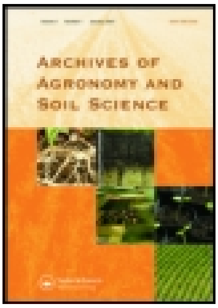

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# Calibration and evaluation of pedotransfer functions to estimate available water capacity of seasonally impounded shrink-swell soils of central India

Nitin Gorakh Patil [a] , Govind Singh Rajput [b] , Rakesh Kumar Nema [b] & Ran Bahadur Singh [b]

[a] Soil Survey Unit, National Bureau of Soil Survey and Land Use Planning (NBSS & LLUP) , Nagpur

[b] College of Agricultural Engineering, Department of Soil Water Engineering, Nehru Krishi Vishwavidyalaya , Krishi Nagar Adhartal, Jabalpur, India

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# Calibration and evaluation of pedotransfer functions to estimate available water capacity of seasonally impounded shrink-swell soils of central India

Nitin Gorakh Patil[a]*, Govind Singh Rajput[b], Rakesh Kumar Nema[b] and Ran Bahadur Singh[b]

[a]*Soil Survey Unit, National Bureau of Soil Survey and Land Use Planning (NBSS & LLUP), Nagpur;* [b]*College of Agricultural Engineering, Department of Soil Water Engineering, Nehru Krishi Vishwavidyalaya, Krishi Nagar Adhartal, Jabalpur, India*

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Pedotransfer functions (PTF) to estimate available water capacity of seasonally impounded shrink-swell soils of central India are presented. Performance of the calibrated PTFs is compared with that of 'Rosetta' a widely used general PTF. Available information on soil properties contained nine point soil water retention data for 175 samples measured at varied potentials, textural composition, bulk density and organic carbon content. Nine widely used water retention functions proposed by different researchers were fitted to the measured data and evaluated for efficacy to describe water retention characteristics (WRC). Of the nine functions evaluated, Brooks-Corey, van Genuchten, and Campbell functions were recommended for describing WRC of these soils. We present point PTFs to estimate available water capacity (AWC) using two approaches-regression and artificial neural networks (ANN). Point estimation PTFs were calibrated for water contents at $-33$ and $-1500$ kPa and consequently AWC. Performance evaluation with root mean square error (RMSE) criteria suggested that ANN based PTFs were better than regression PTFs. Performance evaluation of 'Rosetta' suggested its limited applicability for the study area. Region-specific PTFs to predict AWC were recommended. Increasing the number of predictor variables improved performance of neural PTFs and 'Rosetta'.

**Keywords:** regressions; soil; water; moisture

## Introduction

Soil water content ($\theta$) and unsaturated hydraulic conductivity ($k_s$) as a function matric potential ($h$), are the pre-requisite soil hydraulic functions in many agricultural, hydrological and environmental modeling investigations. For instance, the application of simple water balance models needs an input on available water capacity (AWC) of the soils usually defined as the quantum of difference between water held at field capacity ($\theta_{33}$) and permanent wilting point ($\theta_{1500}$). However, information on these properties on a regional scale is seldom available primarily because of high expenses, manpower requirement and quantum of time involved. Pedotransfer functions (PTF) provide cheaper alternatives to direct measurement of

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*Corresponding author. Email: nitpat03@yahoo.co.uk

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soil hydraulic properties by translating basic soil information (e.g. textural composition, bulk density, CEC etc.) to properties of interest. Many studies on PTFs to estimate different hydraulic properties have been reported (Schaap and Bouten 1996; Schaap and Leij 1998; Cornelis et al. 2001; Rawls et al. 2001; Pachepsky and Rawls 2003), but indirect estimation of water retention curve (WRC) has been most widely researched (Minasny et al. 1999). Depending on the interest, the PTFs could be calibrated to predict a specific point (like $\theta_{33}$) on the WRC termed as point PTF or it could be parametric PTF that predicts parameters of a mathematical function to describe WRC. Numerous PTFs can be found in the literature that can be grouped according to the input soil data used and method of model development (Wosten et al. 2001). A set of measured volumetric moisture contents at varied pressure heads at different soil depths is generally considered as functional variable to evaluate the predictive performance of the PTFs (Espino et al. 1996; Hack-ten Broeke and Hegmans 1996; van Alphen et al. 2001; Nemes et al. 2003). However, reports on the evaluation of PTFs outside the area of development are scanty. In Indian context, reports on calibration of regional PTFs, their comparison with international PTFs, and predictions with independent data sets of hydraulic properties measured in the laboratory are very few. The lack of a soil hydraulic database assigns great value to any prediction with reasonable accuracy.

Of late, productivity of shrink-swell soils in central India has been a concern. Hydromorphic conditions in these parts of the country allow only one seasonal crop in a year as they are impounded for four months (monsoon season) a year. We emphasize that in the past, hydraulic characteristics of seasonally impounded shrink-swell soils have never been measured/analyzed. Obviously, there is no information on PTF development and evaluation using the native data. This study was intended to: (i) identify water retention function to describe WRC of seasonally impounded shrink-swell soils, (ii) calibrate and evaluate point PTFs to predict available water capacity (AWC), and (iii) evaluate performance of widely used PTF-'Rosetta' in predicting water retention properties and thereby AWC.

## Materials and methods

Many expressions to describe WRC have been proposed by researchers, most of which are derived from hypothetical pore space models assuming a unimodal pore size distribution. Almost all the equations can be derived from the following generic form (Leong and Rahardjo 1997):

$$a_1\theta^{b_1} + a_2 \exp\left(a_3\theta^{b_1}\right) = a_4h^{b_2} + a_5 \exp\left(a_6h^{b_2}\right) + a_7 \tag{1}$$

where $a_1$, $a_2$, $a_3$, $a_4$, $a_5$, $a_6$, $a_7$, $b_1$ and $b_2$ are parameters, h = tension. Number of parameters in this equation is generally restricted to minimum primarily to avoid complicated equations when expressions for hydraulic conductivity are sought. The scope of this article is restricted to following nine retention functions.

A power law equation suggested by Brooks and Corey (1964) describes $\theta(h)$ relationship as:

$$\theta = \theta_r + (\theta_s - \theta_r)(\alpha h)^{-1} \quad \alpha h \geq 1 \tag{2}$$

$$\theta = \theta_s \quad \alpha h < 1 \tag{3}$$

where, $\theta_s$ is the saturation water content, $\theta_r$ is residual water content, $\lambda$ is pore distribution index, and $\alpha$ is parameter whose inverse $h_e = \alpha^{-1}$ is frequently referred to as the air entry value. Another most widely used function suggested by van Genuchten (1980) describes the relationship as:

$$\theta = \theta_r + (\theta_s - \theta_r)(1 + |\alpha h|^n)^{-m} \tag{4}$$

This equation is mostly used under the assumption $m = 1 - 1/n$ (e.g. Mualem-based estimation of unsaturated hydraulic conductivity; Mualem 1986) reducing number of parameters to four. In this study these variants of four parameters equation were used. The two variants were termed as VG1 and VG2. Here, $\alpha$, $n$, $m$ are empirical parameters that need to be estimated.

Campbell and Shizawa (1990) described water retention function as:

$$\theta = \theta_s \left(\frac{h}{h_e}\right)^{-1/b} \quad \text{for } h < h_e \tag{5}$$

$$\theta = \theta_s \quad \text{for } h \geq h_e \tag{6}$$

where $b$ is an empirical constant. Apart from the above equations, commonly cited functions were used in this study (Table 1) where, $\alpha$, $\beta$, $\gamma$, $\phi$ – are empirical parameters. Basic soil properties used in this study as input variables were clay, silt, sand content, bulk density, and organic carbon content.

### *Study area*

The soil properties database of seasonally impounded shrink-swell soils were generated during the project work on options to improve crop yields of seasonally impounded soils where crop is grown on residual moisture after recession of rainfall season. The study area is located in Jabalpur district of Madhya Pradesh state in India. The soils of the area are clayey and classified as Vertisols and associated soils. Due to plain topography and high clay content of soils vertical and horizontal drainage is poor. The soils get impounded during monsoon season lasting nearly four months (June–September) that renders 5 million ha cultivated area of the

Table 1. Functions fitted to measured water retention characteristics (WRC) data.

| Name | Restriction | Equation used |
|---|---|---|
| Driessen (1986) | $h \geq 1$ | $\theta = \theta_s h^{-\gamma \ln(h)}$ |
| Farrel and Larson (1972) | $h < h_{crit}$ and $h \geq h_{crit}$ | $\theta = \theta_s$ and $\theta = \theta_r + (\theta_s - \theta_r)(1 - 1/\alpha \ln(h/h_{crit}))$ |
| Libardi et al. (1979) | $\beta < 0$ | $\theta = \theta_s + 1/\beta \ln(h/\alpha + 1)$ |
| Rogowski (1971) | $0 \leq h < h_e$ and<br>$h \geq h_e$ | $\theta = \theta_s$<br>$\theta = \theta_e + [(\theta_{15} - \theta_e)/\ln(h_{15} - h_e + 1)] \ln(h - h_e + 1)$ |
| Simmons et al. (1979) | $\beta < 0$ | $\theta = \phi + 1/\beta \ln(h/\alpha + 1)$ |

H, suction pressure; $\theta_s$, the saturation water content; $\theta_r$, residual water content; $\theta_e$, soil water content at air entry; $\lambda$, is pore distribution index; $h_e$, air entry suction value of soil; $h_{crit}$, critical suction (air entry) pressure; $\theta_{15}$, soil water content at suction pressure; $h_{15}$, $\alpha$, $\beta$, $\gamma$, $\phi$, empirical parameters.

district unsuitable to grow crop. Agricultural crops are raised on residual moisture after cessation of monsoon. The soil database contained information on soil physical properties and water retention characteristics of 41 soil profiles spanning 175 horizons. The dominant series of this area are Sihora and Kunda characterized as Typic Haplusterts and Vertic Haplustepts (Tomar et al. 1996). Geologically, it is a recent alluvium of the mighty 'Narmada' river. On an average, profiles were more than 1 m deep, with only five profiles having depth $<0.5$ m. Though, the soil samples had a wide range of texture, discussion here is limited to three main textures namely clay, clay loam and sandy clay loam (Figure 1). Texturally 103 horizons qualify to have clay texture as per USDA classification (Soil Survey Staff 2006) which is 59% of the total number of horizons. Clay loam and sandy clay loam texture was recognized in 18 and 22 horizons, respectively.

### *Estimating retention function parameters*

Nine different closed form equations with two to five model parameters were fitted to the measured soil water retention data ($-10$, $-20$, $-33$, $-50$, $-100$, $-300$, $-500$, $-1000$, and $-1500$ kPa) obtained using pressure plate apparatus. Soil swelling often underestimates water retention values at equivalent tension by pressure-plate apparatus. Since soils of the study area are of swell-shrink type, measurements on water retention at various tension points were corrected for overburden caused by soil swelling. Coefficient of linear extensibility (COLE) was considered an important indicator to calculate overburden at saturation. Method described by Schafer and Singer (1976) was used for COLE measurements. It was calculated as COLE = (Lm − Ld)/Ld, where, 'Lm' is moist soil-cylinder length (cm) and 'Ld' is the dry soil-cylinder length (cm). Saturation paste was prepared using 100 g soil. The paste was left

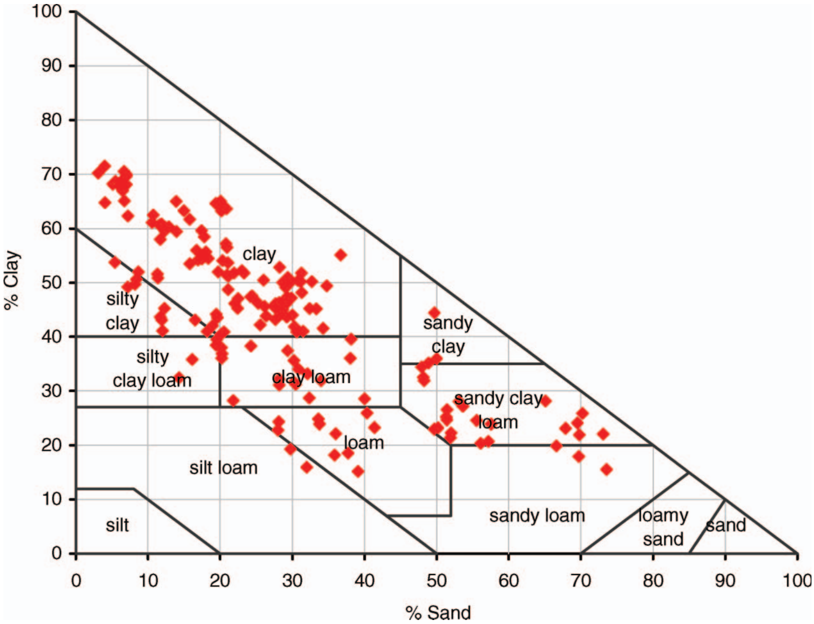

Figure 1. Textural distribution of soils.

to stand for 24 h. A syringe was used to produce soil-cylinders using saturation paste. The end portion of the syringe was cut-off. The paste was placed in the syringe and extruded on a dry metallic tray to form a soil-cylinder of 8–10 cm length. The soil-cylinders were trimmed-off using a knife and 5 cm length was maintained. The tray was transferred into an oven for 24 h at 50°C. The dry length was carefully recorded using a fine thread. This procedure was repeated five times to reduce the error. Soil porosity was assumed at 50% for calculating overburden caused by swelling. At each suction point, water retaining pores were calculated using standard capillary equation. Positive potential created by overburden of water retained in swelled portion was calculated as a product of mass of water in pores (g) and linear swelling (cm $\mathrm{cm}^{-1}$). These values were converted to pascal units and added to the applied equilibrium pressure.

Soil water characteristics curves were thus obtained using the corrected nine point data applying varied tension. Particle size analysis was carried out by the International Pipette method using sodium hexametaphosphate as a dispersing agent (Black 1965). Textural classification was obtained using USDA textural triangle. Bulk density was determined by dry clod (25–30 g natural cleavage clod collected during bulk sampling) coating technique (Black 1965).

SWRC (version 3), a public domain computer code (Dourado-Neto et al. 2000) was used for fitting these functions. SWRC uses the least-squares method and the general iterative method of Newton-Raphson to estimate function parameters of WRC.

PTFs were calibrated using regression and artificial neural network (ANN) methods. In the ANN method, feed forward networks were used following several reports (readers are referred to Wosten et al. 2001 for details). The available dataset on soil properties was divided into training (50%), validation (25%) and testing (25%) sets. Neural networks were trained to establish parametric PTFs, i.e. relationships between soil physical properties and estimates of the parameters fitted to the discrete retention data. After validation, the networks were employed to obtain estimates of parameters.

We considered a very popular PTF 'Rosetta' (Schaap et al. 2001) for our studies primarily because it is calibrated and validated with large multinational databases containing soil data from a wide range of soil types. Main strength of such databases is that the applicability of derived PTFs need not be limited to soils that are similar in their properties and were developed under similar soil-forming conditions. 'Rosetta' constitutes one of the most recent PTFs that overall has shown reasonable predictions in evaluation studies (Frédéric et al. 2004). Its hierarchical structure enables flexible input of limited and more extended sets of predictors. Further, being parametric PTF, it facilitates use of estimated hydraulic parameters in other simulations. For evaluation of PTF 'Rosetta', we used two distinct hierarchical levels of input data: Sand, silt and clay fraction = H1; and H1 + bulk density = H2. VG parameters estimated by each of the hierarchical rule were used for predicting FC and PWP.

### Statistical evaluation

The accuracy of the different models was judged using statistical indices namely coefficient of determination $R^2$ (significance level 0.05), and the Akaike information criteria (AIC):

$$AIC = N[\log(2\pi) + \log\left(\frac{SSE}{N-P}\right) + 1] + P \tag{7}$$

where n is number of observations, P is the number of model parameters, SSE-residual sum of squares. In a review paper, Wosten et al. (2001) observe that the statistical indicator root mean square error (RMSE) is widely used to evaluate PTFs. They also observe that RMSE of PTFs reported in the literature ranged from 0.02–0.11 $m^3m^{-3}$. Notably, the RMSE in measured SWRC data ranged from 0.035–0.05 $m^3m^{-3}$. Therefore, we considered 0.05 $m^3m^{-3}$ as a reasonable magnitude of RMSE, as it is approximately a mid point of the two extremes reported in the literature and is the upper limit of RMSE in measured data.

## Results and discussion

Statistical indices computed to evaluate the retention functions are presented in Table 2. When coefficient of determination ($R^2$) was used for judging fitted retention functions, the VG2 model emerged as the relatively appropriate function explaining more than 98% variance in the fitted SWRC data for clay soils. In clay loam soils, BC (Brooks and Corey model) function could explain 98% variance in clay loam SWRC followed by 97% variance explained by VG2 function. In sandy clay loam

Table 2. Statistical indices to evaluate water retention functions fitted to measured data.

| Function | Mean $R^2$ | Function | Mean AIC |
|---|---|---|---|
| Clay | | | |
| VG2 | 0.9816 | Campbell | −18.7371 |
| VG1 | 0.9794 | VG2 | −17.3930 |
| BC | 0.9782 | VG1 | −17.0733 |
| Campbell | 0.9750 | BC | −16.6529 |
| FL | 0.9506 | FL | −14.3463 |
| SNB | 0.9505 | Simmons | −12.7164 |
| LRN | 0.9254 | LRN | −11.9820 |
| Rogowski | 0.8969 | Rogowski | −10.5638 |
| Driessen | 0.8151 | Driessen | −9.4621 |
| Clay loam | | | |
| BC | 0.9801 | Campbell | −17.7773 |
| VG2 | 0.9797 | VG2 | −16.3136 |
| Campbell | 0.9784 | BC | −16.2202 |
| VG1 | 0.9748 | VG1 | −15.4583 |
| FL | 0.9584 | FL | −13.9487 |
| SNB | 0.9584 | Simmons | −12.3438 |
| LRN | 0.9326 | LRN | −11.5340 |
| Rogowski | 0.9081 | Rogowski | −10.3540 |
| Driessen | 0.8213 | Driessen | −9.0126 |
| Sandy clay loam | | | |
| VG2 | 0.9745 | Campbell | −19.8100 |
| VG1 | 0.9701 | VG2 | −16.5806 |
| Campbell | 0.9620 | BC | −16.2622 |
| BC | 0.9239 | VG1 | −16.0938 |
| LRN | 0.9293 | FL | −13.8792 |
| FL | 0.9520 | Rogowski | −12.7482 |
| Driessen | 0.8381 | Simmons | −12.2759 |
| SNB | 0.9778 | LRN | −11.9756 |
| Rogowski | 0.9743 | Driessen | −9.9288 |

AIC, Akaike Information Criteria; BC, Brooks and Corey; FL, Farrel and Larson; VG, van Genuchten; LRN, Libardi, Reichardt and Nascimento; SNB, Simmons, Nielsen, Biggar.

soils, VG2 function was better with $R^2 = 0.97$ ($p \leq 0.05$). The worst model was Driessen model for clay and clay loam soils and Rogowski model for sandy clay loam soils. BC and Campbell models were of intermediate value with $R^2 > 0.95$ in clay and clay loam soils whereas Campbell model was the only model in sandy clay loam soils with intermediate value. Other functions could not explain variation in the measured data as evidenced by relatively lower $R^2$ values. AIC values suggested that Campbell model was the best performing model in all the three textures of the sampled soils. The mean AIC of model VG2 was ranked second best in the three textures, followed by VG1 (clay and clay loam) and BC (sandy clay loam) model. Driessen model was ranked lowest. BC, VG and Campbell models were therefore screened for calibrating PTFs to estimate available AWC.

### Calibrating PTFs

Efficacy of the regression equations (Table 3) to predict AWC ($\theta_{33}$, $\theta_{1500}$) could be judged from the RMSE that ranged from 0.014–0.0967 $m^3m^{-3}$ (Table 4). Only one PTF had RMSE greater than 0.05 $m^3m^{-3}$. Variability in the fitted data and predicted data did not differ much for clay and clay loam soils. The PTFs for sandy clay loam soils exhibited greater difference when RMSE in fitting and testing data

Table 3. Regression PTFs to estimate field capacity (FC) and permanent wilting point (PWP) of seasonally impounded shrink-swell soils.

| PTF |
|---|
| Clay ($n = 77$) |
| FC = 0.62863 − 0.00541*SAND − 0.00174*SILT − 0.00283*CLAY |
| FC = 0.60891 − 0.00535*SAND − 0.00168*SILT − 0.00284*CLAY + 0.01193*BD |
| FC = 0.57133 − 0.00512*SAND − 0.00153*SILT − 0.0026*CLAY + 0.018702*BD + 0.01852*OC |
| PWP = −0.43337 + 0.00448*SAND + 0.00654*SILT + 0.00632*CLAY |
| PWP = −0.56959 + 0.00493*SAND + 0.00697*SILT + 0.00628*CLAY + 0.08225*BD |
| PWP = −0.68083 + 0.00560*SAND + 0.00741*SILT + 0.00698*CLAY + 0.10227*BD + 0.05482*OC |
| Clay loam ($n = 13$) |
| FC = 2.24479 − 0.01919*SAND − 0.02024*SILT − 0.0193*CLAY |
| FC = 2.15270 − 0.01723*SAND − 0.01727*SILT − 0.01527*CLAY − 0.14994*BD |
| FC = 2.07455 − 0.01618*SAND − 0.01613*SILT − 0.01454*CLAY − 0.14743*BD − 0.08289*OC |
| PWP = 0.87544 − 0.00821*SAND − 0.0087*SILT − 0.00524*CLAY |
| PWP = 0.84598 − 0.00762*SAND − 0.0077*SILT − 0.00395*CLAY − 0.04796*BD |
| PWP = 1.72945 − 0.01731*SAND2 − 0.01753*SILT − 0.01377*CLAY + 0.00349*D2 + 0.04272*OC |
| Sandy clay loam (n = 15) |
| FC = 0.68022 − 0.00517*SAND − 0.00461*SILT − 0.00359*CLAY |
| FC = 2.70643 − 0.02057*SAND − 0.01964*SILT − 0.02092*CLAY − 0.3127*BD |
| FC = 0.54369 − 0.00118*SAND + 0.00161*SILT + 0.00153*CLAY − 0.21649*BD − 0.00335*OC |
| PWP = 0.08847 − 0.00117*SAND + 0.00058*SILT + 0.00227*CLAY |
| PWP = 0.43882 − 0.00384*SAND − 0.00202*SILT − 0.00072*CLAY − 0.05407*BD |
| PWP = −0.19437 + 0.00184*SAND + 0.004205SILT + 0.00585*CLAY − 0.0259*BD − 0.00098*OC |

BD, Bulk density; OC, organic carbon content; *n*, number of observations used for developing PTF.

were compared. The hierarchical PTFs (H1, H2, and H3) for clay and clay loam soils demonstrated improved performance with progressive inclusion of bulk density and OC (organic carbon) as predictor variables. They were also well within the threshold limit in terms of performance judged with RMSE indicator.

Performance of neural PTFs in predicting AWC of clay soils was superior to regression PTFs (Table 5), while the trend was mixed for other two textures. Average RMSE in describing training dataset was 0.01946 $m^3m^{-3}$as against almost twice the average RMSE observed in regression fitting 0.03494 $m^3m^{-3}$. The results are reversed when RMSE of testing datasets are compared. However, it was noted that the reversal was due to higher RMSE in predicting AWC of clay loam and sandy clay soils. We did not consider the results for clay loam and sandy clay loam soils as conclusive because the number of data was 18 (clay loam) and 22 (sandy clay loam) as against 103 for clay texture. As indicated by the RMSE (0.0211–0.0236 $m^3m^{-3}$)

Table 4. Accuracy of hierarchical regression PTFs as indicated by RMSE in estimating available water capacity (AWC).

| Hierarchical model | Model input | RMSE ($m^3m^{-3}$) Training | RMSE ($m^3m^{-3}$) Testing |
|---|---|---|---|
| Clay | | | |
| H1 | Sand silt and clay content | 0.0283 | 0.0240 |
| H2 | H1 and bulk density | 0.0263 | 0.0241 |
| H3 | H2 and organic carbon content | 0.0256 | 0.0262 |
| Clay loam | | | |
| H1 | Sand silt and clay content | 0.0215 | 0.0332 |
| H2 | H1 and bulk density | 0.0189 | 0.0311 |
| H3 | H2 and organic carbon content | 0.0182 | 0.0299 |
| Sandy clay loam | | | |
| H1 | Sand silt and clay content | 0.0510 | 0.0431 |
| H2 | H1 and bulk density | 0.0967 | 0.0355 |
| H3 | H2 and organic carbon content | 0.0280 | 0.0140 |

RMSE, root mean square error.

Table 5. Accuracy of hierarchical neural PTFs as indicated by RMSE in estimating AWC.

| Hierarchical model | Model input | RMSE ($m^3m^{-3}$) Training | RMSE ($m^3m^{-3}$) Testing |
|---|---|---|---|
| Clay | | | |
| H1 | Sand silt and clay content | 0.0236 | 0.0011 |
| H2 | H1 and bulk density | 0.0235 | 0.0138 |
| H3 | H2 and organic carbon content | 0.0211 | 0.0249 |
| Clay loam | | | |
| H1 | Sand silt and clay content | 0.0127 | 0.0579 |
| H2 | H1 and bulk density | 0.0089 | 0.0439 |
| H3 | H2 and organic carbon content | 0.0479 | 0.0584 |
| Sandy clay loam | | | |
| H1 | Sand silt and clay content | 0.0090 | 0.0526 |
| H2 | H1 and bulk density | 0.0218 | 0.0218 |
| H3 | H2 and organic carbon content | 0.0067 | 0.1182 |

for training, the neural networks could accurately describe the relationship between basic soil properties and $\theta_{33}/\theta_{1500}$, and reliability of the calibrated PTFs (clay soils) was found to be acceptable with RMSE of 0.0011–0.0249 $m^3m^{-3}$ in prediction of AWC. Improved performance with increased input variables (Figures 2–4) was evident as the quantum of RMSE decreased from H1 thorough H3. However, testing for reliability yielded opposite trend. It is not clear to us why PTF performance declined despite increase in number of predictor variables, which otherwise improved

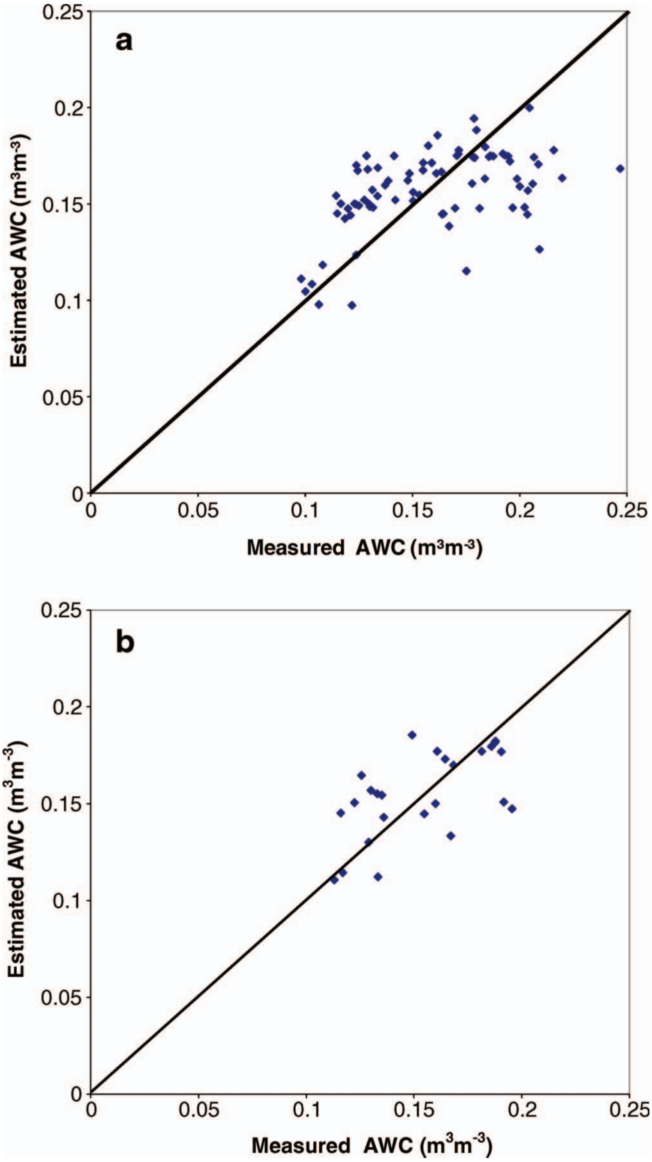

Figure 2. (a) Comparison of measured and neural PTF H1 predicted available water capacity (AWC) of clay soils (training set). (b) Comparison of measured and neural PTF H1 predicted AWC of clay soils (testing set).

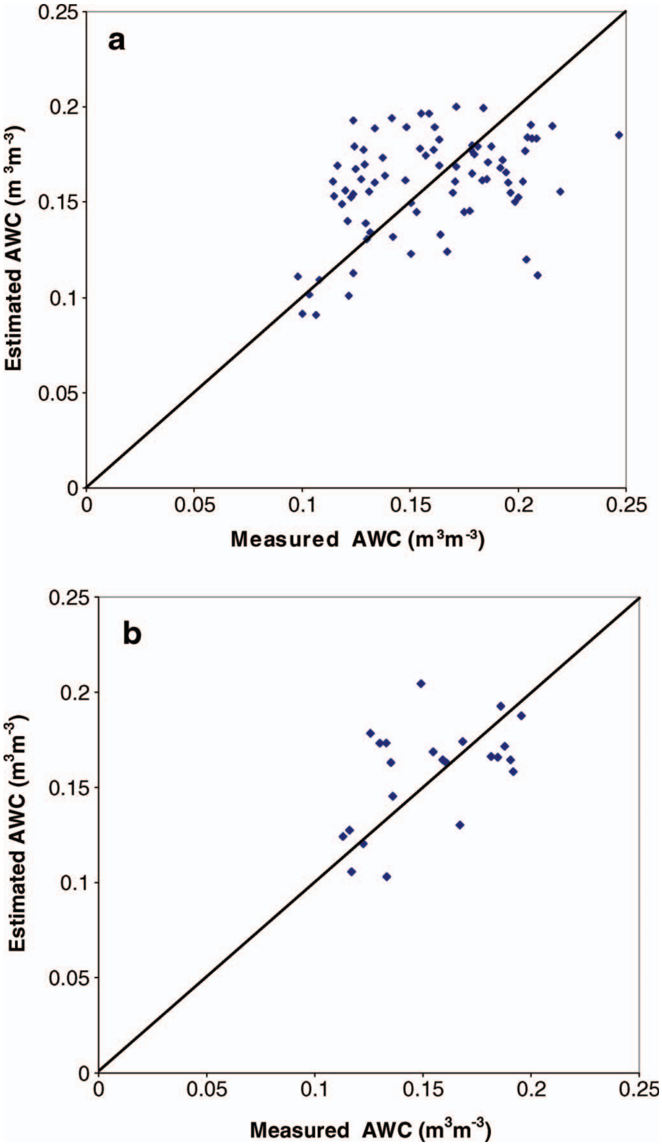

Figure 3. (a) Comparison of measured and neural PTF H2 predicted available water capacity (AWC) of clay soils (training set). (b) Comparison of measured and neural PTF H2 predicted AWC of clay soils (testing set).

the ability of networks to mimic the relationship during training. In general, the model should not be more accurate than data used in the model development (Wosten et al. 2001). They also opine that the future progress of PTFs should be expected to come from the improvement in databases that are available for developing PTFs rather than the advancement in techniques of building PTFs (Wosten et al. 2001). From the comparison of figures for training and testing, it could be observed that the predictions (testing) were as good or as worse as the data used for calibration (training). The graphical depiction though does not show great agreement between measured and predicted AWC, statistical indices of development

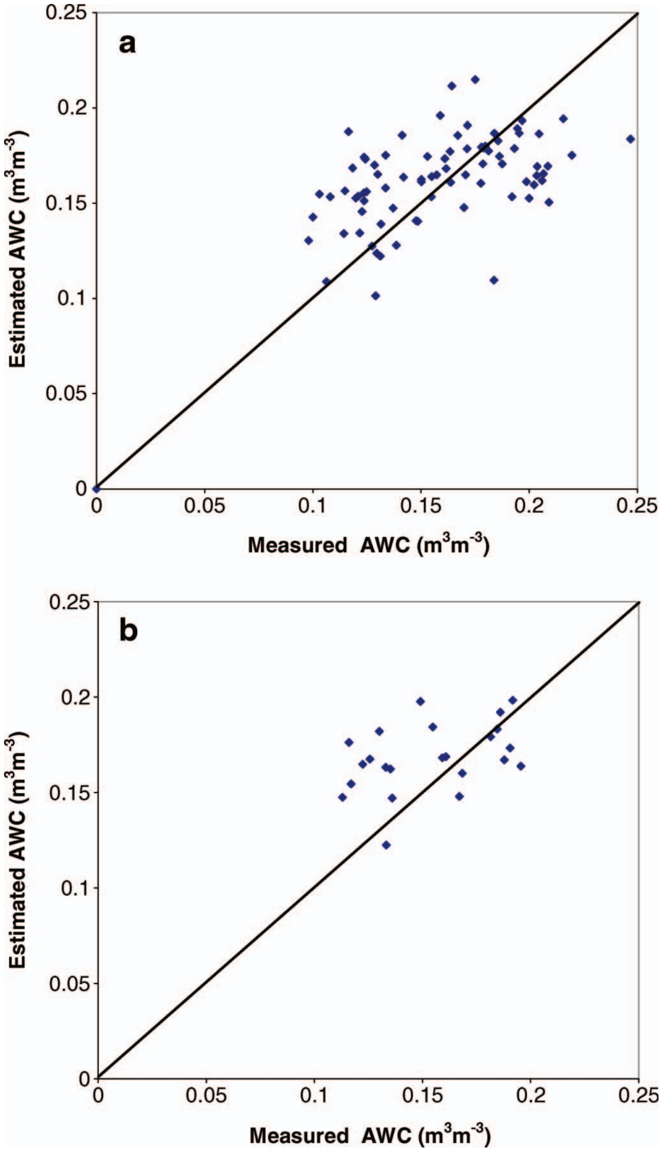

Figure 4. (a) Comparison of measured and neural PTF H3 predicted available water capacity (AWC) of clay soils (training set). (b) Comparison of measured and neural PTF H3 predicted AWC of clay soils (testing set).

and testing dataset indicate acceptable performance (RMSE $<0.05$ m$^3$m$^{-3}$) and hence the calibrated PTFs could be termed useful for predicting SWRC of the study area especially when there is paucity of information.

Every year the farmers take a collective decision on draining off impounded water based on their experience and quantum of rainfall. The bunds are opened during the second week of October in a phased manner and different crops are grown on residual moisture. The farmers have thus traditionally responded to impounding of monsoon water by storing it and adjusting draining schedule to suit their crop choice within the constraints. Prediction of AWC using calibrated PTFs would help in simulating options over crop choice, growth of the crop, soil moisture dynamics and finally crop yield.

### *Performance of 'Rosetta'*

Average RMSE in predictions obtained by 'Rosetta' was highest of all (0.0383 $m^3m^{-3}$) when compared to calibrated PTFs. But 'Rosetta' predictions of AWC were evidently acceptable as the magnitude was $<0.05$ $m^3m^{-3}$ in clay and clay loam soils, while it was marginally higher in sandy clay loam soils (Table 6). However, calibrated neural PTFs were better than 'Rosetta' because of lower RMSE across the textures. Comparison with regression PTFs showed mixed results, with better predictions by 'Rosetta' in clay loam soils but regression PTFs being superior in clay and sandy clay loam soils. It was also observed that performance of 'Rosetta' improved with addition of input variable namely-bulk density to the input data (Figures 5 and 6). Though the RMSE was within the threshold limit (0.05 $m^3m^{-3}$), it could be observed

Table 6. Evaluation of PTF 'Rosetta' in predicting AWC.

| Hierarchical model | Model input | RMSE ($m^3m^{-3}$) |
|---|---|---|
| Clay | | |
| H1 | Sand silt and clay content | 0.0332 |
| H2 | H1 and bulk density | 0.0331 |
| Clay loam | | |
| H1 | Sand silt and clay content | 0.0304 |
| H2 | H1 and bulk density | 0.0254 |
| Sandy clay loam | | |
| H1 | Sand silt and clay content | 0.0571 |
| H2 | H1 and bulk density | 0.0506 |

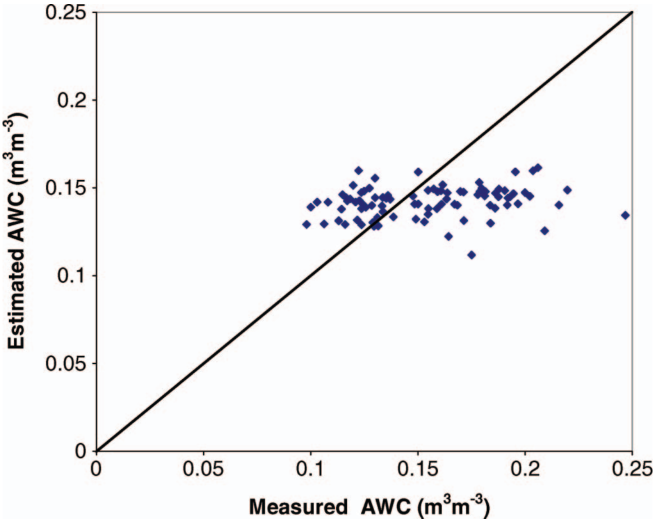

Figure 5. Comparing measured available water capacity (AWC) of clay soils with PTF 'Rosetta' predictions using textural composition as an input.

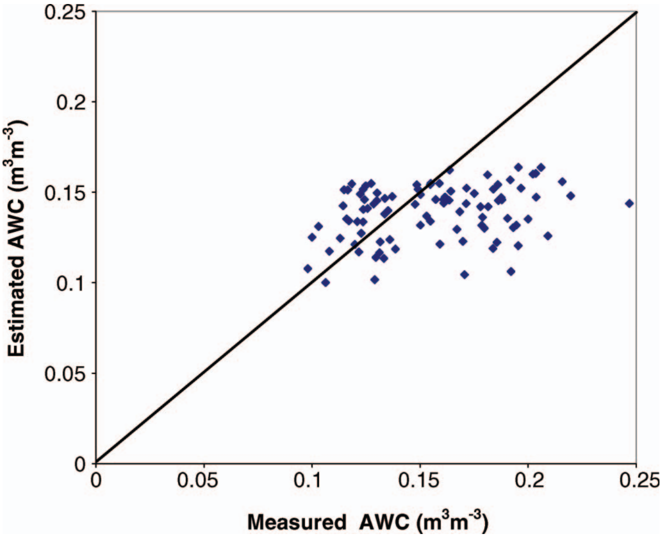

Figure 6. Comparing measured AWC of clay soils with PTF 'Rosetta' predictions using textural composition and bulk density as an input.

from Figure 5 that the estimates of AWC (especially when the measured AWC exceeded 0.15 $m^3m^{-3}$) were lower than measured AWC. Though the performance improved with additional input, (Figure 6) underestimation beyond AWC 0.15 $m^3m^{-3}$ was again apparent. Improvement in predictions with increasing number of predictors has been reported earlier by Nemes et al. (2003). Rawls et al. (2001) and Wosten et al. (2001) have also reported such trend in evaluation studies of PTFs. Based on Figures 5 and 6, it could be said that 'Rosetta' has limited application value despite acceptable magnitude of RMSE. It may be noted that 'Rosetta' estimates VG parameters exclusively, and VG function was already found suitable to describe WRCs.

## Conclusion

Regression and neural PTFs for predicting AWC of seasonally impounded shrink-swell soils were calibrated and demonstrated to be of value in crop planning and management of seasonally impounded soils. Brooks-Corey, van Genuchten and Campbell functions were recommended for describing WRC of seasonally impounded shrink-swell soils. Generic PTF 'Rosetta' was shown to have limited utility for the study area and hence region-specific PTFs to predict AWC were recommended.

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