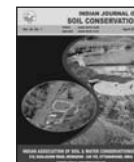




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### Statistical assessment of soil-water characteristic models

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#### ABSTRACT

A statistical assessment of curve fitting to soil water retention curve has been carried out for two different types of soils viz., Kharagpur sandy loam soil (four layers) and Black clay soil of Akola. The closed form equation describing soil water retention function of van Genuchten [VG (m, n) and VG (n)] and Brooks-Corey (BC) was fitted using RETc software and detailed statistical analysis was carried out to compare their performance. Results revealed that all the three models were found to perform reasonably well. The statistical analysis performed to discriminate the models such as  $R^2$ , AIC, t-value and RSS had showed a little difference among the models used for comparison. However, considering the relative ease at which the computation of hydraulic properties can be performed and the practical situation that can be accommodated, VG(n) is the best model among all the three models. This represents a simple closed form equation that can be derived to express the hydraulic conductivity function as compared to VG (m, n).

#### 1. INTRODUCTION

The unsaturated soil hydraulic functions involving the soil water retention curve (SWRC) and the hydraulic conductivity provide useful integrated indices of soil quality. Several continuously differentiable (smooth) equations have been proposed to improve the description of soil water retention characteristic. Most of these functions are mathematically too complicated to be easily incorporated into predictive pore-size distribution models for the hydraulic conductivity, or lack a simple inverse relationship which makes them less attractive for many soil water studies and hence often a weak link in modeling efforts. Popular expressions for this retention relationship,  $\theta$  ( $\Psi$ ) include the Brooks and Corey (1966) and van Genuchten (1980) equations.

The Brooks and Corey (1966) equation has been shown to produce fairly accurate results for many coarse-textured soils characterized by relatively narrow pore or particle-size distributions (large  $\lambda$ -values). Results have generally been less accurate for fine-textured and undisturbed, structured

field soils because of the absence of a well-defined air-entry value for these soils.

Van Genuchten, (1980) equation with variables 'm' and 'n' gives an excellent fit to observed retention data for most soils (van Genuchten *et al.*, 1992). The only exceptions are certain structured or aggregated soils characterized by very distinct bimodal pore-size distributions. Of the three cases with restricted empirical constant (m) values,  $m=1-1/n$  seems to perform best for many but not all soils. Although the variables 'm' and 'n' always produce superior results, its use is not necessarily recommended when only a limited range of retention data (usually in the wet range) is available.

RETc (REtention Curve) program (van Genuchten *et al.*, 1991) is used to predict the hydraulic conductivity from observed soil water retention data assuming that an estimate of the saturated hydraulic conductivity is available.

Therefore, an attempt has been made to investigate the performance of RETc along with fitting VG and BC equations in their restrictions. The models were applied to

two different types of soils viz. lateritic sandy loam soil of Kharagpur and black clay soil of Akola. The best model was selected after appropriate statistical assessment of various models.

## 2. MATERIALS AND METHODS

RETc provides a wide range of the models used to describe the soil hydraulic properties. Three models, such as (1) van-Genuchten model with  $m$  and  $n$  independent variables i.e. VG ( $m$ ,  $n$ ), (2) van-Genuchten model with Mualem's constraint on  $m$  ( $=1-1/n$ ) i.e. VG ( $n$ ) and (3) Brooks-Corey model i.e. BC, are used to generate the soil water retention curve. Gharde *et al.* (2007) used VG ( $m$ ,  $n$ ) and BC models in their study on black soil of Akola.

RETc is a descendant of the SOHYP code previously documented by van Genuchten (1987). The program permits one to fit analytical functions simultaneously to observed water retention and hydraulic conductivity data, or to predict the hydraulic curves from specified model parameters, if no retention and conductivity data are available. The soil water retention curve,  $\theta$ , according to van Genuchten (1980) contains five potentially unknown parameters:  $\theta_r$ ,  $\theta_s$ ,  $\alpha$ ,  $m$  and  $n$ . The model parameters are represented schematically by the parameter vector  $b = (\theta_r, \theta_s, \alpha, m, n)$ . The RETc code may be used to fit any one, several, or all of these parameters simultaneously to observed data. The most general formulation considers parameters  $m$  and  $n$  as independent. The restrictions  $n \rightarrow \infty$  (i.e. the BC-function) and  $m=1-1/n$  reduces the maximum number of independent parameters from five to four. In addition to imposing restrictions on  $m$  and  $n$ , it is possible to keep one or more of the other coefficients (e.g.  $\theta_s$ ,  $K_s$ ) constant during the parameter optimization process, if an estimate of those coefficients is available. For example, the model parameter vector reduces to  $b = (\theta_r, \theta_s, \alpha, n)$  when the Mualem restriction  $m=1-1/n$  (Mualem, 1984) is implemented and only retention data are used in the optimization.

A statistical discriminatory test "Akaike Information Criterion" (AIC) was used (Russo, 1988) to find out the best model that fits best to the data obtained from pressure plate apparatus. The model having the lowest AIC was selected as the best model. It is possible to judge different model from the AIC value but it would be arbitrary to assign a value above which a given model is 'rejected' (Wikipedia, 2010).

AIC can be defined as,

$$AIC = 2(L+p) \quad \dots [1]$$

Where,  $L$  is the negative log likelihood of the fitted model and  $p$  is the total number of independently adjusted parameters.

For a Gaussian process, AIC can be estimated from the residual sum of the squares (RSS) of deviations from the

fitted model (Russo, 1988)

$$AIC = N \left\{ \log(2\pi) + \log \left[ \frac{RSS}{(N-p)} \right] + 1 \right\} + p \quad \dots [2]$$

Where, RSS= Residual sum of squares, and  $N$  = number of data used for estimation.

Besides AIC, the statistical performance indicators generated from RETc output were also used to describe a meaningful presentation of the fitted models.

### Estimating and Optimizing Soil Hydraulic Parameters

RETc uses a nonlinear least-squares optimization approach to estimate the unknown model parameters from observed retention and/or conductivity or diffusivity data. The aim of the curve fitting process is to find an equation that maximizes the sum of squares associated with the model, while minimizing the residual sum of squares (RSS). The residual sum of squares reflects the degree of bias (lack of fit) and the contribution of random errors. RSS will be referred to as the objective function  $O(b)$  in which  $b$  represents the unknown parameter vector. RETc minimizes  $O(b)$  iteratively by means of a weighted least-squares approach based on Marquardt's maximum neighborhood method (Marquardt, 1963). During each iteration step, the elements  $b_j$  of the parameter vector  $b$  are updated sequentially, and the model results are compared with those obtained at the previous iteration level. RETc offers the option to print, among other information,  $O(b)$  for each iteration. When both retention and conductivity data are available, the objective function is given by

$$O(b) = \sum_{i=1}^N \{w_i [\theta_i - \hat{\theta}_i(b)]\}^2 + \sum_{i=N+1}^M \{w_i W_1 W_2 [Y_i - \hat{Y}_i(b)]\}^2 \quad \dots [3]$$

Where,  $\theta_i$  and  $\hat{\theta}_i$  are the observed and fitted water contents, respectively,  $Y_i$  and  $\hat{Y}_i$  are the observed and fitted conductivity data,  $W_1$  and  $W_2$  are weighing factors as explained below,  $N$  is the number of retention data points and  $M$  is the total number of observed retention and conductivity data points. The weighing factors  $w_i$  reflect the reliability of the measured data points, and ideally should be set equal to the observation error. Because reliable estimates for  $w_i$  are often lacking, these weighing factors are frequently set equal to unity.

The weighing factor  $W$  in Eq. [3] allows one to place more or less weight on the hydraulic conductivity data in their entirety, relative to the soil water retention data. Because conductivity data usually show considerably more scatter than water content data, and generally are also less precise, it is often beneficial to assign relatively less weight to the conductivity data.

The parameter  $W_2$  is introduced to ensure that proportional weight is given to the two different types of data in Eq.[3], i.e.,  $W_2$  corrects for the difference in number of data points and also eliminates, to some extent, the effect

of having different units for  $q$  and  $K$ . The value for  $W_2$  is calculated internally in the program according to

$$W_2 = (M-N) \sum_{i=1}^N w_i \theta_i / N \sum_{i=N+1}^M w_i |Y_i| \quad \dots[4]$$

The effect of Eq.[4] is to prevent one data type in Eq. [3] from dominating the other type solely because of larger numerical values.

The RETC output includes a matrix, which specifies the degree of correlation between the fitted coefficients in the different hydraulic models. It is suggested to always perform a "backward" type of regression, *i.e.*, by initially fitting all parameters and then fixing certain parameters one by one if these parameters exhibit high correlations. One of the possible restrictions is on  $m$  and  $n$ , unless the observed data shows little scatter and cover a wide range of pressure head and/or hydraulic conductivity. It is also possible to fix the residual water content at zero, or some other value, while keeping  $m$  and  $n$  independent, or assuming  $m=1-1/n$ . Fixing  $\theta_r$  is especially appropriate when few data at relatively low water contents or pressure heads are available.  $K_s$  and  $\theta_s$  are both very susceptible to experimental errors and should ordinarily not be fixed. In some cases the results may even improve when the "saturated" water content is deleted entirely from the parameter optimization analysis.

An important measure of the goodness of fit is the  $R^2$  value for regression of the observed versus fitted values. A value of 1 indicates a perfect correlation between the fitted and observed values. RETC provides additional statistical information about the fitted parameters such as mean, standard error,  $t$ -value, and lower and upper bounds at the 95% confidence level around each fitted parameter  $b_j$ . It is desirable that the real value of the target parameter always be located in a narrow interval around the estimated mean as obtained with the optimization program.

Finally, because of possible problems related to convergence and parameter uniqueness the program must re-run with different initial parameter estimates to make sure that the program converges to the same global minimum in the objective function. Although RETC will not accept initial estimates that are out of range, it is ultimately the user's responsibility to select meaningful initial estimates.

### Datasets

The soils used in the laboratory experiments were collected from the Plasticulture Development Center Experimental Plot, Indian Institute of Technology, Kharagpur (IIT, KGP), West Bengal, India and Dr. Punjabrao Deshmukh Krishi Vishwavidyalaya (PKV) farm site, Akola, Maharashtra state, India during 2002. For IIT, KGP, the soil samples were collected up to 85 cm depth. The soil samples, whereas for PKV, Akola, were collected upto 60 cm depth. The particle size distribution and bulk density of each layer are given in Table 1 and 2. The samples

collected were dried and mixed thoroughly. To remove the coarser substances, roots, stones etc. the samples were then crumbled and passed through 2 mm size sieve and stored in the laboratory for experiment purpose. The soil water retention data we developed for four layers of Kharagpur sandy loam soil and aggregated samples of PKV, Akola clay soil using pressure plate apparatus.

**Table: 1**  
**Particle size distribution and bulk density of Kharagpur sandy loam soil**

| Soil depth<br>(cm) | Particle Size Distribution |          |          | Bulk density<br>(g cc <sup>-1</sup> ) |
|--------------------|----------------------------|----------|----------|---------------------------------------|
|                    | Clay (%)                   | Silt (%) | Sand (%) |                                       |
| 0-15               | 14.3                       | 26.2     | 59.5     | 1.69                                  |
| 15-25              | 21.0                       | 19.3     | 59.7     | 1.56                                  |
| 25-55              | 27.3                       | 20.2     | 52.5     | 1.59                                  |
| 55-85              | 28.6                       | 19.2     | 52.2     | 1.63                                  |

**Table: 2**  
**Particle size distribution and bulk density of Akola clay soil**

| Soil depth<br>(cm) | Particle size distribution |          |          | Bulk density<br>(g cc <sup>-1</sup> ) |
|--------------------|----------------------------|----------|----------|---------------------------------------|
|                    | Clay (%)                   | Silt (%) | Sand (%) |                                       |
| 0-15               | 56.4                       | 24.2     | 19.4     | 1.22                                  |
| 15-30              | 53.8                       | 26.4     | 19.8     | 1.35                                  |
| 30-60              | 54.9                       | 27.4     | 17.7     | 1.50                                  |

To evaluate different candidate models of soil hydraulic properties in terms of their accuracy and consistency with the experimental data using different models, the soil hydraulic properties were determined from data obtained from pressure plate outflow experiments by parameter estimation procedure using the software RETC. RETC uses Marquard-Lavenberg parameter optimization technique to estimate best-fit parameters. In this technique both residual moisture content  $\theta_r$  and saturated moisture content  $\theta_s$  were also optimized instead of assuming them to be, conventionally, corresponding values at 15 bar and 0 bar pressure, respectively. Three parametric models such as (1) van-Genuchten model with the parameters ' $m$ ' and ' $n$ ' as variable [VG ( $m,n$ )], (2) Mualem constraint imposed over ' $m$ '( $=1-1/n$ ) [VG( $n$ )] and (3) Brooks-Corey [BC] were used for the comparison

### 3. RESULTS AND DISCUSSION

Pressure plate outflow data obtained from four soil layers such as 0-15, 15-25, 25-55 and 55-85 cm of Kharagpur soil were used for non-linear parameter fitting procedure used in RETC. For comparative performance of all the models soil water characteristic curves are fitted for both type of soils and is presented in Fig.1 and with summarizing the best fit parameter (Table 3). It can be

observed that over the whole range of suction head all the three models perform reasonably well.

The value of  $R^2$  is observed to be above 0.975 for all the cases. Thus it is difficult to select the best model based on  $R^2$ .

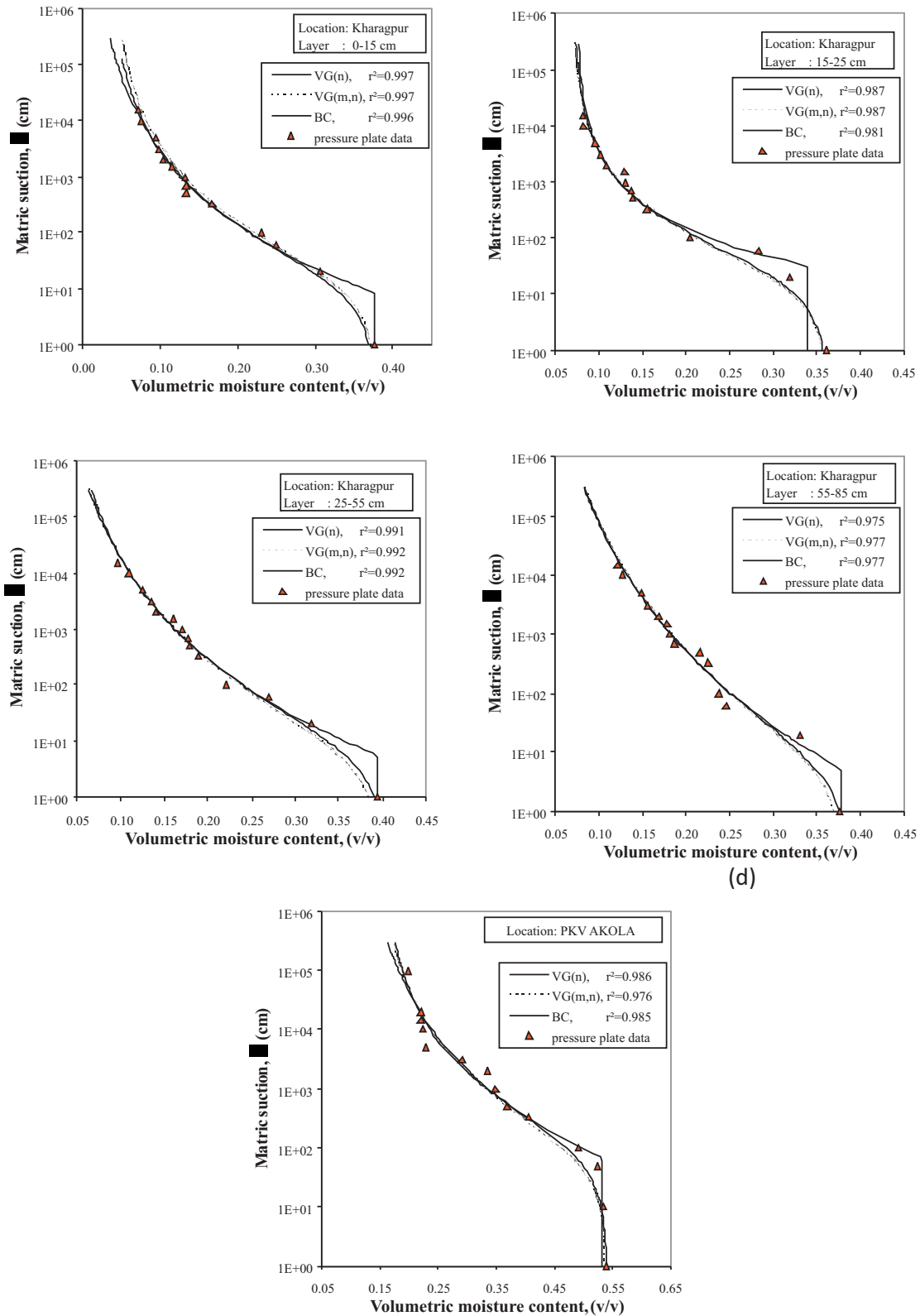


Fig. 1. Comparison of soil water characteristic curve for Kharagpur (a) sandy loam soil (0-15 cm), (b) sandy clay loam soil (15-25 cm), (c) sandy clay loam (25-55 cm), (d) sandy clay loam (55-85 cm), (e) PKV, Akola clay soil fitted to pressure plate outflow data using different parametric models (RETc)

**Table: 3****Estimation of parameters for different parametric models obtained by non-linear fitting to pressure plate outflow data**

| (a) Kharagpur sandy loam soil (0-15 cm)       |            |            |                |         |        |           |       |
|-----------------------------------------------|------------|------------|----------------|---------|--------|-----------|-------|
| Model                                         | $\theta_r$ | $\theta_s$ | $\beta/\alpha$ | m       | n      | $\lambda$ | $R^2$ |
| VG (n)                                        | 0.0269     | 0.3773     | 0.07341        | 0.2276  | 1.2947 | --        | 0.997 |
| VG (m, n)                                     | 0.0324     | 0.3780     | 0.06273        | 0.2254  | 1.1370 | --        | 0.997 |
| BC                                            | 0.0000     | 0.3763     | 0.11698        | --      | --     | 0.2274    | 0.996 |
| (b) Kharagpur sandy clay loam soil (15-25 cm) |            |            |                |         |        |           |       |
| Model                                         | $\theta_r$ | $\theta_s$ | $\beta/\alpha$ | m       | n      | $\lambda$ | $R^2$ |
| VG (n)                                        | 0.0711     | 0.3620     | 0.03252        | 0.3281  | 1.4884 | --        | 0.987 |
| VG (m,n)                                      | 0.0681     | 0.3602     | 0.03661        | 0.2655  | 1.7183 | --        | 0.987 |
| BC                                            | 0.0739     | 0.3405     | 0.03108        | --      | --     | 0.4928    | 0.981 |
| (c) Kharagpur sandy clay loam soil (25-55 cm) |            |            |                |         |        |           |       |
| Model                                         | $\theta_r$ | $\theta_s$ | $\beta/\alpha$ | m       | n      | $\lambda$ | $R^2$ |
| VG (n)                                        | 0.0198     | 0.4015     | 0.1607         | 0.16319 | 1.1950 | --        | 0.991 |
| VG (m,n)                                      | 0.0085     | 0.3942     | 0.1773         | 0.05960 | 2.9934 | --        | 0.992 |
| BC                                            | 0.0077     | 0.3940     | 0.1784         | --      | --     | 0.1774    | 0.992 |
| (d) Kharagpur sandy clay loam soil (55-85 cm) |            |            |                |         |        |           |       |
| Model                                         | $\theta_r$ | $\theta_s$ | $\beta/\alpha$ | m       | n      | $\lambda$ | $R^2$ |
| VG (n)                                        | 0.0000     | 0.3862     | 0.2079         | 0.12285 | 1.1401 | --        | 0.975 |
| VG (m,n)                                      | 0.0020     | 0.3779     | 0.1906         | 0.0564  | 2.4740 | --        | 0.977 |
| BC                                            | 0.0017     | 0.3770     | 0.1873         | --      | --     | 0.1396    | 0.977 |
| (e) Akola clay soil                           |            |            |                |         |        |           |       |
| Model                                         | $\theta_r$ | $\theta_s$ | $\beta/\alpha$ | m       | n      | $\lambda$ | $R^2$ |
| VG (n)                                        | 0.1504     | 0.5411     | 0.00780        | 0.2577  | 1.3471 | --        | 0.986 |
| VG (m,n)                                      | 0.1353     | 0.5387     | 0.01020        | 0.1706  | 1.7400 | --        | 0.976 |
| BC                                            | 0.0970     | 0.5330     | 0.01459        | --      | --     | 0.2235    | 0.985 |

However, the VG (n) and VG (m, n) had performed slightly better over BC with the  $R^2$  values 0.997 each for the layer of 0-15 cm. Though  $R^2$  represents the extent to which the parametric estimates were explained but cannot be assumed to be a condition of sufficiency to pick a model with the best estimate. So we invoke a few other estimates (Table 4(a)) namely the t-statistics, Residual sum of squares (RSS) and Akaike Information Criterion (AIC) to have a fair comparison. It can be observed that for all the models fitted to the soil data for sandy loam soil of Kharagpur representing 0-15 cm layer the t-values were found to be significant at 95% level and AIC was found to be least for VG (n) with a value -37.04 as compared to -35.71 for VG (m, n) and -35.60 for BC model. This evidently advocates VG (n) as the best model for this particular class of soil.

For the sandy clay loam soil layer between 15-25 cm (Table 3(b) & 4(b)) depth of Kharagpur, VG (n) came out to be a clear cut choice over the other two models. It can be seen that some parametric estimates with VG (m, n) have t-values non-significant at 95% level even though the  $R^2$  was found to be 0.987 equaling to that of VG (n) as compared to the BC model with the lowest one at 0.981. AIC value for VG (n) was also the lowest again at -30.01 as compared to -28.45 and -27.68 for VG (m, n) and BC, respectively.

A similar observation can also be made with the other two layers representing 25-55 cm and 55-85 cm of the

Kharagpur soil. Both of these soils are sandy clay loam in texture. But unlike the other two layers the focus of competition shifted over to BC with the highest  $R^2$  values computed as 0.992 and 0.977 for 25-55cm and 55-85 cm layers, respectively. But VG (n) still has an edge over the BC with the lowest AIC of 34.05 and 28.53 for both the layers in the same order of precedence (Table 4(c) and (d)).

The second soil used for the study is a clay soil (composite of 0-60 cm depth) collected from Punjab Rao Deshmukh Agricultural University, Akola, Maharashtra state, India. The experimental data obtained through pressure plate outflow experiment were subjected to non-linear curve fitting using same procedure. Fig. 1(e) shows the comparative performance of the different parametric models with the summaries of the best-fit estimates Table 3(e). A similar trend (Table 5) is also observed in this case with VG (n) being the best model out of the three models tested by the discriminant analysis indicator AIC. VG (n) observed the lowest AIC (20.01) followed BC with (19.64) and VG (m, n) (18.40). The high computed  $R^2$  value was also the highest for model VG (n) at 0.986.

$R^2$  is not directly affected by the number of parameters used in different model whereas AIC penalizes for bigger mode, therefore in addition to best fitting, VG (n) with less number of parameter may have lower AIC than VG (m, n). In figure 1 all three models fit relatively better for higher

**Table: 4(a)****Discriminatory test criterion (AIC)**

Soil: Kharagpur sandy loam

Layer : 0-15 cm

Model: VG(n)

| Statistical parameters | $\theta_r$ | $\theta_s$ | $\beta$              | n       |           | $R^2$ | RSS     | AIC    |
|------------------------|------------|------------|----------------------|---------|-----------|-------|---------|--------|
| Estimate               | 0.027      | 0.377      | 0.0734               | 1.295   |           |       |         |        |
| SEE                    | 0.00164    | 0.00499    | 0.0142               | 0.04113 |           |       |         |        |
| t-value                | 16.42      | 75.68      | 39                   | 31.48   |           | 0.997 | 0.00052 | -37.04 |
| Critical $t_{0.975}$   | 2.23       |            | Critical $t_{0.995}$ | 3.17    |           |       |         |        |
| 95% CI Lower           | -0.009     | 0.366      | 0.0422               | 1.204   |           |       |         |        |
| Upper                  | 0.063      | 0.388      | 0.1046               | 1.385   |           |       |         |        |
| Model: VG(m,n)         |            |            |                      |         |           |       |         |        |
| Statistical parameters | $\theta_r$ | $\theta_s$ | $\beta$              | m       | n         | $R^2$ | RSS     | AIC    |
| Estimate               | 0.032      | 0.378      | 0.06273              | 0.2254  | 1.137     |       |         |        |
| SEE                    | 0.01217    | 0.00509    | 0.00819              | 0.03364 | 0.1085    |       |         |        |
| t-value                | 2.66       | 74.29      | 7.66                 | 3.453   | 10.48     | 0.997 | 0.0005  | -35.71 |
| Critical $t_{0.975}$   | 2.26       |            | Critical $t_{0.995}$ |         | 3.25      |       |         |        |
| 95% CI Lower           | 0.006      | 0.367      | 0.0447               | 0.1130  | 0.898     |       |         |        |
| Upper                  | 0.059      | 0.389      | 0.0807               | 0.3294  | 1.376     |       |         |        |
| Model: BC              |            |            |                      |         |           |       |         |        |
| Statistical parameters | $\theta_r$ | $\theta_s$ | $\alpha$             |         | $\lambda$ | $R^2$ | RSS     | AIC    |
| Estimate               | 0          | 0.376      | 0.11698              |         | 0.22745   |       |         |        |
| SEE                    | --         | 0.00517    | 0.01376              |         | 0.00679   |       |         |        |
| t-value                | --         | 72.8       | 8.5                  |         | 33.51     |       |         |        |
| Critical $t_{0.975}$   | 2.23       |            | Critical $t_{0.995}$ |         | 3.17      | 0.996 | 0.00064 | -35.60 |
| 95% CI Lower           | --         | 0.365      | 0.087                |         | 0.2127    |       |         |        |
| Upper                  | --         | 0.388      | 0.147                |         | 0.2422    |       |         |        |

**Table: 4(b) Discriminatory test criterion (AIC)**

Soil: Kharagpur Sandy clay loam

Layer : 15-25 cm

Model: VG(n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | n       |  | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|---------|---------|--|-------|---------|--------|
| Estimate               | 0.071      | 0.362                | 0.03252 | 1.48843 |  |       |         |        |
| SEE                    | 0.01442    | 0.01153              | 0.00537 | 0.10224 |  |       |         |        |
| t-value                |            |                      | 6.05586 |         |  |       |         |        |
|                        | 4.93       | 31.4                 | 6       | 14.56   |  | 0.987 | 0.00143 | -30.01 |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ | 3.17    |         |  |       |         |        |
| 95% CI Lower           | 0.039      | 0.336                | 0.0116  | 1.2606  |  |       |         |        |
| Upper                  | 0.103      | 0.388                | 0.0534  | 1.7162  |  |       |         |        |

Model: VG(m,n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | m       | n       | $R^2$ | RSS    | AIC    |
|------------------------|------------|----------------------|---------|---------|---------|-------|--------|--------|
| Estimate               | 0.068      | 0.360                | 0.03661 | 0.26551 | 1.71834 |       |        |        |
| SEE                    | 0.0207     | 0.01294              | 0.02058 | 0.23364 | 1.02282 |       |        |        |
| t-value                | 3.29       | 27.83                | 1.78    | 1.14    | 1.68    | 0.987 | 0.0014 | -28.45 |
| Critical $t_{0.975}$   | 2.26       | Critical $t_{0.995}$ | 3.25    |         |         |       | 2      |        |
| 95% CI Lower           | 0.0212     | 0.3309               | -0.01   | -0.263  | -0.5954 |       |        |        |
| Upper                  | 0.1149     | 0.3895               | 0.0832  | 0.794   | 4.0321  |       |        |        |

Model: BC

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\alpha$ | $\lambda$ | $R^2$ | RSS   | AIC    |
|------------------------|------------|----------------------|----------|-----------|-------|-------|--------|
| Estimate               | 0.0739     | 0.3405               | 0.03108  | 0.49277   |       |       |        |
| SEE                    | 0.02846    | 0.00999              | 0.00688  | 0.11674   |       |       |        |
| t-value                | 2.596627   | 34.08                | 4.52     | 4.22      | 0.981 | 0.002 | -27.68 |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ | 3.17     |           |       |       |        |
| 95% CI Lower           | 0.0372     | 0.3182               | 0.0157   | 0.2327    |       |       |        |
| Upper                  | 0.1106     | 0.3628               | 0.0464   | 0.7529    |       |       |        |

**Table: 4(c) Discriminatory test criterion (AIC)**

Soil: Kharagpur sandy clay laom Layer : 25-55 cm

Model: VG(n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | n      | $R^2$ | RSS    | AIC   |
|------------------------|------------|----------------------|---------|--------|-------|--------|-------|
| Estimate               | 0.0198     | 0.4015               | 0.1607  | 1.1950 |       |        |       |
| SEE                    | 0.0426     | 0.0079               | 0.0624  | 0.0528 |       |        |       |
| t-value                | 0.46       | 50.76                | 2.58    | 22.62  |       |        |       |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ | 3.17    |        | 0.991 | 0.0008 | 34.05 |
| 95% CI Lower           | -0.0753    | 0.3772               | -0.0006 | 1.0773 |       |        |       |
| Upper                  | 0.1148     | 0.4258               | 0.3221  | 1.3127 |       |        |       |

Model: VG(m,n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | m       | n        | $R^2$ | RSS    | AIC    |
|------------------------|------------|----------------------|---------|---------|----------|-------|--------|--------|
| Estimate               | 0.0085     | 0.3942               | 0.1773  | 0.0596  | 2.9934   |       |        |        |
| SEE                    | 0.0629     | 0.0125               | 0.0916  | 0.6449  | 31.0955  |       |        |        |
| t-value                | 0.14       | 31.66                | 1.94    | 0.09    | 0.10     |       |        |        |
| Critical $t_{0.975}$   | 2.26       | Critical $t_{0.995}$ | 3.25    |         |          | 0.992 | 0.0007 | -33.08 |
| 95% CI Lower           | -0.1338    | 0.3660               | -0.0299 | -1.3992 | -67.3487 |       | 3      |        |
| Upper                  | 0.1508     | 0.4224               | 0.3845  | 1.5184  | 73.3354  |       |        |        |

Model: BC

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\alpha$ | $\lambda$ | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|----------|-----------|-------|---------|--------|
| Estimate               | 0.0077     | 0.3940               | 0.1784   | 0.1774    |       |         |        |
| SEE                    | 0.0415     | 0.0085               | 0.0517   | 0.0409    |       |         |        |
| t-value                | 0.18       | 46.15                | 3.45     | 4.34      |       |         |        |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ | 3.17     |           | 0.992 | 0.00081 | -33.96 |
| 95% CI Lower           | -0.0849    | 0.3750               | 0.0632   | 0.0863    |       |         |        |
| Upper                  | 0.1002     | 0.4130               | 0.2936   | 0.2685    |       |         |        |

**Table: 4(d) Discriminatory test criterion (AIC)**

Soil: Kharagpur sandy clay loam Layer : 55-85 cm

Model: VG (n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | n      | $R^2$ | RSS    | AIC    |
|------------------------|------------|----------------------|---------|--------|-------|--------|--------|
| Estimate               | 0.0000     | 0.3862               | 0.2079  | 1.1401 |       |        |        |
| SEE                    | 0          | 0.0156               | 0.1095  | 0.0106 |       |        |        |
| t-value                | --         | 24.70                | 1.90    | 107.65 |       |        |        |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ |         | 3.17   | 0.975 | 0.0018 | -28.53 |
| 95% CI Lower           | --         | 0.3518               | -0.0332 | 1.1167 |       |        |        |
| Upper                  | --         | 0.4206               | 0.4490  | 1.1634 |       |        |        |

Model: VG(m,n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | m       | n        | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|---------|---------|----------|-------|---------|--------|
| Estimate               | 0.0020     | 0.3779               | 0.1906  | 0.0564  | 2.4740   |       |         |        |
| SEE                    | 0.1580     | 0.0258               | 0.1722  | 0.6549  | 24.8316  |       |         |        |
| t-value                | 0.01       | 14.65                | 1.11    | 0.09    | 0.10     | 0.976 | 0.00164 | -27.45 |
| Critical $t_{0.975}$   | 2.26       | Critical $t_{0.995}$ |         | 3.25    |          |       |         |        |
| 95% CI Lower           | -0.3554    | 0.3195               | -0.1989 | -1.4250 | -53.6983 |       |         |        |
| Upper                  | 0.3593     | 0.4362               | 0.5801  | 1.5377  | 58.6463  |       |         |        |

Model: BC

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\alpha$ | $\lambda$ | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|----------|-----------|-------|---------|--------|
| Estimate               | 0.0017     | 0.3770               | 0.1873   | 0.1396    |       |         |        |
| SEE                    | 0.0979     | 0.0127               | 0.1022   | 0.0676    |       |         |        |
| t-value                | 0.02       | 29.59                | 1.83     | 2.07      |       |         |        |
| Critical $t_{0.975}$   | 2.23       | Critical $t_{0.995}$ | 3.17     |           | 0.977 | 0.00182 | -28.33 |
| 95% CI Lower           | -0.2165    | 0.3486               | -0.0404  | -0.0109   |       |         |        |
| Upper                  | 0.2199     | 0.4054               | 0.4150   | 0.2902    |       |         |        |

**Table: 5 Discriminatory test criterion (AIC)**

Soil: PKV, Akola Clay

Model: VG(n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | n      | $R^2$ | RSS    | AIC    |
|------------------------|------------|----------------------|---------|--------|-------|--------|--------|
| Estimate               | 0.1504     | 0.5411               | 0.0078  | 1.3471 |       |        |        |
| SEE                    | 0.03853    | 0.0121               | 0.0031  | 0.1045 |       |        |        |
| t-value                | 3.90       | 44.89                | 2.56    | 12.89  |       |        |        |
| Critical $t_{0.975}$   | 2.18       | Critical $t_{0.995}$ | 3.06    |        | 0.986 | 0.0031 | -20.00 |
| 95% CI Upper           | 0.0646     | 0.5143               | 0.0010  | 1.1143 |       |        |        |
| Lower                  | 0.2363     | 0.5680               | 0.0147  | 1.5799 |       |        |        |

Model: VG(m,n)

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\beta$ | m       | n       | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|---------|---------|---------|-------|---------|--------|
| Estimate               | 0.1353     | 0.5387               | 0.0102  | 0.1706  | 1.7400  |       |         |        |
| SEE                    | 0.0638     | 0.0138               | 0.0068  | 0.1896  | 1.2427  |       |         |        |
| t-value                | 2.12       | 38.92                | 1.50    | 0.90    | 1.40    |       |         |        |
| Critical $t_{0.975}$   | 2.20       | Critical $t_{0.995}$ | 3.11    |         |         | 0.976 | 0.00305 | -18.40 |
| 95% CI Lower           | -0.0091    | 0.5073               | -0.0052 | -0.2583 | -1.0711 |       |         |        |
| Upper                  | 0.2797     | 0.5700               | 0.0255  | 0.5996  | 4.5511  |       |         |        |

Model: BC

| Statistical parameters | $\theta_r$ | $\theta_s$           | $\alpha$ | $\lambda$ | $R^2$ | RSS     | AIC    |
|------------------------|------------|----------------------|----------|-----------|-------|---------|--------|
| Estimate               | 0.0970     | 0.5330               | 0.0146   | 0.2235    |       |         |        |
| SEE                    | 0.0597     | 0.0104               | 0.0037   | 0.0631    |       |         |        |
| t-value                | 1.63       | 51.14                | 3.97     | 3.54      |       |         |        |
| Critical $t_{0.975}$   | 2.18       | Critical $t_{0.995}$ | 3.06     |           | 0.985 | 0.00326 | -19.64 |
| 95% CI Lower           | -0.0359    | 0.5097               | 0.0064   | 0.0829    |       |         |        |
| Upper                  | 0.2299     | 0.5562               | 0.0229   | 0.3642    |       |         |        |

RSS: Residual sum of squares, AIC: Akaike Information criterion, SEE: Standard error of estimates, CI : Confidence interval, t-value: Parametric t-statistics

matric suction as compared lower suction value. As  $R^2$  is relatively more biased for higher value, all the three models tested shows good  $R^2$  and relatively poor fitting for lower suction value could not be captured. AIC could reasonably capture the fitting of model for lower suction.

#### 4. CONCLUSIONS

The statistical analysis performed to discriminate the models such as  $R^2$ , AIC, t-value and RSS had showed a little difference between the models used for comparison. However, considering the relative ease at which the computation of hydraulic properties can be performed and the practical situation that can be accommodated representing the moisture transport processes, VG (n) is the best model out of three models used. The reason being a simple closed form equation that can be derived to express the hydraulic conductivity function as compared to VG (m, n). Though BC represents even a simpler form for the expression of hydraulic conductivity function, the assumption of the volumetric moisture content at air entry value being equaled to that of the saturation moisture content rendered its application, practically, unsuitable for a near saturation flow processes especially trickle/drip irrigation process.

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