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Calibrating pedotransfer functions to estimate soil hydrolimits using limited data

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The water retained in the soil is determined by factors such as soil texture, structure, organic matter content, clay content and its type. However, laboratory or *in-situ* determination of water retention curve or hydrolimits is an exhaustive process with time, manpower and capital requirement. Researchers, therefore, prefer indirect estimation of soil moisture retention using pedotransfer functions (PTF). PTFs can be defined as predictive functions of certain soil properties from other easily, routinely, or cheaply-measured properties (Minasny and McBratney 2002). Regression tools are often used for establishing such relationships. Regression analysis requires prior knowledge of relationship or at least expected relationship and assumptions to be made regarding probability distribution of the errors. Statistical tests are made on the basis of these assumptions. New methods like artificial neural networks (ANN) do not require prior knowledge or assumptions about error distribution. An ANN is configured for a specific application such as pattern recognition or data classification, through a learning process. It then mimics the relationship between related variables learnt from historical data.

It was hypothesized that performance of the PTFs calibrated from native data would be better than the existing PTFs. An attempt was made to evaluate five existing PTFs and calibrate new PTFs for estimating field capacity (FC) and permanent wilting point (PWP) using particle-size distribution (sand, silt, clay content) and bulk density (BD) data (Tomar *et al.* 1996). The data relate to 28 major soil series of Vertisols and associated soils of the state of Madhya Pradesh. The area covered includes Kymore plateau and satpura hills, Central Narmada valley, Malwa plateau, Nimar valley, and Vindhya plateau zone. Some of the relevant characteristics of the soils are presented in table 1. Main textural classes reported were clay loam, sandy clay loam, silty clay, and silty clay loam.

Regression PTFs

Five PTFs for each of the two moisture constants were developed (Table 2). It was observed that the use of three textural fractions as an input resulted in relatively better prediction of FC and PWP. It could be noted that nearly 50% of the variation in PWP could be explained by the independent variables sand, silt, clay and bulk density. Different combinations arrived at by removing one of the three textural components did not affect accuracy, implying flexibility of using any two of the textural classes for prediction. The prediction of FC was less accurate (only 36% of the variation explained).

The plot of measured values against PTF (with highest R^2) estimated FC and PWP are depicted in figure 1 and 2. Regression analysis indicated that independent variables that affected the field capacity in the decreasing order of influence were the sand content (R^2=0.35), clay content (R^2 =0.22), silt content (R^2 =0.21) and bulk density (R^2 =0.004) for the best performing PTF (R^2=0.37). The influence of clay fraction was greater in prediction of FC than PWP. Canbolat (1999) reported that the sand fraction influenced FC and AWC more than the permanent wilting point. However, here the variation in PWP to the extent of 50% ema-

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Table 1. Salient physical properties (mean) of some soils of Madhya Pradesh

Profile no.	Sand	Silt	Clay	Bulk density	Field capacity	Permanent wilting Point
	(%)			(Mgm^{-3})	($m^3 m^{-3}$)	(%)
1	29.5	31.7	38.8	1.4	32.9	17.8
2	21.1	36.7	42.0	1.6	36.0	18.8
3	24.8	29.8	44.5	1.6	35.7	18.9
4	8.0	46.4	45.6	1.5	28.4	20.3
5	19.5	23.8	55.9	1.5	31.2	20.8
6	37.3	15.8	47.0	1.5	26.1	15.1
7	27.9	28.5	43.6	1.5	31.6	17.5
8	32.3	24.8	43.0	1.4	34.1	18.8
9	28.0	26.8	45.2	1.4	30.8	17.1
10	23.0	27.3	39.8	1.5	30.2	17.4
11	20.9	25.5	53.7	1.5	26.0	16.7
12	28.7	37.2	34.2	1.5	33.1	17.4
13	23.2	35.1	41.7	1.5	34.4	18.4
14	21.4	36.6	41.9	1.4	34.9	18.8
15	29.1	32.3	38.7	1.4	32.7	18.7
16	47.0	19.0	34.0	1.4	29.0	15.1
17	29.5	31.7	38.8	1.4	32.9	17.8
18	23.2	36.1	40.7	1.5	35.2	17.1
19	21.4	35.1	43.5	1.6	35.7	18.6
20	20.1	34.5	45.2	1.6	36.9	18.8
21	21.1	39.7	38.1	1.5	35.4	19.3
22	22.0	40.1	37.9	1.7	35.4	19.3
23	21.1	36.7	42.0	1.6	36.0	18.8
24	26.3	32.6	41.0	1.5	34.7	18.7
25	23.4	24.3	47.3	1.5	35.1	18.7
26	21.2	30.1	48.7	1.5	35.5	18.8
27	26.9	31.2	41.9	1.6	35.9	19.0
28	25.2	30.4	44.5	1.6	36.4	19.1
Mean	29.4	29.1	41.4	1.5	29.2	16.9
Minimum	4.2	6.0	12.2	1.1	7.6	4.3
Maximum	73.1	50.2	65.1	1.8	38.9	24.5
S.D.	15.47	8.72	11.14	0.12	7.52	3.91
Variance	239.56	76.05	124.1	0.01	56.66	15.29

Table 2. PTFs derived for estimation of FC and PWP

Estimated point	Input	PTF	R^2
FC	Sand, silt, clay, B.D.	0.20*sand + 0.53*silt + 0.48*clay + 2.98*B.D. -16.51	0.37
FC	Sand, silt, clay	0.19*sand + 0.52*silt + 0.46*clay -10.62	0.37
FC	Sand, clay, B.D.	-0.30*sand + -0.02*clay + 2.49*B.D. - 35.22	0.35
FC	Sand, silt, B.D.	-0.26*sand + 0.08*silt + 1.86*B.D. + 31.59	0.35
FC	Silt, clay, B.D.	0.33*silt + 0.28*clay + 2.71*B.D. + 3.99	0.37
PWP	Sand, silt, clay, B.D.	-0.02*sand + 0.17*silt + 0.15*clay -2.68*B.D. + 10.34	0.52
PWP	Sand, silt, clay	-0.01*sand + 0.17*silt + 0.17*clay + 5.06	0.51
PWP	Sand, clay, B.D.	-0.18*sand + 0.001*clay + -2.83*B.D. + 26.47	0.51
PWP	Sand, silt, B.D.	0.19*silt + 0.17*clay + -2.65*B.D. + 8.29	0.52
PWP	Silt, clay, B.D.	-0.17*sand + 0.02*silt + 3.04*B.D. + 25.76	0.51

nated from change in sand content as against 34.6 % variation in FC and the relationship was negative in both the cases. Similar analysis of the best performing PTF for PWP indicated that the variables sand (R^2 =0.50), silt (R^2=0.25), clay (R^2 =0.35) and B.D. (R^2 =0.05) influenced PWP in decreasing order. The effect of silt was less in prediction of FC compared to PWP.

Other PTFs

Categorized PTFs for textural classes were also calibrated but they were not found acceptable. Amongst the existing PTFs, only one PTF (PWP) proposed by Bhavanarayana (1986) came close to the R^2 values obtained by us (Table 3). Further the PTFs developed by us appear to be better.

Neural PTFs

The results of using ANN were mixed. There was substantial improvement in prediction of FC as 43.5 % variation in FC could be explained by the PTF. This has a clear advantage of almost 8 % (absolute terms) over an average 36 % variation accounted using other PTFs. ANNs have

Table 3. PTFs Proposed by Others and their statistical performance

Author	PTF	R^2(FC)
Aina and Periaswamy (1985)	FC = -7.18+(0.77*CLAY)+(0.66*SILT) PWP=2.13+0.31*CLAY	0.36
Bhavanarayana (1986)	FC=43.97-(0.3998*SAND) PWP=27.96-(0.2657*SAND)	0.35
Gupta and Larson (1979)	FC=6.0721+(CLAY*0.2745)+(SILT*0.2745) PWP=2.0235+(CLAY*0.5153)	0.35
Rao (1998)	FC=32.1793-(0.3184*SAND)+(0.4174*CLAY) PWP=8.687-(0.068*SAND)+(0.257*CLAY)	0.50
Tomasella and Hodnett (2003)	FC=4.046+(0.426*SILT)+(0.404*CLAY) PWP=0.91+(0.15*SILT)+(0.396*CLAY)	0.36

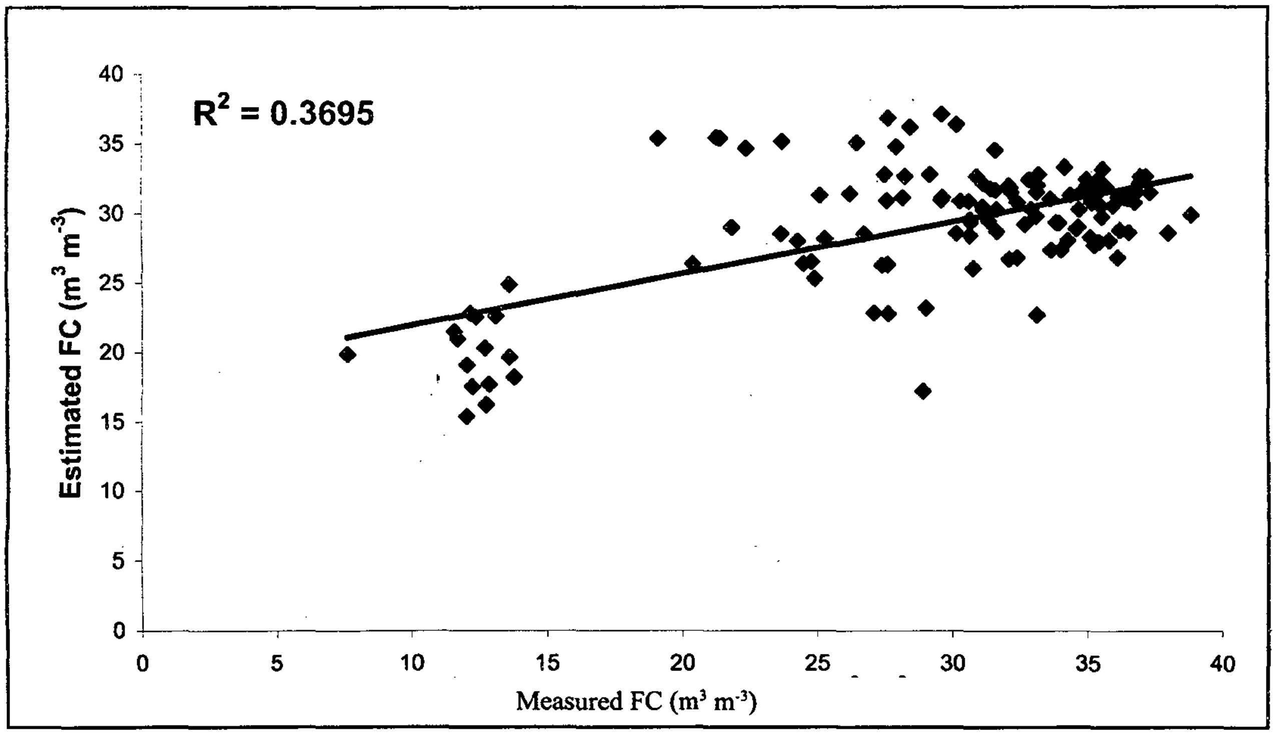

Fig.1. Measured and estimated Field Capacity

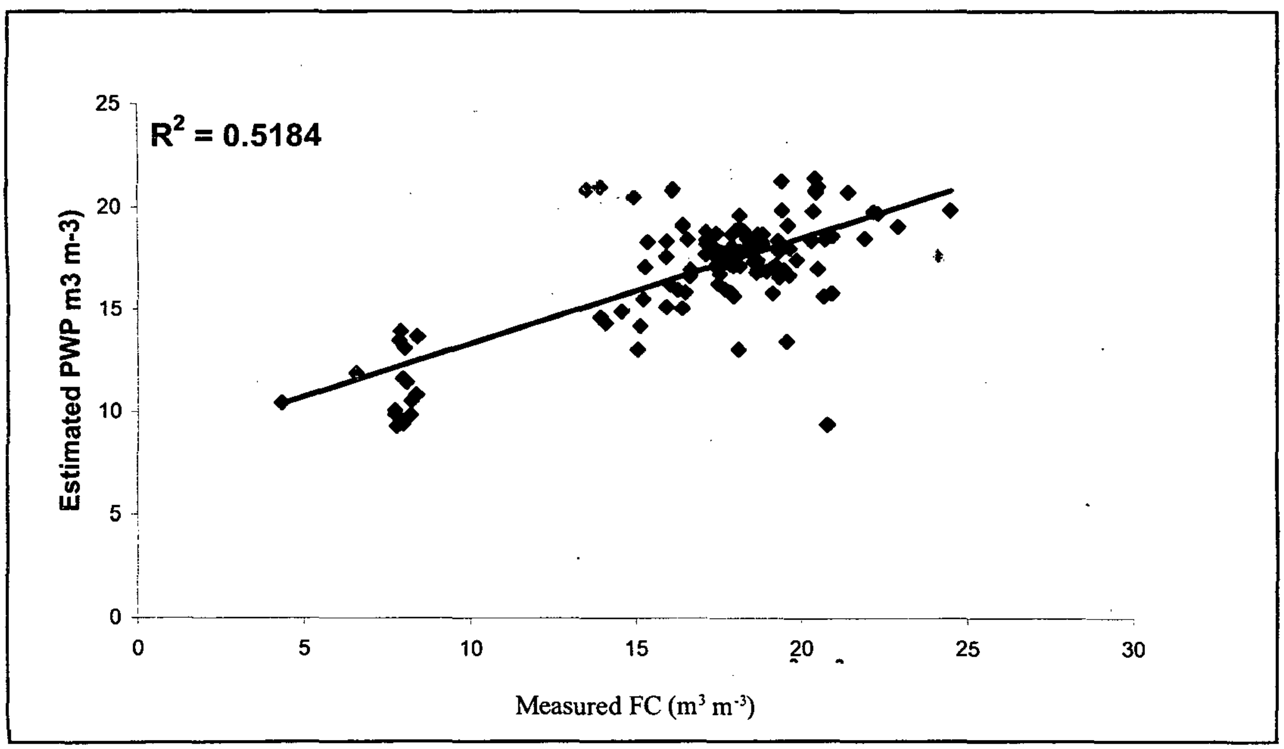

Fig.2. Measured and estimated permanent wilting point

been reported to perform better than regression equations when the number of inputs is larger than three (Hecht-Nielsen 1990) and our results confirmed these findings. However, prediction of PWP was poor (R^2=0.1277) as compared to the PTF developed by us using statistical regression or other PTFs tried.

The results in general, outlined the need to develop a strong database for calibrating PTFs. The proposed PTFs lacked accuracy and main reason for inability to represent the underlying relationship between basic soil properties and hydrolimits was attributed to inadequate data. The variance in the input textural fractions data was well above 70 %. Though bulk density varied very less, it did not show any influence in developed PTFs. The independent variables FC and PWP also exhibited 56 and 15 % variation respectively. Relatively lower variation in PWP was reflected in PTFs for predicting PWP as they performed better. ANN as a tool proved to be superior to regression. The performance of neural PTFs was relatively better mostly due to the ability of neural networks to mimic the behavior pattern of input data and its relationship with output.

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