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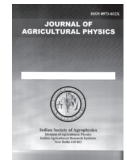

Research Article

Pedo-transfer Functions for Predicting Soil Hydraulic Properties of Jute Growing Soils in Lower Indo-Gangetic Plains, India

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ABSTRACT

Pedo-transfer functions (PTFs) have been developed for estimation of soil water retention characteristics under jute growing areas of lower Indo-Gangetic plains in Cooch Behar and Jalpaiguri districts have been using commonly and easily measurable soil properties e.g., soil texture, bulk density and organic carbon content. Soil organic carbon content plays a vital role in influencing the soil water retention by reducing the bulk density. Few other selected PTFs were also evaluated on large independent soil datasets under present study. Among the various models *i.e.*, Rawls *et al*. (1982); Aina and Periaswamy (1985); Bhavanarayana *et al*. (1986); and Rao *et al*. (1988) tested, equation under Tomasella and Hoddnett model (1998), was found to be satisfactory for prediction of soil moisture characteristics under present condition, associated with ME value (0.63) near zero. Results revealed that PTFs based on soil texture, bulk density and organic carbon content performed better for soil moisture prediction under diverse jute based cropping systems of humid tropical agro-ecosystem.

Key words: Pedo-transfer functions, Soil water retention, Jute agro-ecosystem, Lower Indo-Gangetic plains, India

Characterization of soil moisture dynamics is continuously increasing with increasing attention for environmental management. Movement of water through soil profile is a function of agricultural management practices, which are manifested through soil hydrological properties including water entry into the soil column following precipitation or irrigation; Infiltration, water movement through saturated soil; Saturated hydraulic conductivity and thereafter, water retention-release behaviour of the soil; Soil water function. Efficient management of limited water resources for sustainable crop production both under irrigated and rainfed conditions require a thorough understanding of the pertinent soil water dynamics, *i.e.* hydraulic properties, soil water retention characteristics and available water capacity of the soils. The time, cost and difficulty involved in on-site measurement of these soil properties and subsequently deriving the relationship between actual and potential soil moisture content of the selected sites remain a major constraint to the wider application of simulation models. Pedo-transfer function (PTF) describes functional relationships that transfer basic soil properties available from routine surveys into properties that are not available like soil water hydraulic properties (Bouma and van Lanen, 1987). These PTFs have proved to be excellent tools for

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predicting the hydraulic properties of soil (Saxton *et al*., 1986; Singh, 1989; Gupta, 1992).

Cultivation of jute in India particularly in northern parts of the state of West Bengal, one of the major quality jute fibre producing region of the country, is facing problems for the last few years because of erratic rainfall pattern due to the prevalent climate change phenomena. Therefore, a clear understanding of the hydraulic functions of such soils may help in formulating improved water management strategies for jute, and enable us in improving the quality fibre production scenario of jute crop in the region, thereby ensuring increased domestic availability of quality jute fibre in the country. Although there is considerable amount of data on soil organic carbon, bulk density, soil texture etc., very little information is available on soil water dynamics of the jute growing soils of this region. In view of the above, the present study was undertaken to make use of more readily available soil data of jute growing areas of lower Indo-Gangetic plains *i.e.*, Cooch Behar and Jalpaiguri districts and to relate these to the soil water dynamics/retention-release pattern of these soil through pedo-transfer functions.

Materials and Method

Study area

The study was conducted under ICAR-All India Network Project on Jute & Allied Fibres (AINPJAF) programme on the soils of jute growing blocks of Jalpaiguri and Cooch Behar districts of West Bengal (Fig. 1). Jalpaiguri district is situated between 26°16′ and 27°03′ North latitudes and 88°04′ and 89°53′ East longitudes with an altitude 89m from msl. As this district is located on the foothill of the Himalayas, these areas receive a high amount of rainfall throughout the year. The average annual rainfall is approximately 3400 mm. In summer, the temperature varies from a minimum of 20-22°C to a maximum of 28-34°C. Cooch Behar district is located in between 25°57′ and 26°36′ North Latitude and 88°47′ and 89°54′ East Longitude. Cooch Behar is essentially a flat basin with a slight south-eastern slope along which the main rivers of the district flow. Most of the high lands lie in Sitalkuchi area and most of the low lands lie in Dinhata area. The soil is alluvial of very recent formation. A highly humid atmosphere and abundant rains characterise the climate of this

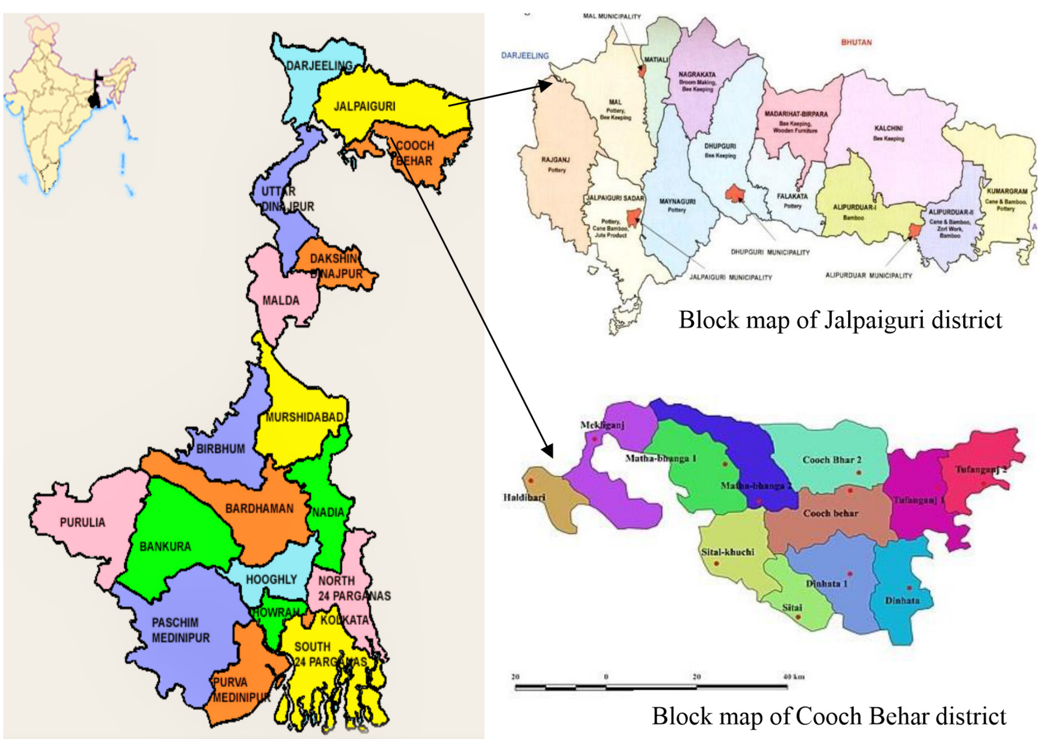

Fig. 1. Physiographic location of the experimental areas

district, with the temperature being seldom excessive. The period from June to beginning of October is south-west monsoon season. The rainfall generally increases from the south-west to the north-east. About 70% of the annual rainfall is received during the southwest monsoon season, June being the rainiest month. On an average there are about 102 rainy days with records of more than 400 mm rainfall in 24 hours.

Soil Sampling and Analysis

Soil samples were collected from surface (0-0.15 m) and sub-surface (0.15-0.30 and 0.30-0.45 m) depth of 91 data points of the four blocks of Jalpaiguri district namely Maynaguri, Dhupguri, Kalchini and Falakata and five blocks of Cooch Behar district namely Sitai, Dinhata, Mathbhanga, Sitalkuchi and Tufanganj during the period 2017-2020. Soil samples were air dried and passed through a sieve with 2 mm size opening and thereafter were analyzed for determination of pH using 1:2.5 (soil: water) soil water suspension by pH meter, particle size distribution by international pipette method (Jackson, 1973) and organic carbon content by wet oxidation method (Walkley and Black, 1934). Bulk density (BD) values of the soil samples were determined after packing soil samples into 5 cm diameter and 10 cm height of cylinders with proper compaction effect so as to get the representative samples like in field condition. Soil water retention characteristics (ψ - θ) were determined by using pressure plate apparatus at 5 points (Richards and Fireman, 1943).

Soil moisture retention capacity was mainly defined by two extreme limits *i.e.* moisture contents at field capacity (θ_{FC}) and permanent wilting point (θ_{PWP}). Moisture retained at field capacity helps in deciding the amount of irrigation water to be applied for recharging the rooting depth to its capacity, and also ensuring negligible drainage loss and thus enhancing the applied water use efficiency. Normally, it is defined as the moisture content at 0.03 MPa suction. The wilting point is generally referred to as the moisture retained at soil water suction (1.5 MPa) in which the water availability to roots for its uptake ceases. Multivariate simple linear regression technique was used to develop the PTF in the present study. The different test-PTFs were evaluated for moisture content at field capacity (θ_{FC}) *i.e.*, at 0.03 MPa and permanent wilting point (θ_{PWP}) *i.e.*, at 1.5 MPa using the readily available soil data set under present study and the results were compared with their corresponding actual values.

Tomasella and Hodnett (1998): θ_v *(cm^{-3} cm^{-3}) = a + b (% silt) + c (% clay)* …(i)

Rao *et al.* (1988): θ_v (%) = *a + b (% sand) + c (% clay)* …(ii)

Bhavanarayana *et al.* (1986): θ_g *(%) = a + b (% sand)* …(iii)

Aina and Periaswamy (1985): θ_g *(%) = a + b (% clay) + c (% silt)* …(iv)

Rawls *et al.* (1982): θ_v *(cm^{-3} cm^{-3}) = a + b (% sand) + c (% clay) + d (% organic matter)* …(v)

where,

θ_v =Volumetric moisture content, θ_g = gravimetric moisture content

a, b, c and d are model constants/ parameters

\# Constant/ Parameter non-significant at specified matric potential

Mean error (ME), absolute mean relative error (AMRE) and root mean square prediction difference (RMSPD) were used to evaluate the predictive potential and general applicability of the test-PTFs.

$$ME = {}^{1}/{}_{n}\sum_{i=1}^{n}(y_i - \bar{y}_i)$$

$$AMRE = {}^{1}/{}_{n}\sum_{i-1}^{n}\frac{y_i - \bar{y}_i}{y_i}$$

$$RMSPD = \sqrt{{}^{1}/{}_{n}\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

Where, y_i = observed θ_{FC}, θ_{PWP} ith observation point, $\bar{y}_i$ = predicted θ_{FC}, θ_{PWP} ith observation point and n = total number of observations

Results and Discussion

Physico-chemical Properties of Soils

The soils are mostly acidic in reaction and silt loam in texture. However, there is significant

Table 1. The soil physico-chemical characteristics of Jute growing areas of Jalpaiguri and Cooch Behar districts, West Bengal

Study area (Block/District)	pH (1:2.5)	SOC (%)	Particle size distribution			BD (Mg m^{-3})	Moisture content (q) at	
			Sand (%)	Silt (%)	Clay (%)		FC (0.03 MPa)	PWP (1.5 MPa)
Jalpaiguri District								
Maynaguri	4.94-5.87 (5.31)	0.41-0.56 (0.47)	43.7-53.9 (49.0)	28.4-37.9 (34.2)	13.6-18.6 (16.6)	1.12-1.46 (1.27)	35.50-40.74 (37.64)	18.85-23.54 (20.43)
Dhupguri	5.04-5.71 (5.30)	0.43-0.63 (0.51)	42.5-51.3 (46.1)	34.1-40.1 (36.5)	14.3-19.4 (17.3)	1.05-1.28 (1.14)	37.08-41.90 (39.11)	17.60-22.67 (19.74)
Kalchini	4.72-5.78 (5.27)	0.61-0.83 (0.71)	46.3-51.4 (49.2)	31.3-37.9 (35.4)	14.3-19.4 (18.1)	0.95-1.08 (1.01)	39.52-43.11 (41.37)	15.90-19.66 (17.35)
Falakata	4.09-4.98 (4.59)	0.49-0.84 (0.67)	43.2-51.3 (46.1)	34.3-37.8 (36.8)	14.4-19.4 (17.1)	0.98-1.17 (1.08)	38.86-42.30 (40.52)	16.07-19.11 (17.05)
Cooch Behar District								
Sitai	5.09-5.79 (5.52)	0.65-0.86 (0.76)	47.9-51.9 (49.3)	33.5-35.0 (34.5)	14.6-17.0 (16.2)	0.89-1.02 (0.94)	38.60-42.59 (40.51)	13.06-17.44 (15.09)
Dinhata	4.89-6.86 (5.96)	0.41-0.83 (0.73)	43.9-48.3 (46.0)	33.2-37.8 (36.1)	16.5-19.4 (17.9)	0.92-1.05 (0.99)	38.11-42.44 (40.15)	14.80-18.76 (16.11)
Mathabhanga	4.99-6.98 (5.75)	0.43-0.84 (0.67)	40.5-43.8 (41.9)	34.8-38.9 (37.0)	19.5-24.6 (21.1)	1.00-1.16 (1.07)	35.77-39.85 (37.03)	15.22-18.60 (16.33)
Sitalkuchi	4.04-4.13 (4.08)	0.59-0.78 (0.66)	41.3-46.9 (43.5)	34.8-44.2 (43.4)	13.5-28.1 (20.0)	0.99-1.19 (1.10)	34.25-38.70 (36.08)	15.98-17.53 (16.18)
Tufanganj	4.14-4.82 (4.42)	0.55-0.79 (0.67)	44.9-52.6 (48.1)	34.8-38.6 (36.4)	13.5-19.1 (15.6)	0.98-1.20 (1.12)	37.13-41.56 (38.84)	16.11-19.84 (17.52)

variation in soil pH (Table 1) ranging from 4.04 to 6.98 in Cooch Behar district as compared to Jalpaiguri district (range: 4.09 - 5.71). The organic carbon content of the soils varied significantly among the districts. In Jalpaiguri district, Kalchini block had the highest organic carbon content (0.71%) and Maynaguri block had lowest SOC (0.47%). However, the mean SOC of Cooch Behar district had marginal variation among the various blocks ranging in between 0.66 to 0.76%. These fluctuations may be attributed to the topographical changes as well as to variation in precipitation and cropping systems. There is very little variation in soil bulk density (range: 0.94 to 1.14 Mg m^{-3}) among the various blocks of both the two districts except in Maynaguri block which is having mean soil bulk density of 1.27 Mg m^{-3}. Soil water retention characteristics (ψ - θ relationships) revealed that moderate to high water retention at 0.03 MPa among the various blocks of Jalpaiguri and Cooch Behar districts (range: 36.08 – 41.37%). Similarly at 1.5 MPa, the soil water retention fluctuated in between 15.09 to 20.43% among the various blocks of Jalpaiguri and Cooch Behar districts.

Development of Pedo-transfer Functions

Multivariate simple linear pedo-transfer functions were developed to predict the soil moisture retention at FC, PWP and for available water capacity (Table 2) taking into consideration the basic soil properties of total 91 data points for four consecutive years (2017-2020). The soil property like organic carbon content plays a vital role in influencing the soil water retention by reducing the bulk density. It is also evident from the correlation coefficient values (Table 3). Data showed that available water was highly correlated with organic carbon content (at 5% level) and bulk density (at 1% level). Bulk density was also observed to be an important factor for prediction of soil moisture at different matric potentials as it exhibited high correlation coefficient values (0.79** and 0.50**, respectively at FC and PWP). The silt and clay content also had an important contribution for soil moisture retention as they yielded significant coefficient values at 1 and 5% level, respectively. The result is in conformity with the findings of Santra and Das (2008).

Table 2. Pedo-transfer functions (PTFs) for field capacity (ψ_{FC}), permanent wilting point (ψ_{PWP}) and available water for the experimental soils

PTF 1

y = Moisture content (% vol.) at 0.03 MPa

$y = -43.02 + 0.63x_1 + 0.05\ x_2 + 56.14\ x_3 + 0.18\ x_4\ (R^2 = 0.79)$

PTF 2

y = Moisture content (% vol.) at 1.5 MPa

$y = -58.92 + 0.52x_1 - 0.20\ x_2 + 44.35\ x_3 + 0.14\ x_4\ (R^2 = 0.68)$

PTF 3

y = Available moisture content (% vol.)

$y = 23.16 - 0.22x_1 + 0.35\ x_2 - 3.53\ x_3 + 0.04\ x_4\ (R^2 = 0.88)$

where, x_1 : Clay (%), x_2 : Organic carbon (%), x_3: Bulk density (Mg m^{-3}), x_4 : Silt (%)

Table 3. Correlation coefficient between different soil properties of the experimental soils

Soil properties	Sand	Silt	Clay	SOC	Bulk density	θ at 0.03 MPa	θ at 1.5 MPa	Available water
Sand	1							
Silt	-0.717**	1						
Clay	-0.669**	-0.123	1					
SOC	-0.488**	0.471**	-0.546*	1				
Bulk density	-0.540**	0.595**	0.056	0.719**	1			
θ at 0.03 MPa	0.211	-0.141	0.374**	0.436**	0.791**	1		
θ at 1.5 MPa	-0.109	0.169	0.211	0.258*	0.503**	0.499**	1	
Available water	-0.205	0.383**	0.289*	-0.283*	0.749**	0.715**	-0.221	1

*Significant at 5% level; **Significant at 1% level

Evaluation of Performance of Pedo-transfer Functions for Soil Moisture Retention Capacity

The different PTFs were evaluated for moisture contents at ψ_{FC} and ψ_{PWP} and the algorithm and the parameter equation and constant values have been presented in Table 4. The soil water retention characteristics *i.e.* moisture content at ψ_{FC} and ψ_{PWP} were estimated using the PTFs and compared with the actual values. The validation results of different PTFs are presented in Table 5. The results revealed that Tomasella and Hoddnett method and equation under present study for estimation of moisture content at field capacity (0.03 MPa) was associated with positive ME value (0.63 and 0.48, respectively), which indicated underestimation of actual values, while the other methods *i.e.*, Rawls *et al*. (1982); Aina and Periaswamy (1985); Bhavanarayana *et al*. (1986); and Rao *et al.* (1988) methods, associated with negative ME values (-2.43 to -5.08), overestimated the θ_{FC} of the soils in the evaluation data set. Among the various models tested, equation under present study and Tomasella and Hoddnett model out of all PTFs, were associated with ME value (0.48 and 0.66) near zero. In addition to ME, application of AMRE and RMSPD statistical measures (Table 5) confirmed the performance of the PTFs. It is noticeable that the PTFs given by Aina and Periaswamy (1985); Bhavanarayana *et al*. (1986); and Rao *et al.* (1988) were associated with higher AMRE (0.69, 0.57 and 0.45, respectively) and RMSPD (9.71, 8.63 and 8.50, respectively) values, which confirms the poor performance of these models under present set of conditions. The AMRE (0.23) and RMSPD (7.06) values showed that the models given by Tomasella and Hoddnett model appeared to be better and comparable followed by Rawls *et al.* model (0.35 and 7.87, respectively) for soil moisture estimation at field capacity (0.03 MPa).

Table 4. Different pedo-transfer functions (PTFs) and the constant values for evaluation of soil moisture estimations

PTFs	Matric potential (MPa)	Algorithms/Parameter equation/Constants			
Tomasella and Hodnett (1998)		θ_v (cm^{-3} cm^{-3}) = a + b (% silt) + c (% clay)			
		a	b	c	
	0.03	5.239	0.216	0.283	
	1.5	1.580	0.174	0.019	
Rao *et al*. (1988)		θ_v (%) = a + b (% sand) + c (% clay)			
		a	b	c	
	0.03	26.813	-0.211	0.017	
	1.5	35.422	-0.154	0.190	
Bhavanarayana *et al.* (1986)		θ_g (%) = a + b (% sand)			
		a	b		
	0.03	23.743	-0.258		
	1.5	25.345	-0.094		
Aina and Periaswamy (1985)		θ_g (%) = a + b (% clay) + c (% silt)			
		a	b	c	
	0.03	44.738	-0.263	0.226	
	1.5	18.337	0.028	#	
Rawls *et al.* (1982)		θ_v (cm^{-3} cm^{-3}) = a + b (% sand) + c (% clay) + d (% organic matter)			
		a	b	c	d
	0.03	0.2546	-0.0023	0.0017	0.0045
	1.5	0.3269	#	0.0019	0.0017

where, θ_v =Volumetric moisture content, θ_g = gravimetric moisture content

a, b, c and d are model constants/ parameters

Constant/ Parameter non-significant at specified matric potential

Table 5. Soil moisture prediction potential of test-PTFs at field capacity (ψ_{FC}) and permanent wilting point (ψ_{PWP}) matric potentials

Test PTFs	Soil moisture prediction at					
	Field capacity (FC)			Permanent wilting point (PWP)		
	ME* (% vol.)	AMRE*	RMSPD * (% vol.)	ME* (% vol.)	AMRE*	RMSPD * (% vol.)
Tomsella and Hodnett (1998)	0.63	0.23	7.06	-1.01	0.49	3.54
Rao *et al.* (1988)	-4.22	0.45	8.50	-1.65	0.78	5.56
Bhavanarayana *et al.* (1986)	-4.75	0.57	8.63	-5.76	1.32	7.44
Aina and Periaswamy (1985)	-5.08	0.69	9.71	-1.29	0.68	4.75
Rawls *et al.* (1982)	-2.43	0.35	7.87	-3.66	1.09	6.73
Under present study	0.48	0.09	1.74	-0.11	0.13	2.33

However, the equation under present study was best for moisture content at field capacity as shown in the AMRE (0.09) and RMSPD (1.74) values. At wilting point (1.5 MPa matric potential), all PTFs showed over-prediction than the actual values, as all were associated with negative ME values (-5.76 to -0.11). Tomasella and Hoddnett, Aina and Periaswamy, Rao methods were found to be associated with low to moderate bias (*i.e.* ME: -1.01 to -1.65) while Rawls and Bhavanarayana models were found to be associated with very high biasness (*i.e.* ME: -3.66 and – 5.76, respectively). Application of AMRE and RMSPD statistical measures, in addition to ME, confirmed the poor performance of Rawls and Bhavanarayana model (AMRE: 1.09 and 1.32 and RMSPD: 6.73 and 7.44, respectively). Among other PTFs, Tomasella and Hoddnett's model was observed to be with the lowest AMRE (0.49) and RMSPD (3.54) values followed by Aina and Periaswamy model (AMRE: 0.68 and RMSPD: 4.75). However, the lowest biasness was observed under the models developed in present study (AMRE: 0.13 and RMSPD: 2.33). It has been observed that the accuracy of soil moisture prediction at ψ_{FC} was much lower as compared to that obtained at $\psi_{PWP.}$ This is because of the fact that soil moisture retention at higher matric potentials, is primarily controlled by soil structure while at lower matric potentials, it is mainly governed by soil texture (Brady, 1990).

While considering their overall applicability, it was observed that Rawls' model was not satisfactory although it is based on organic matter and clay content of the soil. It may be due to the fact that Rawls model was developed for temperate climate, which completely differs from the climatic condition of present study. Moreover, in tropical country like India, organic matter is quite low in most agricultural soils may not be representative for Rawls' model (Adhikary *et al.*, 2008). Aina and Periaswamy model was a function of both silt and clay contents at θ_{FC} while θ_{PWP} estimated through function of only clay content. As this method excluded the soil with high silt and low sand contents therefore this explained its very poor and reasonably good performance at ψ_{FC} and $\psi_{PWP,}$ respectively, on the evaluation data set soils. The other evaluated models *i.e.*, performance of Bhavanarayana and Rao methods was poor, because the soil of the evaluation data set were quite different from those on which these methods were developed. Tomasella and Hoddnett model gave much better result as compared to other PTFs. This may be ascribed to the effect of inclusion of silt fraction into the model, which plays a significant role in moisture retention. It is evident from the correlation coefficient values (Table 3). Although Tomasella and Hoddnett method covered the whole range of evaluation data set yet its performance was rated as only moderate, at both ψ_{FC} and ψ_{PWP} soil matric potential, primarily because it was developed for the forest soils with high organic matter contents (0- 99%). As the present study was conducted in the conditions with moderate organic carbon (0.47 - 0.73%) and clay content (15.6 to 21.1%), which is a typical soil characteristic of humid/ perhumid climate, the presently developed equations performed very well taking into consideration two primary factors *i.e.* organic carbon and bulk density.

Conclusions

It can be concluded from the present study that primary soil properties like clay and silt content, organic carbon and bulk density etc. should be always taken into consideration for development of pedo-transfer functions for predicting soil moisture retention capacity of soil under hilly eco-system. This result may provide the opportunity to develop PTFs for these areas where sufficient database on soil hydraulic properties are not available. However, Tomasella and Hoddnett's model were found to be satisfactory for estimation of soil moisture retention under diverse farming systems of humid tropical agro-ecosystem.

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