the study was to develop pedotransfer functions for estimating soil moisture at 0.033 and 1.5 MPa and validate them for a wide range of soil texture in coastal Odisha.

Materials and Methods

Thirty eight soils from the surface (0 to 0.25 m depth) were collected from various sites in Astaranga and Erasama area in coastal Odisha. Samples were also collected in metal cores (length 0.06 m, diameter 0.045 m) for measurement of bulk density at field moisture level. Soils collected other than in core were processed and analyzed for EC at 1:2 soil and water ratio with the help of a calibrated EC meter (EuTech made Waterproof EC Scan High), soil textural components following Pipette method (Gee and Bauder, 1986) and soil moisture at 0.033 and 1.5 MPa by using pressure plate apparatus (Model: 1500F1 Pressure Extractor).

Data were processed first through descriptive statistics and then simple correlation (pearson coefficient) among the variables was worked out. Correlated variables were further processed through step – wise regression to recognize the relative influence of exogenous variables for determining endogenous soil parameters. Multiple linear regression equations for determining bulk density, and soil moisture at FC and PWP were formed.

To test the validity of the derived PTFs, a separate set of 59 soil samples were collected from various locations in east coast of Odisha and analyzed for bulk density and soil moisture content at 0.033 and 1.5 MPa. Applying PTF 1 and 2 the field capacity and PTF 3 and 4 the PWP of the soils were simulated. The PTF 5 was used for predicting BD of the soil. The t – test between the observed and estimated value was performed. Based on t – values the suitability of PTF was assessed and then the relation between observed and predicted values estimated by the corresponding selected PTF was determined. Results between observed and predicted values were further tested through R^2 statistics, mean absolute error (MAE), root mean square error (RMSE), mean squared residual (MSE), model efficiency (EF), coefficient of residual mass (CRM) as elaborated by Kvalseth (1985) and Homaee *et al*. (2002). Mathematical expressions of the estimates are given below:

$$R_1^2 = 1 - \sum(y - \acute{y})^2 / \sum(y - y_m)^2 \quad \ldots(1)$$

$$R_2^2 = \sum(\acute{y} - y)^2 / \sum(y - y_m)^2 \quad \ldots(2)$$

$$R_3^2 = \sum(\acute{y} - \acute{y}_m)^2 / \sum(y - y_m)^2 \quad \ldots(3)$$

$$R_4^2 = 1 - \sum(e - \hat{e})^2 / \sum(y - y_m)^2, \text{ where } e = y - \acute{y} \quad \ldots(4)$$

R_5^2 = Squared multiple correlation coefficient between regressand and regressors …(5)

R_6^2 = Squared correlation coefficient between y and $\acute{y}$ …(6)

Table 1. Descriptive statistics of selected soil properties

Soil Properties	Statistical estimates				
	Minimum	Maximum	Mean	Standard Deviation	Standard Error
ECe dSm^{-1}	0.01	5.25	1.34	1.52	0.27
Bulk Density gm cm^{-3}	1.10	1.52	1.34	0.09	0.01
Sand gm 100 gm^{-1} soil	21.46	93.78	59.59	19.12	3.10
Silt gm 100 gm^{-1} soil	1.33	37.50	14.64	7.92	1.28
Clay gm 100gm^{-1} soil	3.07	57.07	25.77	14.27	2.31
θ at 0.033 MPa	0.04	0.39	0.24	0.10	0.02
θ at 0.15 MPa	0.02	0.27	0.14	0.07	0.01

Table 2. Pearson correlation coefficient among the selected soil properties

Soil Properties	θ at 0.033 MPa	θ at 1.5 MPa	Bulk Density gm cm^{-3}	Sand gm 100 gm^{-1}soil	Silt gm 100 gm^{-1} soil	Clay gm 100 gm^{-1} soil
θ at 0.033 MPa	1.00	0.93^{b}	-0.64^{b}	-0.73^{b}	0.43^{b}	0.74^{b}
θ at 1.5 MPa		1.00	-0.63^{b}	-0.73^{b}	0.34^{a}	0.78^{b}
Bulk Density gm cm^{-3}			1.00	0.94^{b}	-0.76^{b}	-0.84^{b}
Sand gm 100 gm^{-1} soil				1.00	-0.74^{b}	0.93^{b}
Silt gm 100 gm^{-1} soil					1.00	0.44^{b}
Clay gm 100 gm^{-1} soil						1.00

^{a} and ^{b} are significant at P 0.05 and 0.01 level respectively

$$CRM = [\sum y - \sum \acute{y}]/ \sum y \qquad ...(7)$$

$$MAE = \sum|y - \acute{y}|/n \qquad ...(8)$$

$$RMSE = [\sum(y - \acute{y})^2/n]^{0.5} \qquad ...(9)$$

$$MSE = \sum(y - \acute{y})^2/(n-p) \qquad ...(10)$$

$$EF = [\sum(y - y_m)^2 - \sum(\acute{y} - y)^2]/ \sum(y - y_m)^2 \qquad ...(11)$$

where, y = observed value, y_m = mean observed value, ý = predicted or simulated value, $\acute{y}_m$= mean predicted value, p = no. of model parameters and n = no. of observations. All the statistical analyses were carried out in SPSS 6.0 software.

Results and Discussion

Soils were not saline except in 5% cases where ECe varied from 3.25 to 6.25 dSm^{-1}. Soil texture ranged from sand (5.26%), loamy sand (7.89%), sandy loam (31.58%), sandy clay loam (31.58%), sandy clay (2.63%), clay loam (5.26%) and clayey (15.79%) with bulk density ranging from 1.1 to 1.52 gm cm^{-3}. Estimates of descriptive statistics (Table 1) reflect the range of heterogeneity in measured soil properties. The range (minimum and maximum) and standard deviation value reveal that bulk density and sand content of soil were relatively more homogenous than other widely varied properties.

Results in Table 2 show positive correlation between soil moisture at field capacity ($\theta_{0.033}$) and silt and clay content and negative correlation with sand content, significant at 0.01 level. This means that increasing of soil water content is promoted by fine particles and discouraged by coarse particle content. Bulk density is the reflection of the arrangement of soil particles in three-dimensional matrix. It thus showed positive relation with sand and negative relation with silt and clay content. However, ECe didn't show any relation either with soil moisture or soil textural components and thus was not considered for the regression analysis.

Derivation of Pedotransfer Functions

Assuming soil moisture at $\theta_{0.033}$ and $\theta_{1.5}$ and bulk density as endogenous variables, a step – wise regression analysis was performed to eliminate the low or meagerly related exogenous soil parameter/s. Then based on coefficient of determination significant at 0.01 probability level, two PTFs containing silt, clay and bulk density values were formed for estimating point soil moisture at $\theta_{0.033}$ and $\theta_{1.5}$ and one PTF containing sand and clay content value was formed for determining bulk density of soil (Table 3). No contribution of sand for determining soil moisture was however vivid in these samples. Increase of sand particles in soil structure increases macro porosity, increases bulk density and decreases total porosity of soil (Hillel, 1982). Soil moisture retention is mostly related with soil porosity and that too meso and micro porosity at high suction level such as $\theta_{1.5}$.

Validations of Derived PTFs

The PTF 1 derived from silt, clay and bulk density values and PTF 2 from silt and clay content were applied to estimate soil moisture content at $\theta_{0.033}$ of fifty nine soil samples. Predicted value was then compared with observed soil moisture values by performing t- test. The t

Table 3. Detail of multiple regressions derived for selected soil properties

Endogenous soil properties	Expressions of regressions	PTF No.	Coefficient of determination	t-statistic between observed and predicted estimates	Level of significance of t-statistic
θ at 0.033 MPa	-0.23 + 0.0028(Silt) + 0.00564 (Clay) + 0.21(BD)	1	0.56^b	1.22	Non significant
	0.0878 + 0.00162(Silt) + 0.00481 (Clay)	2	0.55^b	4.31^b	Significant
θ at 1.5 MPa	-0.25 + 0.00105(Silt) + 0.00475(Clay) + 0.19(BD)	3	0.62^b	1.09	Non significant
	0.0344 – $6.06*10^{-6}$(Silt) + 0.004(Clay)	4	0.61^b	1.27	Non significant
Bulk Density gm cm^{-3}	0.96 + 0.005(Sand) + 0.002(Clay)	5	0.89^b	1.99^a	Significant

[a] and [b] are significant at P 0.05 and 0.01 level, respectively

statistics was non- significant for the value derived by PTF 1 but found significant for the value predicted by using PTF 2. A non – significant t- value indicates good agreement between observed and predicted estimate and thus signify the acceptability of PTF 1 for estimating soil moisture at 0.033 MPa. Likewise using PTF 3 and 4 the soil moisture value determined at 1.5 MPa showed a good agreement with observed value of soil moisture at 1.5 MPa as the t- test was non-significant in both the cases. Illustration of data in figure 1 reveals that the predicted soil moisture at $\theta_{0.033}$ and at $\theta_{1.5}$ was significantly related to corresponding values of observed soil moisture that further denote the acceptability of PTF 1 and PTF 3 and 4 for estimating $\theta_{0.033}$ and $\theta_{1.5}$, respectively. Soil bulk density however didn't show any conformity between observed and predicted estimate by using PTF 5 and thus the perdotransfer function was not considered.

Quantitative Comparison of Observed and Simulated Soil Properties

The R^2 statistics indicate the significance of the models, which are highly significant for all the suggested PTFs (Table 4). The model efficiency (EF) compares the predicted values to the averaged measured values and the maximum value of modeling efficiency is one. In our model, the EF values varied from 0.83 to 0.968. The coefficient of residual mass (CRM) measures the tendency of the model to overestimate or underestimate the predicted value, therefore if there was no difference between predicted and observed value then CRM and all residual error values will be zero. It means lower value of those statistics indicates the good fit by the pedotransfer function.

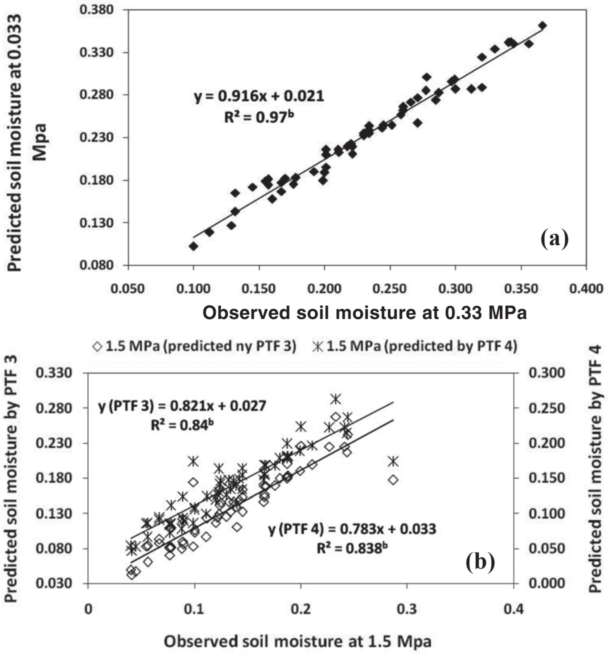

Fig. 1. Relations between observed and simulated soil moisture at two pressure heads (a) 0.33 MPa and (b) 1.5 MPa

Table 4. Statistical estimates of validated pedotransfer functions

Measures of significance	Pedotransfer functions		
	$\theta_{0.033}$= -0.23 + 0.0028(Silt) + 0.00564 (Clay) + 0.21(BD)	$\theta_{1.5}$= -0.25 + 0.00105(Silt) + 0.00475(Clay) + 0.19(BD)	$\theta_{1.5}$= 0.0344 – 6.06×10^{-6} (Silt) + 0.004(Clay)
EF	0.968	0.838	0.830
CRM	-0.008	-0.024	-0.029
MAE	0.009	0.015	0.016
RMSE	0.012	0.023	0.024
MSE	0.005	0.004	0.004
R_1^2	0.968	0.838	0.830
R_2^2	0.866	0.805	0.736
R_3^2	0.999	0.996	0.994
R_4^2	0.968	0.841	0.835
R_5^2	0.560	0.620	0.610
R_6^2	0.960	0.830	0.840

Conclusions

Pedotransfer function derived from bulk density, silt and clay content was found a suitable alternative to determine soil moisture at 0.033 MPa while the PTFs formed from BD, silt and clay contents and also from silt and clay contents were proved suitable to estimate soil moisture at 1.5 MPa. Thus, without the availability of soil moisture measuring instrument, the point estimation of soil moisture could be generated from easily measurable soil parameters by employing generated PTFs.

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