Agropedology, 2000, ***10****, 183-194*

Modelling pF curve of clay, clay loam and silt loam soils under different quality waters

S.K. Chaudhari and R.B. Somawanshi

Department of Agricultural Chemistry and Soil Science, Mahatma Phule Krishi Vidyapeeth, Rahuri 413 722, India

Abstract

Water retention curve of clay (Typic Haplusterts), clay loam (Vertic Haplustepts) and silt loam (Lithic Ustorthents) soils were modelled by six different approaches. A modified exponential form with log of suction (pF) as the dependent and relative water content (water content as a fraction of saturation water content) as the independent variable, predicted this relationship very satisfactorily under different water quality combinations in clay and clay loam soils with an average R^2 values of 96.6 and 98.9 per cent, respectively. An inverse polynomial form predicted this relationship very satisfactorily with an average R^2 value of 98.3 per cent in silt loam soil. Rise in sodium adsorption ratio under low electrolyte solutions declined the R^2 values of various models, however under high electrolyte solutions R^2 values remained almost constant.

Additional keywords : Water retention curve, sodium adsorption ratio, electrolyte solution.

Introduction

Retention, release and movement of water through soils basically decided by the water retention characteristic curve. Therefore, it has direct relevance to the crop production and successful soil and water management. Water quality affects the nature of soil-water characteristic curve to a great extent (Malik et al. 1992). In the recent past many workers used this property in estimating the unsaturated hydraulic conductivity (van Genuchten and Nielsen 1985; Hopmans and Overmars 1986). To describe the soil-water characteristic curve, researchers (van Genuchten 1980; Singh 1982; Singh *et al.* 1998) have proposed different types of relation, varying from empirical to semi-empirical and analytical in nature. For predictive purposes, it is also imperative that the model used should describe the retention curve over the entire range from saturation to dryness. In this study, the performance of six different models in clay, clay loam and silt loam soils was evaluated under different quality waters during 1997-98.

Materials and methods

The bulk soil samples were collected from upper 30 cm depth of the A or Ap horizon of clay (Typic Haplusterts), clay loam (Vertic Haplustepts) and silt loam (Lithic Ustorthents) soils from Post Graduate Institutes' research farm of Mahatma Phule Krishi Vidyapeeth, Rahuri. The basic physical and chemical properties of these soils are presented in table 1. Dry soil samples (<2 mm) were equilibrated with different quality waters consisting three levels of sodium adsorption ratio (SAR) viz. 5, 15 and 30 m $mol^{1/2}$ $L^{-1/2}$ and two levels of total electrolyte concentractions (TEC) viz. 5 and 50 meL^{-1}. Pure chloride salts of calcium, magnesium and sodium at Mg:Ca = 1:2 were used to prepare water quality combinations. Equilibrated soil samples packed at 1.3, 1.35 and 1.45 g cm^{-3} were used to determine the water retention characteristic of clay, clay loam and silt loam soils, respectively. At saturation, water retention was determined by using the keen boxes. In the low suction range of 1 to 5 kPa it was determined by using a sand box apparatus. Water retention at and above 10 kPa was determined by using a pressure plate apparatus as described by Bruce and Luxmoore (1986). Water retention characteristic of three soils under various quality waters were determined at 14 points i.e. 0, 1, 5, 10, 20, 33, 50, 70, 100, 300, 500, 700, 1000 and 1500 kPa suction in order. The pF was determined as the logarithm of the soil-water suction expressed in terms of cm of water column. The pF curve for three soils under selected water quality combinations are presented in figure 1.

Table 1. Physical and chemical properties of soils

Soil type	Sand	Silt	Clay	pH	EC	CaCO3	O.C.	CEC	ESP
	-------	%	-------		dS m^{-1}	(%)	g kg^{-1}	cmol (p+) kg^{-1}	
Clay	23.5	21.2	55.3	7.9	0.68	2.75	6.4	55.2	1.9
Clay loam	40.5	23.8	35.7	8.2	0.54	3.32	4.2	36.5	1.5
Silt loam	42.6	34.0	23.4	7.8	0.79	0.96	3.2	18.3	0.6

In order to describe the functional dependence of pF on the soil-water content, six different models were examined (Table 2). The magnitude of a, b, c and d (the coefficients) of models differ among equations. These coefficients were estimated by the least square technique.

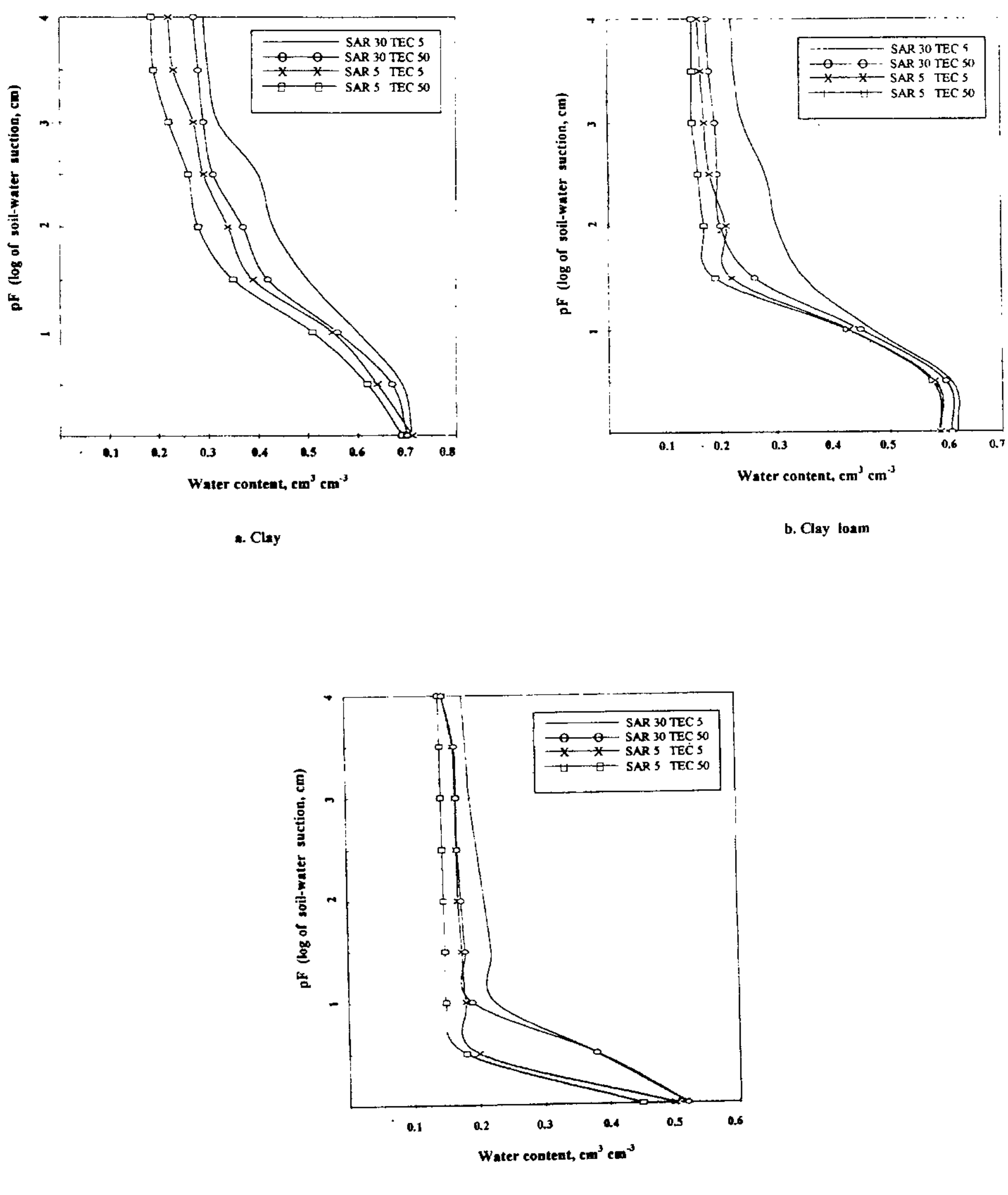


Fig. 1. pF curves of three soils under selected water quality combinations.

Table 2. Functional relationship for modelling pF curve

Model No.	Functional relationship	Reference
I	$pF = a + b\theta$	Ali *et al.* (1966)
II	$pF = a + b \log\theta$	Gardner *et al.* (1970)
III	$pF = a + b \log(\theta s - \theta) + c \log\theta$	Visser (1966)
IV	$pF = a^* + b \log(\theta/\theta s)$	Campbell (1974)
V	$pF = a + b\theta + c\theta^2 + d\theta^3$	Singh (1982)
VI	$pF = a + b\theta + c\theta^{-1}$	Singh (1989)

* air entry suction.

pF = log. of suction expressed in cm of water column.

Results and discussion

The performance of various models in describing the soil-water characteristic curve under each quality water over the entire range between 0 and 1500 kPa was expressed in terms of R^2 values and the coefficients obtained by the least square technique have been presented in table 3. The results showed that the R^2 values ranged between 89.3 and 97.3, 88.8 and 99.2 and 80.7 and 99.0 per cent in clay, clay loam and silt loam soils, respectively, under different quality waters. The best fit was obtained by model IV in clay and clay loam soils and model VI in silt loam soil.

The observed and calculated values obtained by six models were also compared by working out the slope and intercept values irrespective of water quality for three soils. The distribution of the observed and calculated values around the line of agreement (slope unity and intercept zero) has been illustrated for clay, clay loam and silt loam soils in figure 2. Model IV in clay and clay loam, and model VI in silt loam soils had slope nearly unity and near zero intercept with extremely high correlation coefficient between the observed and fitted values indicating almost perfect fit in these soils. Model III also had low intercept values (0.08, 0.08 and 0.08) and slope close to unity (0.97, 0.98 and 0.97) with r-values of 0.98, 0.98 and 0.98 for clay, clay loam and silt loam soils, respectively. The other models followed the trend indicated in table 4.

Table 3. Least square coefficients of six models under different SAR (m mol $^{1/2}$ $L^{-1/2}$) and TEC (me L^{-1}) levels.

a. Clay soil

SAR	TEC	a	b	c	d	R^2	a	b	c	d	R^2
			Model I						**Model IV**		
5	5	5.494	−7.1618	--	--	97.26	0.89	−7.89	--	--	97.35
	50	5.344	−6.9833	--	--	95.92	0.79	−8.00	--	--	97.25
15	5	6.069	−7.6984	--	--	96.81	0.92	−7.46	--	--	95.45
	50	5.744	−7.4434	--	--	96.60	0.87	−7.76	--	--	96.85
30	5	6.418	−7.7385	--	--	94.56	0.96	−7.32	--	--	95.78
	50	5.99	−7.329	--	--	95.68	0.90	−7.57	--	--	96.98
			Model II						**Model V**		
5	5	−0.2609	−2.9813	--	--	93.88	15.78	-6.31×10^{-1}	3.83×10^{-3}	-6.25×10^{-5}	97.35
	50	−0.0869	−2.746	--	--	93.80	15.25	-5.46×10	2.72×10^{-3}	-6.7×10^{-5}	97.25
15	5	5.29×10^{-3}	−3.0408	--	--	92.48	16.22	-8.21×10	4.23×10^{-3}	-4.1×10^{-5}	95.45
	50	0.0229	−2.7715	--	--	92.33	14.21	-3.74×10	2.32×10^{-3}	-2.7×10^{-5}	96.85
30	5	0.2091	−3.1801	--	--	89.33	16.59	-7.23×10	3.29×10^{-3}	-4.6×10^{-5}	95.78
	50	0.255	−2.8154	--	--	90.54	15.19	-6.39×10	2.27×10^{-3}	-6.23×10^{-5}	96.88
			Model III						**Model VI**		
5	5	9.85	0.87	−5.11	--	96.21	5.13	−0.060	18.39	--	93.27
	50	9.35	0.83	−5.14	--	96.25	5.06	−0.063	18.52	--	92.46
15	5	10.02	0.91	−5.21	--	96.45	5.21	−0.037	17.89	--	92.26
	50	9.83	0.89	−4.94	--	96.33	5.12	−0.041	18.24	--	91.46
30	5	10.45	0.94	−5.31	--	.94.56	5.32	−0.068	19.96	--	92.86
	50	10.05	0.87	−5.24	--	96.07	5.23	−0.074	19.27	--	91.86

b. Clay loam soil

SAR	TEC	a	b	c	d	R^2	a	b	c	d	R^2
		Model I					**Model IV**				
5	5	6.628	–10.6744	–	–	93.09	1.41	–2.67	–	–	98.45
	50	5.511	–8.5155	–	–	98.01	1.33	–2.71	–	–	99.03
15	5	6.230	–9.4011	–	–	96.30	1.46	–2.54	–	–	98.86
	50	5.901	–9.1744	–	–	97.04	1.49	–2.26	–	–	98.91
30	5	6.29	–9.0003	–	–	95.20	1.49	–2.26	–	–	98.91
	50	5.822	–8.468	–	–	96.19	1.36	–2.63	–	–	99.23
		Model II					**Model V**				
5	5	–1.2623	–2.8205	–	–	88.82	13.48	-6.85×10^{-1}	6.32×10^{-2}	-3.27×10^{-5}	96.25
	50	–0.4815	–2.6705	–	–	95.05	12.65	-4.27×10^{-1}	7.21×10^{-2}	-1.29×10^{-6}	97.32
15	5	–0.5346	–3.1262	–	–	91.41	14.21	-2.89×10^{-2}	6.19×10^{-2}	-4.68×10^{-4}	96.83
	50	–0.5446	–2.9010	–	–	92.81	13.50	-2.21×10^{-2}	9.36×10^{-1}	-6.38×10^{-4}	97.37
30	5	–0.4593	–3.2542	–	–	97.92	14.70	-8.92×10^{-2}	1.96×10^{-2}	-6.88×10^{-4}	97.58
	50	–0.2973	–2.8073	–	–	92.42	13.92	-6.28×10^{-1}	2.69×10^{-2}	-9.37×10^{-4}	97.98
		Model III					**Model VI**				
5	5	7.79	1.21	–2.13	–	97.24	4.26	–0.049	8.46	–	92.16
	50	7.47	1.17	–2.52	–	98.09	4.29	–0.053	9.21	–	92.16
15	5	8.46	1.67	–2.32	–	96.45	4.37	–0.051	8.68	–	92.83
	50	8.03	1.59	–2.47	–	97.99	4.16	–0.048	9.63	–	89.23
30	5	8.91	1.83	–1.69	–	96.43	4.33	–0.054	8.89	–	90.03
	50	8.31	1.69	–2.52	–	97.45	3.69	–0.062	7.98	–	87.24

contd.....

c. Silt loam soil

SAR	TEC	a	b	c	d	R2	a	b	c	d	R2
		Model I					**Model IV**				
5	5	6.038	−12.0562	–	–	94.52	1.43	−3.63	–	–	82.49
	50	5.372	−10.9637	–	–	96.48	1.57	−3.14	–	–	93.21
15	5	6.244	−11.4760	–	–	91.97	1.32	−2.69	–	–	87.40
	50	5.818	−11.3002	–	–	92.01	1.29	−2.73	–	–	84.94
30	5	6.409	−11.6050	–	–	87.9	1.37	−3.29	–	–	82.42
	50	5.715	−10.2700	–	–	89.00	1.43	−2.94	–	–	83.24
		Model II					**Model V**				
5	5	−0.8988	−2.6729	–	–	86.39	10.62	-5.86×10^{-2}	5.36×10^{-3}	-2.9×10^{-4}	82.32
	50	−0.4902	−2.096	–	–	89.39	10.15	-2.43×10^{-1}	5.59×10^{-3}	-2.8×10^{-4}	82.84
15	5	−0.6472	−2.6649	–	–	83.86	10.91	-4.27×10^{-2}	6.28×10^{-3}	-3.7×10^{-5}	82.13
	50	−0.2635	−2.1607	–	–	81.89	9.23	-5.26×10^{-2}	3.76×10^{-3}	-2.5×10^{-5}	82.64
30	5	−0.6287	−2.7929	–	–	80.73	9.50	-7.28×10^{-2}	1.69×10^{-3}	-2.6×10^{-5}	82.78
	50	−0.1278	−2.1605	–	–	81.12	9.14	-5.16×10^{-2}	2.97×10^{-3}	-1.4×10^{-5}	83.03
		Model III					**Model VI**				
5	5	5.09	1.21	−3.5	–	93.36	3.92	−0.070	2.26	–	97.52
	50	4.93	0.98	−2.5	–	93.66	3.84	−0.062	2.46	–	98.63
15	5	5.57	1.52	−2.93	–	93.29	3.98	−0.080	1.96	–	98.74
	50	5.13	1.29	−2.47	–	94.34	3.89	−0.071	2.32	–	98.64
30	5	5.96	1.73	−3.06	–	94.24	4.09	−0.062	2.23	–	97.59
	50	5.31	1.52	−2.91	–	95.38	4.01	−0.083	2.45	–	98.99

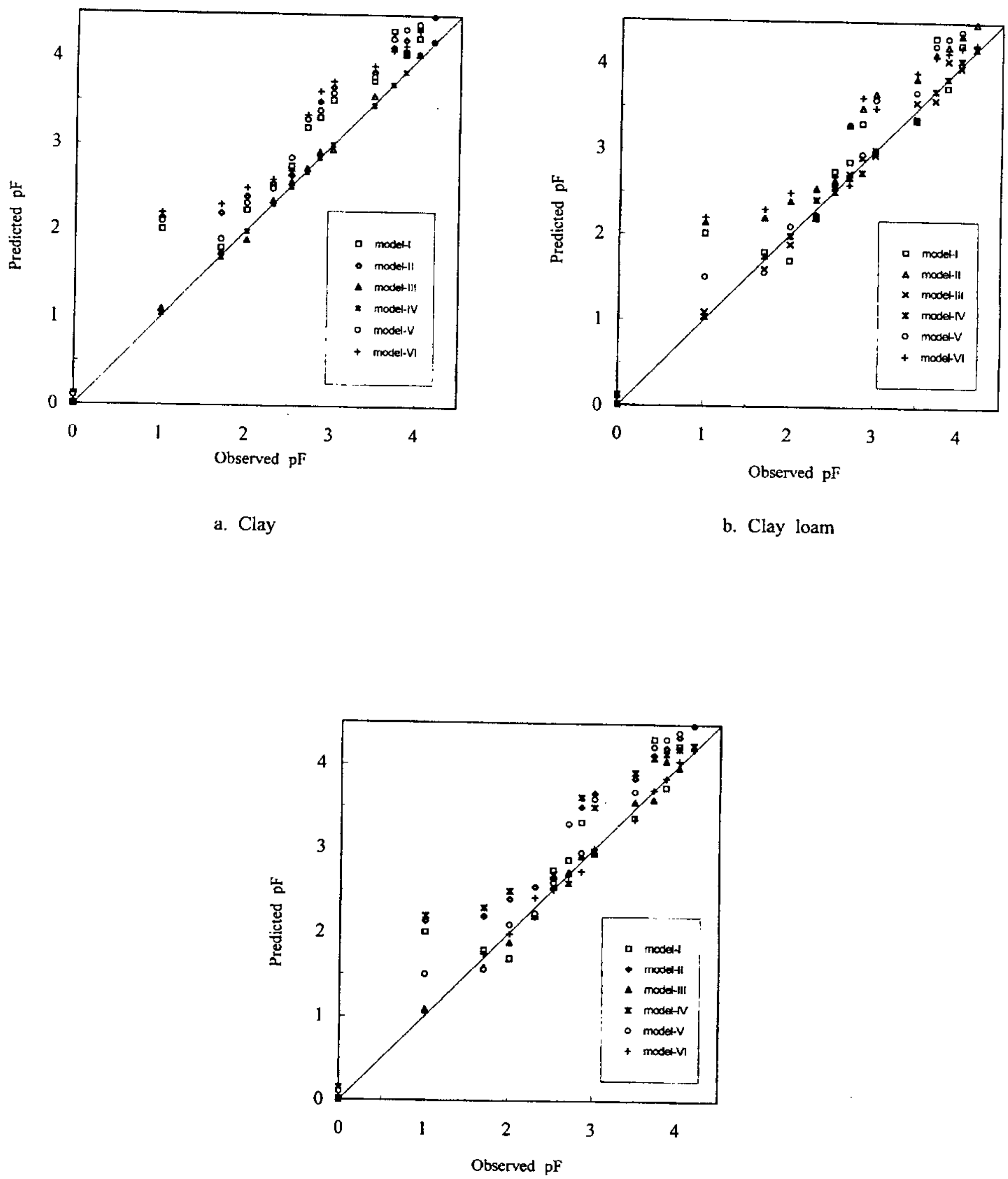
The exponential form of soil-water suction and soil-water content relationship (model I) was suggested by Ali *et al.* (1966) to be applicable for suctions above 1 atmosphere. Bache *et al.* (1981) observed that 'b' value is inversely related to the available water in the soil. In the present study this model performed better than models II and V.

Campbell (1974) and Ghosh (1976) used pF = a+b log θ in a modified form. A new term 'Ψe' defined as the 'air entry suction' was introduced to replace 'a' and the effective saturation i.e. the ratio of θ to θs, instead of θ was taken as the independent variable. This modified form represented by model IV was found to be the most effective in describing the relationship between pF and water content (Tables 3, 4 and Fig. 2) in clay and clay loam soils as compared to other models. In silt loam soil, however, the inverse polynomial form (model VI) was found to be the best in describing the pF curve under different water quality combinations.

Table 4. Comparison of observed and predicted values obtained by different models in three soils

Parameters	Model No.					
	I	II	III	IV	V	VI
			Clay			
Intercept	0.1699	0.2234	0.0827	0.0326	0.1727	0.2354
Slope	0.9420	0.9219	0.9714	0.9898	0.9399	0.9154
r-value	0.9704	0.9616	0.9875	0.9993	0.9697	0.9608
			Clay loam			
Intercept	0.2316	0.4321	0.0806	0.0024	0.0921	0.4371
Slope	0.9213	0.8927	0.9821	0.9899	0.9240	0.8889
r-value	0.9632	0.9187	0.9882	0.9988	0.9833	0.9203
			Silt loam			
Intercept	0.1419	0.2329	0.0812	0.2296	0.2137	0.0004
Slope	0.9523	0.9826	0.9702	0.9736	0.9029	0.9994
r-value	0.9738	0.9587	0.9875	0.9496	0.9645	0.9998

The polynomial form of degree three (Singh 1982) represented by model V had slope values of 0.94, 0.92 and 0.93, with intercept values of 0.97, 0.98 and 0.96 in clay, clay loam and silt loam soils, respectively.



a. Clay

b. Clay loam

c. Silt loam

Fig. 2. Observed and predicted (using various models) pF values at different soil-moisture contents for different soil textures.

Under low electrolyte solutions (TEC 5 meL^{-1}), increase in SAR from 5 to 30 m $mol^{1/2}$ $L^{-1/2}$ decreased R^2 values of all models in clay and most models in clay loam soil. However, such decrease was marginal in clay loam soil. Negligible effects of low electrolyte solutions was noticed on the R2 values of six models in silt loam soil. Under high electrolyte solutions (TEC 50 meL^{-1}), an increase in SAR from 5 to 30 m $mol^{1/2}$ $L^{-1/2}$ had no marked effect on the R^2 values of different models in clay soil except model II, where R^2 value declined. In clay loam soil, decline in the R^2 values of model I, II, III and VI was observed, however, R^2 values of model IV and V remained almost constant. In silt loam soil, rise in SAR under high electrolyte solutions resulted into decline in R^2 values of model I and II, and increase in R^2 values of model III, however, R^2 values of other models remained constant.

Effects of water quality on the predictability of different models did not show any definite trend, however, these can be generalized as i) rise in SAR at low electrolyte concentrations declined the R^2 values and such decline was higher in clay as compared to clay loam and silt loam soils, and ii) rise in SAR at high electrolyte concentrations did not show marked effects on the R^2 values.

Increase in SAR of water resulted into increased water retention due to soil dispersion. Such increase is more in clay soil than other two soils. Under low electrolyte solutions, decrease in drainable water (water retained between 0 and 33 kPa) and increase in available water (water retained between 33 and 1500 kPa) was observed due to rise in SAR. In all the soils, increase in available water was observed at the cost of decrease in drainable water. Effects of water quality were more in clay soil due to its higher clay content as compared to other two soils. Increase in SAR under high electrolyte waters could not bring marked changes in water retention of different soils, because high electrolyte concentration prevents the soil dispersion due to contraction of diffuse double layer (Chaudhari 1998) and hence the R^2 values remained almost constant with a few exceptions.

On the basis of six models tested for modelling pF curve, it was concluded that the model IV with pF (log of suction, cm) as dependent and $\theta/\theta s$ (water content as the fraction of saturation water content) as independent variable in clay and clay loam soils and inverse polynomial model in silt loam soil were the relationships which could be used very satisfactorily to describe the pF curve over the entire range of soil-water suction.

References

Ali, M.H., Chatterjee, R.K., and Biswas, T.D. (1966). Soil moisture tension relationship of some Indian soils. *Journal of the Indian Society of Soil Science* **14,** 51-62.

Bache, B.W., Frost, C.A., and Inkson, R.H.E. (1981). Moisture release characteristic and porosity of twelve Scottish soil series and their variability. *Journal of Soil Science* **32,** 505-520.

Bruce, R.R., and Luxmoore, R.J. (1986). Water retention : Field methods. In 'Methods of Soil Analysis' Part I, (Ed. A. Klute) (Agronomy Monograph. No. **9**) pp.663-686.

Campbell, G.S. (1974). A simple method for determining unsaturated conductivity from moisture retention data. *Soil Science* **117,** 311-314.

Chaudhari, S.K. (1998). Effect of water quality on hydraulic properties and predictability of exchangeable sodium percentage by mechanistic and layer models in three texturally different soils. Ph.D. thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri.

Gardner, W.R., Hillel, D., and Benyamini, Y. (1970). Post-irrigation movement of soil water. I. Redistribution. *Water Resources Research* **6,** 851-861.

Ghosh, R.K. (1976). Models of the soil moisture characteristic. *Journal of the Indian Society of Soil Science* **24,** 353-355.

Hopmans, J.W., and Overmars, B. (1986). Presentation and application of an analytical model to describe soil hydraulic properties. *Journal of Hydrology* **87,** 135-143.

Malik, M., Mustafa, M.A., and Letey, J. (1992). Effect of mixed Na-Ca solutions on swelling, dispersion and transient water flow in unsaturated montmorillonitic soils. *Geoderma* **52,** 17-28.

Singh, A.K. (1982). Evaluation of soil water content suction relationship. *Transactions of the 12th International Congress on Soil Science* **6,** 1.

Singh, A.K. (1989). Modelling pF curve of soils. *Journal of the Indian Society of Soil Science* **37,** 216-222.

Singh, J.P., Rakesh, A.P., Mishra, V.K., and Sinha, B.K. (1998). Use of various equations for modelling pF curve of soils of Jian, Muzaffarpur in Bihar. *Agropedology* **8,** 10-14.

van Genuchten, M.Th. (1980). A closed form equation for predicting the hydraulic conductivity of unsaturated soils. *Soil Science Society of America Journal* **44,** 892-898.

van Genuchten, M. Th., and Nielsen, D.R. (1985). On describing and predicting the hydraulic properties of unsaturated soils. *Annals of Geophysics* **3,** 615-628.

Visser, W.C. (1966). Progress in the knowledge about the effect of soil moisture content on plant production. Technical Bulletin No. 45, (Institute for Land and Water Management : Wageningen.)

(Received : April, 1999; Accepted : September, 2000)