

production of 95.6 µg/ml)<sup>23</sup>, *Lyptolingbya* sp. (maximum production of 51.06 µg/ml)<sup>8</sup>, *Gietlerinema* sp. (maximum production of 67.87 µg/ml)<sup>8</sup>, *Oscillatoria* sp. TCC4 (maximum production of 10.65 µg/ml)<sup>24</sup> and *Arthrospira platensis* strain MMG-9 (maximum production of 113 µg/ml)<sup>6</sup>. The production of IAA by *F. muscicola* is highest (maximum production of 286.82 µg/ml) among the bacteria and cyanobacteria reported so far. Hence, the extract of this strain promotes growth of rice seedlings several times in comparison to control. This cyanobacterium can be a good biofertilizer and the extract can be used instead of synthetic agents for organogenesis induction in tissue culture.

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## Pedotransfer functions for predicting soil hydraulic properties in semi-arid regions of Karnataka Plateau, India

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**Soil hydraulic properties are important for irrigation scheduling and proper land-use planning. Field capacity, permanent wilting point and infiltration rate are the three vital hydraulic properties which determine the availability and retention of water for crop growth. These properties are difficult to measure and time-consuming, but can be easily predicted from the available information like soil texture, bulk density,**

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organic carbon content, etc. through pedotransfer functions (PTFs). PTFs were developed for field capacity and permanent wilting point for two different regions of Karnataka, viz. Northern Karnataka Plateau (512 soil samples) and Southern Karnataka Plateau (228 soil samples), separately. PTF for infiltration rate was developed using 100 soil samples for the entire Karnataka. Cross-validation techniques were used to validate the PTFs, and the results are satisfactory with low RMSE and higher  $R^2$ . The developed PTFs are useful in determining soil hydraulic properties of the semi-arid regions of southern India.

**Keywords:** Pedotransfer functions, field capacity, permanent wilting point, infiltration rate, semi-arid regions.

GROWTH of plants mainly depends on available water content of the soil. The quality and quantity of water available for plant growth is determined by the soil hydraulic properties. When the water content reduces beyond 15 bar (1500 kPa), most of the crops starts wilting. Hence, information about the soil water regime is important for judicial planning of irrigation<sup>1</sup>. Soil moisture constants, viz. field capacity, wilting point and infiltration rate are the most important soil hydraulic properties which decide the application and frequency of irrigation. Field capacity refers to the soil water content retained in soil micropores and macropores at a tension of  $-0.033$  MPa, whereas permanent wilting point is the soil water content at a tension of  $-1.5$  MPa. The difference in field capacity and permanent wilting point is the water available to the plants. Infiltration is defined as the process by which a fluid passes through or into another substance travelling through pores and interstices<sup>2</sup>, which widely influences irrigation, contaminant transport, groundwater recharge, and ecosystem viability<sup>3</sup>. Determination of these soil hydraulic properties is much important as it decides the soil moisture availability and suitability for crop production.

In large areas measuring the field capacity, wilting point and infiltration rate even within an agricultural field is time-consuming and expensive<sup>4</sup>, and it is also impossible to take enough measurements as these properties vary at each sampling point. Several methods have been proposed to estimate soil hydraulic properties from easily measured soil properties, e.g. texture and bulk density (BD), and/or limited data collected during soil surveys<sup>5-7</sup>. An equation or model developed for indirect estimation of a particular soil property is termed as pedotransfer function (PTF)<sup>8</sup>. PTFs are an alternative method for estimation of hydraulic properties using available soil parameters, since field measurement of soil hydraulic properties consumes time, is tedious and costly. Practically most of the PTFs use the particle size distribution data of the soil, or its derived parameters, and other easily measurable soil properties, e.g. soil texture, BD, calcium carbonate content, pH value, etc.<sup>9,10</sup>. PTFs add value to this basic information by translating it into estimates of

other more laborious and expensively determined soil properties<sup>11</sup>.

Several PTFs were developed in India to estimate the soil hydraulic properties<sup>7,12-14</sup>. PTFs developed for a particular agroecological regions may not be useful for other region. Cornelis *et al.*<sup>15</sup> showed that a PTF yields more accurate estimates when it is applied to the geographical region for which it was developed. In India, interrelationships between soil texture, water retention and transmission characteristics have been worked out in the past<sup>7,13,16,17</sup>. PTFs were developed for the Indo-Gangetic Plains (IGP)<sup>7,18</sup>, black soil region (BSR)<sup>18</sup> and arid western India<sup>1</sup>. PTFs developed for a particular region have limited applicability in another region<sup>12</sup>. For southern India Deccan Plateau (semi-arid region), no comprehensive PTFs are available. In this context, the present study was aimed to develop PTFs for field capacity, permanent wilting point and infiltration of Karnataka Plateau representing semi-arid regions of southern India.

The present study was carried out in two different regions of Karnataka Plateau, viz. Northern Karnataka Plateau (NKP) and Southern Karnataka Plateau (SKP). The study area extends from  $11^{\circ}30'N$  to  $18^{\circ}30'N$  and  $74^{\circ}E$  and  $78^{\circ}30'E$  (Figure 1). Northern Karnataka Plateau (Koppal, Raichur, Yadgir and Gulbarga districts): This region experiences hot, semi-arid climate with rainfall in the range 600–750 mm and potential evapotranspiration (PET) of 1600–1700 mm. The average annual rainfall is 672 mm. The length of growing period (LGP) ranges between 90 and 120 days. The major area comes under rainfed cultivation with rainfed crops like sorghum, pigeon pea and pearl millet. Northern Karnataka falls under Krishna and Godavari basins, and has topography of 300–600 m with sporadic hills. Substantial area is underlined by basalts with continuation of Deccan Trap of Maharashtra. The major soils are shallow to deep black soils, red loam soils, red clay soils, alluvio-colluvial soils and laterite gravelly soil<sup>19</sup>.

Southern Karnataka Plateau (Tumkur and Chamarajanager districts): This region comes under hot semi-arid climate, with rainfall in the range 600–900 mm and mean annual rainfall of 735 mm. The LGP ranges between 120 and 150 days. The major crops under rainfed cultivation are finger millet, pigeon pea and groundnut. Under irrigated condition, the major land use is paddy and sugarcane. Southern Karnataka falls under the Cauvery basin and has topography of 600–900 m with residual hills. Most of the area is underlined by granite and granite gneiss. The major soils are red gravelly loamy soils, red loam soils, red gravelly clay soils, red clay soils, laterite soils and aluvio-colluvial soils.

Soil physical properties such as sand, silt, clay, organic carbon (OC), pH, electrical conductivity (EC), cation exchange capacity (CEC) and exchangeable sodium percentage (ESP), field capacity (FC) and permanent wilting point (PWP) for major soil groups in study region under

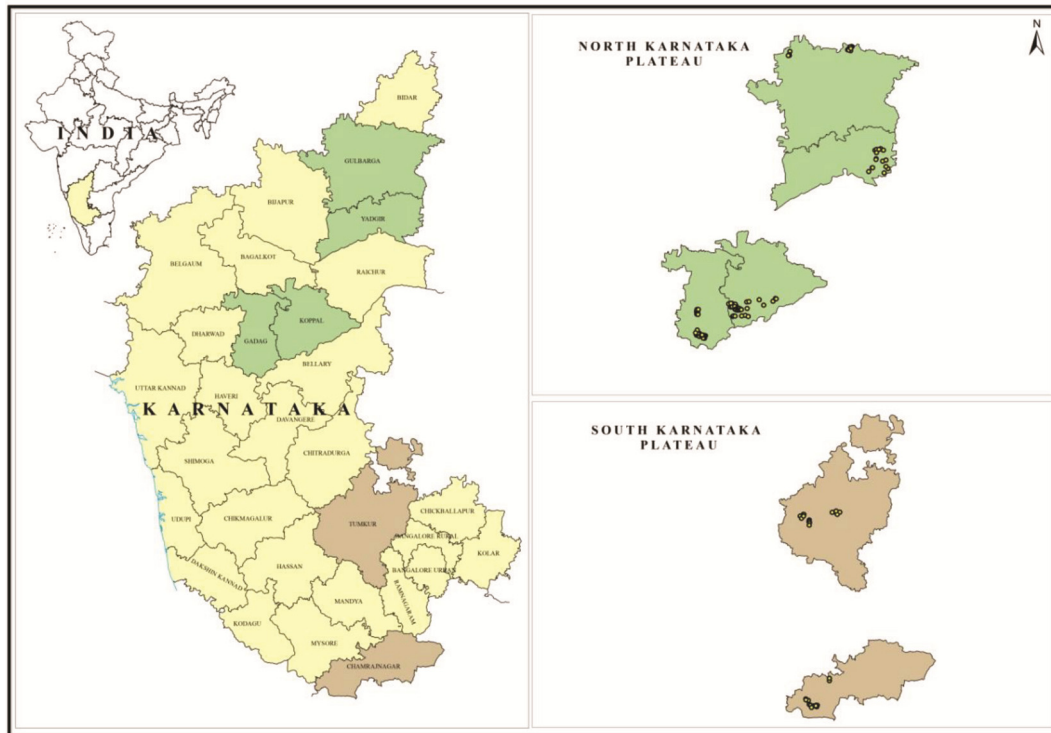


Figure 1. Study area.

Sujala III project<sup>20</sup> ([http://watershed.kar.nic.in/SujalaIII\\_Doc.htm](http://watershed.kar.nic.in/SujalaIII_Doc.htm)) were used for developing PTFs. A total of 512 soil samples (106 profiles) in NKP and 228 samples (43 soil profiles) in SKP were collected and analysed at ICAR–National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), Bengaluru according to standard protocol. Infiltration rate was measured at field using double-ring infiltrometer<sup>21</sup> by the University partners under Sujala III project.

The random forest 4.6 package in R environment was used to identify the most important variables or predictors<sup>22</sup>. Random forest model (RFM) works based on assemblage of a number of classification and regression trees using two levels of randomization for every tree in the forest<sup>23</sup>. RFM also identifies the relatively important variables based on the number of times a variable was used in the nodes<sup>24,25</sup>. Three topmost important variables were utilized for PTF development using multiple regression technique.

Multiple regression technique was used for developing PTFs in R environment (RStudio10.0). The PTFs for FC and PWP were developed separately for soils of NKP and SKP, since soils and climate of these regions are significantly different. The results were validated using cross-validation techniques. The top-most important variables selected were used for estimating FC at –33 kPa and PWP at –1500 kPa. In addition, clay content (%) alone was used as an independent variable to relate FC and PWP. The relationship between clay content and hydraulic properties was evaluated, since the amount of clay in the

soil sample is one of the easily measurable properties compared to the others. Similarly, PTFs were developed to predict infiltration rate for Karnataka from a database of 100 observations/soils.

Cross-validation was carried out to analyse the performance of PTF models. Ten-fold cross-validation techniques with 20 times repetition were used to evaluate the performance with indicators such as coefficient of determination ( $R^2$ ), root mean square error (RMSE) and mean error (ME). Coefficient of determination is defined by the percentage of variation explained by the model. Good models have coefficient of determination equal or close to 1, and RMSE close to 0.

$$\text{Coefficient of determination } (R^2) = 1 - \frac{\sum_{i=1}^n (p_i - o_i)^2}{\sum_{i=1}^n (o_i - \bar{o}_l)^2},$$

$$\text{Bias (ME)} = \frac{1}{n} \sum_{i=1}^n (o_i - p_i),$$

$$\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^n (o_i - p_i)^2},$$

where  $p_i$  and  $o_i$  are the predicted and observed values,  $\bar{o}_l$  is the mean of observed values.

Table 1 provides descriptive statistics of soil properties of NKP soils. pH of the soils ranges from very strongly acidic to very strongly alkaline, with a mean of 8.1. EC

## RESEARCH COMMUNICATIONS

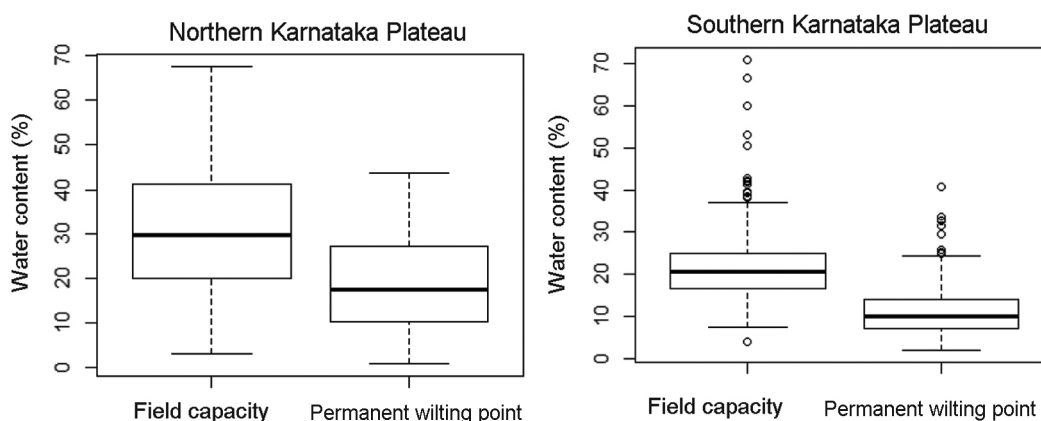
**Table 1.** Statistics of physico-chemical soil properties in Northern Karnataka Plateau ( $N = 512$ )

| Property | pH   | EC (dS/m) | OC (%) | Sand (%) | Clay (%) | Silt (%) | FC (%) | PWP (%) | CEC (C mol p <sup>+</sup> kg <sup>-1</sup> ) | ESP (%) |
|----------|------|-----------|--------|----------|----------|----------|--------|---------|--|---------|
| Mean     | 8.1  | 0.4       | 0.5    | 39.8     | 43.2     | 17.1     | 29.9   | 19.0    | 33.6   | 7.0     |
| Maximum  | 10.4 | 6.5       | 1.6    | 94.0     | 80.8     | 40.7     | 62.1   | 43.7    | 80.9   | 68.5    |
| Minimum  | 4.7  | 0.0       | 0.03   | 2.7      | 1.2      | 2.4      | 3.2    | 0.9     | 1.7  | 0.0     |
| SD       | 1.0  | 0.6       | 0.3    | 24.3     | 19.6     | 7.7      | 13.3   | 10.9    | 21.0   | 11.9    |
| Kurtosis | 0.4  | 38.0      | 0.3    | -1.0     | -0.9     | -0.3     | -0.9   | -0.9    | -1.2   | 7.9     |
| Skewness | -0.8 | 5.4       | 0.6    | 0.3      | -0.2     | 0.4      | 0.1    | 0.3     | 0.3  | 2.7     |
| CV (%)   | 12.4 | 177.3     | 48.2   | 61.2     | 45.4     | 45.2     | 44.6   | 57.4    | 62.3   | 170.7   |

EC, Electrical conductivity; OC, organic carbon; FC, field capacity; PWP, permanent wilting point; CEC, cation exchange capacity; ESP, exchangeable sodium percentage.

**Table 2.** Statistics of physico-chemical soil properties in Southern Karnataka Plateau ( $N = 228$ )

| Property | pH   | EC (dS/m) | OC (%) | Sand (%) | Clay (%) | Silt (%) | FC (%) | PWP (%) | CEC (C mol p <sup>+</sup> kg <sup>-1</sup> ) | ESP (%) |
|----------|------|-----------|--------|----------|----------|----------|--------|---------|--|---------|
| Mean     | 7.6  | 0.10      | 0.40   | 53.5     | 31.5     | 15.0     | 22.2   | 11.4    | 14.7   | 3.0     |
| Minimum  | 4.5  | 0.02      | 0.08   | 4.4      | 5.8      | 2.0      | 4.1    | 2.1     | 52.6   | 33.1    |
| Maximum  | 9.1  | 0.48      | 2.00   | 92.3     | 67.8     | 36.0     | 70.9   | 41.0    | 1.2  | 0.0     |
| SD       | 0.9  | 0.08      | 0.23   | 16.5     | 13.1     | 6.4      | 9.5    | 6.3     | 9.5  | 3.4     |
| Kurtosis | 0.1  | 2.98      | 10.49  | 0.7      | -0.2     | 0.7      | 5.4    | 3.1     | 2.9  | 28.3    |
| Skewness | -0.8 | 1.57      | 2.22   | -0.6     | 0.3      | 1.0      | 1.8    | 1.5     | 1.6  | 4.2     |
| CV (%)   | 12.0 | 81.7      | 57.81  | 30.9     | 41.5     | 42.8     | 43.1   | 55.4    | 65.1   | 115.1   |



**Figure 2.** Distribution of field capacity and permanent wilting point in Northern Karnataka Plateau and Southern Karnataka Plateau.

of the soil also varies from 0.0 to 6.5 dS m<sup>-1</sup>. OC ranges between 0.03% and 1.6%, with mean of 0.5%. The clay, sand and silt contents vary between 1.2% and 80.8%, 2.7% and 94% and 2.4% and 40.7% respectively. CEC in NKP soils ranges from 1.7 to 80.9 C mol p<sup>+</sup> kg<sup>-1</sup>. The maximum exchangeable sodium percentage recorded in NKP soils is 68.5. The FC and PWP range from 3.2% to 62.1% (mean 29.9%) and 0.9% to 43.7% (mean 19.0%) respectively, with high coefficient of variation (Figure 2). Except pH and clay, other parameters are positively skewed.

Table 2 provides descriptive statistics of soil properties of SKP soils. pH of the soils ranges from very strongly acidic (4.5) to very strongly alkaline (9.1), with a mean of

7.6. EC of the soil varies from 0.02 to 0.48 dS m<sup>-1</sup>. OC content ranges from 0.08% and 2.0%, with a mean of 0.4%. The clay, sand and silt contents vary between 5.8% and 67.8%, 4.4% and 92.3% and 2.0% and 36.0% respectively. The EC in SKP soils ranges from 4.1% to 70.9% with a mean of 22.2%, while PWP ranges from 2.1% to 41.0% with a mean of 11.4%. CEC (C mol p<sup>+</sup> kg<sup>-1</sup>) of the soil varies from 1.2 and 52.6 with mean value of 14.7. Except pH and sand content, other parameters are positively skewed, and among the soil properties, soil pH shows least variability with 12% CV.

The results of correlation studies show that FC in NKP soils is significantly positively correlated with CEC (0.867\*\*), clay (0.848\*\*) and silt (0.549\*\*), and

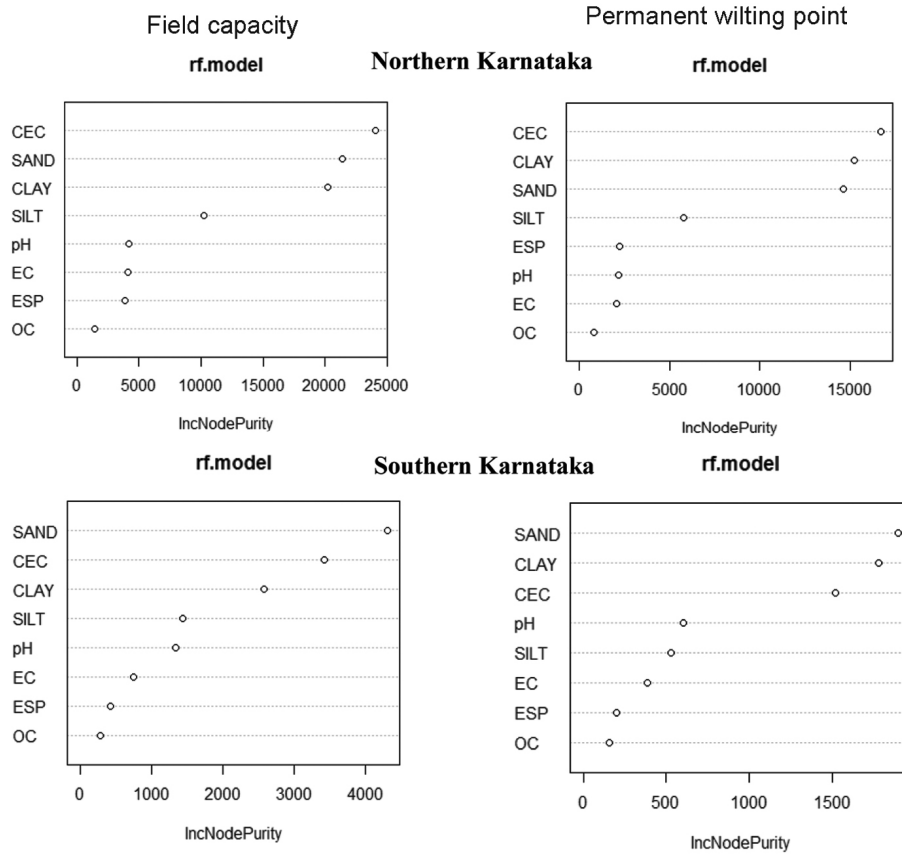


Figure 3. Variable importance rankings in predicting soil moisture constants in NKP and SKP.

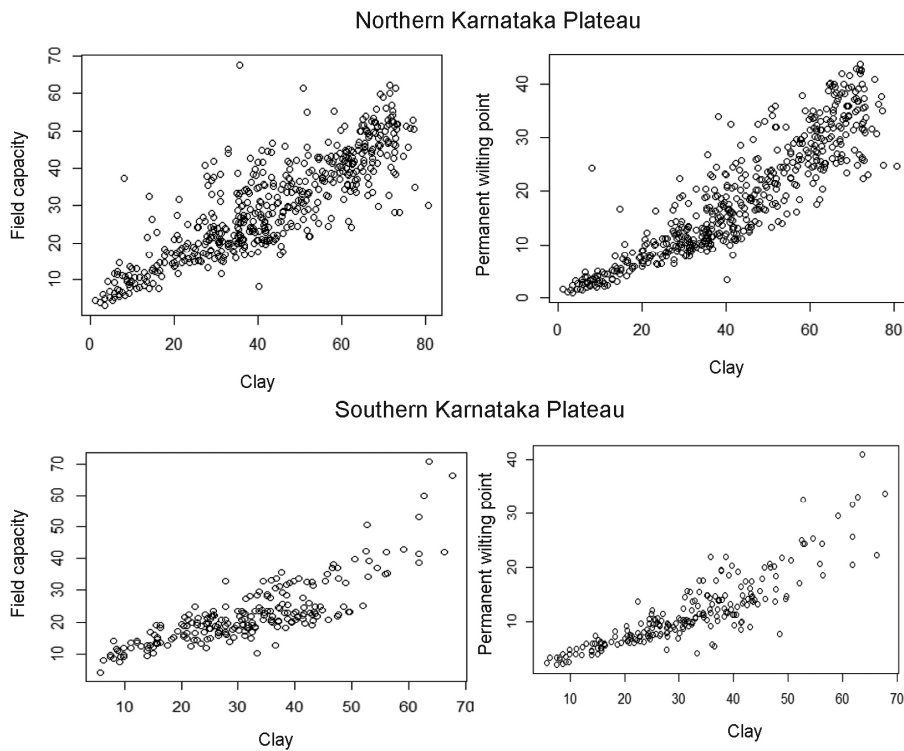


Figure 4. Relationship between soil moisture constants and clay content in NKP and SKP.

**Table 3.** Multiple regression analysis of water content at field capacity and permanent wilting point in NKP

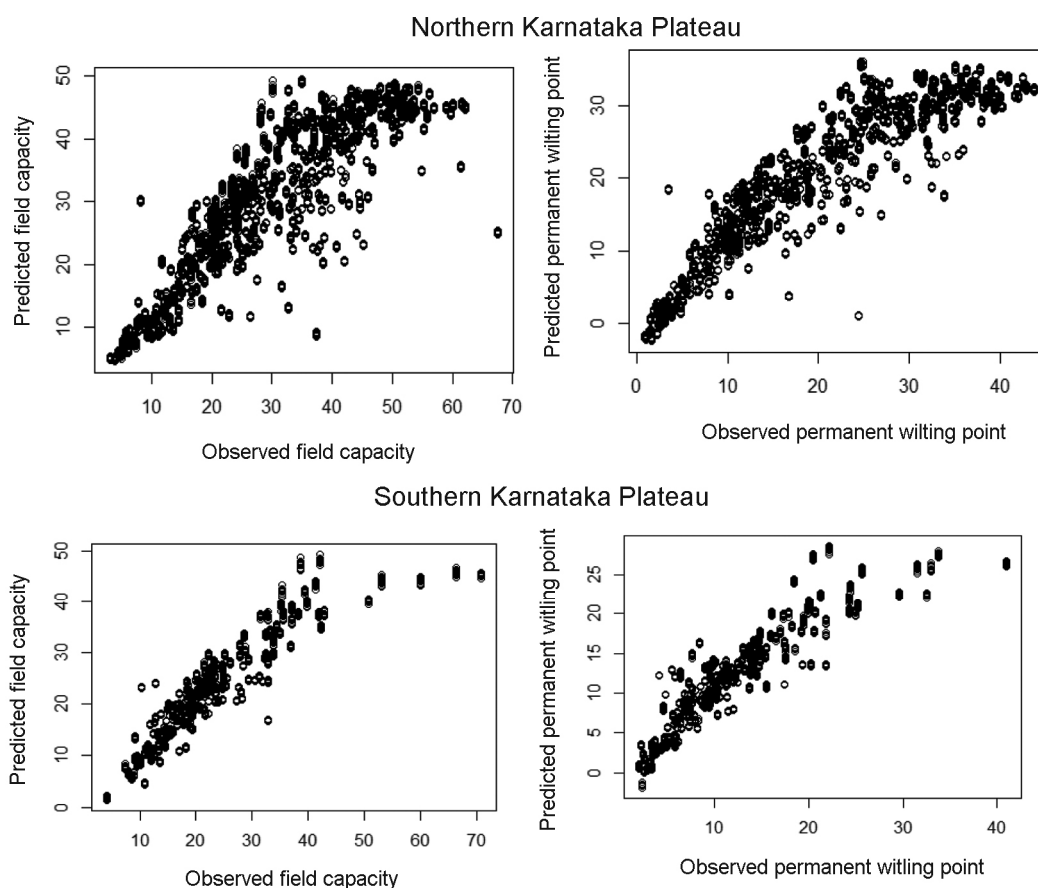
| Property  | Field capacity |                | Permanent wilting point |                |
|-----------|----------------|----------------|-------------------------|----------------|
|           | Estimate       | Standard error | Estimate                | Standard error |
| Intercept | 13.82          | 3.823***       | -5.776                  | 2.724*         |
| Clay      | 0.205          | 0.046***       | 0.315                   | 0.033***       |
| Sand      | -0.088         | 0.042*         | 0.050                   | 0.030          |
| CEC       | 0.316          | 0.025***       | 0.271                   | 0.018***       |

\*\*\*Significant at 0.001; \*Significant at 0.05.

**Table 4.** Regression analysis of water content at field capacity and permanent wilting point using clay content in NKP

| Property  | Field capacity |                | Permanent wilting point |                |
|-----------|----------------|----------------|-------------------------|----------------|
|           | Estimate       | Standard error | Estimate                | Standard error |
| Intercept | 4.968          | 0.789***       | -2.443                  | 0.520***       |
| Clay      | 0.586          | 0.017***       | 0.500                   | 0.011***       |

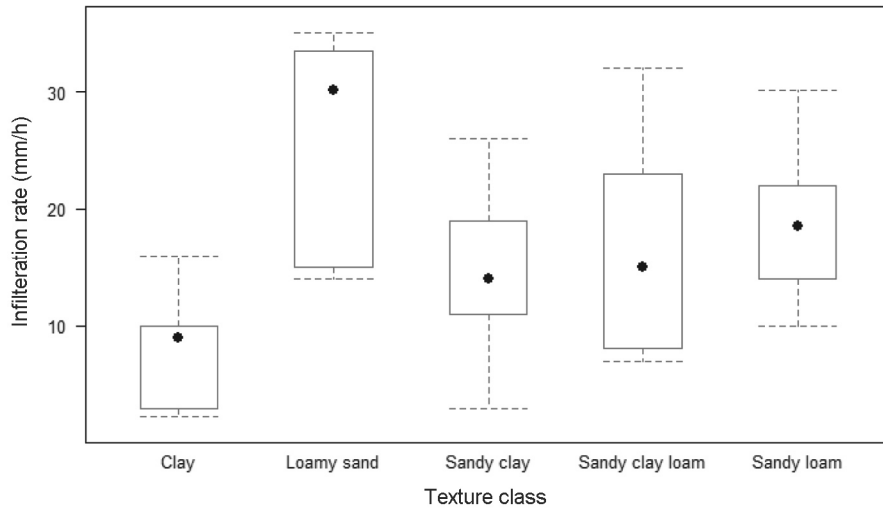
\*\*\*Significant at 0.001.



**Figure 5.** Observed and predicted soil moisture constants in NKP and SKP.

negatively correlated with sand (-0.857\*\*). PWP in NKP soils is significantly positively correlated with CEC (0.902\*\*), clay (0.898\*\*), silt (0.526\*\*), pH (0.335\*\*), and negatively correlated with sand (-0.890\*\*). Like NKP soils, FC and PWP in SKP soils are significantly

correlated with all the soil properties, except soil organic carbon. Adhikary *et al.*<sup>26</sup> also recorded that there is no significant relationship between soil organic matter and the corresponding FC and PWP in 800 samples studied across the country.



**Figure 6.** Infiltration rates under different texture classes in Karnataka.

**Table 5.** Multiple regression analysis of water content at field capacity and permanent wilting point in SKP

| Property  | Field capacity |                | Permanent wilting point |                |
|-----------|----------------|----------------|-------------------------|----------------|
|           | Estimate       | Standard error | Estimate                | Standard error |
| Intercept | 39.179         | 3.618***       | 8.227                   | 2.635**        |
| Clay      | -0.041         | 0.045          | 0.168                   | 0.032***       |
| Sand      | -0.371         | 0.040***       | -0.101                  | 0.029***       |
| CEC       | 0.257          | 0.035***       | 0.217                   | 0.025***       |

\*\*\*Significant at 0.001; \*\*Significant at 0.01.

**Table 6.** Performance of pedotransfer functions in predicting water content at field capacity (FC) and permanent wilting point (PWP)

| Property   | Northern Karnataka |                | Southern Karnataka |             |
|------------|--------------------|----------------|--------------------|-------------|
|            | FC                 | PWP            | FC                 | PWP         |
| $R^2$ (%)  | 83 ± 5.4           | 88 ± 4.2       | 84 ± 9.4           | 83 ± 8.6    |
| Mean error | -0.004 ± 0.76      | -0.0002 ± 0.54 | -0.002 ± 0.65      | 0.001 ± 0.5 |
| RMSE       | 5.25 ± 0.80        | 3.71 ± 0.61    | 3.05 ± 0.84        | 2.17 ± 0.53 |

The random forest model has the advantage that it helps to identify the importance of each predictor variable on prediction<sup>24,25</sup>. The analysis showed that CEC, sand and clay are the three top most important variables for prediction of FC and PWP in both regions (Figure 3). The order of important variables is CEC > sand > clay for FC, and CEC > clay > sand for PWP in NKP soils. It is sand > CEC > clay for FC, and sand > clay > CEC for PWP in case of SKP soils.

The PTFs were developed using the selected soil properties, viz. CEC, sand and clay as independent variables. The FC and PWP of soil were determined by the following equations

$$FC = a + b(CEC) + c(\text{sand}) + d(\text{clay}),$$

$$PWP = a + b(CEC) + c(\text{sand}) + d(\text{clay}),$$

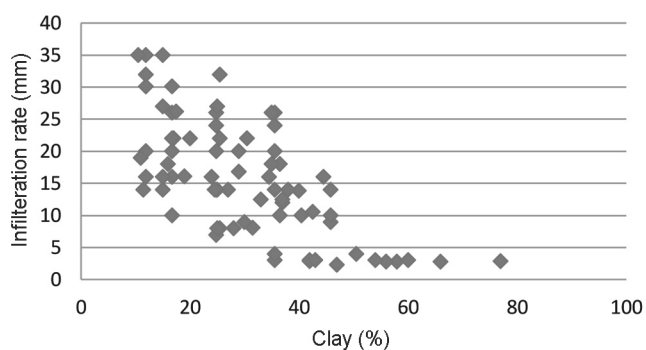
where  $a-d$  are the regression coefficients. The PTFs of soil hydraulic properties (FC and PWP) were developed separately for both regions, viz. North and South Karnataka. In case of infiltration rate, PTFs were developed for the entire Karnataka due to availability of limited datasets. The developed PTFs were cross-validated by ten-fold cross-validation techniques. Criteria of 1% and 5% level of significance were used for acceptance or rejection of a predictor variable in these models. The prediction of FC and PWP through the developed PTFs was satisfactory with low RMSE and high  $R^2$  (64–88%), except PTF for infiltration rate which had poor and acceptable  $R^2$  (41%).

For NKP, the PTFs of FC and PWP were developed using 512 soil layer observations of 100 profiles collected

**Table 7.** Regression analysis of water content at field capacity and permanent wilting point using clay content in SKP

| Property  | Field capacity |                | Permanent wilting point |                |
|-----------|----------------|----------------|-------------------------|----------------|
|           | Estimate       | Standard error | Estimate                | Standard error |
| Intercept | 3.724          | 0.993***       | -1.979                  | 0.559***       |
| Clay      | 0.581          | 0.029***       | 0.428                   | 0.016***       |

\*\*\*Significant at 0.001; \*\*Significant at 0.01.



**Figure 7.** Infiltration rate versus clay content in Karnataka.

in Gulburga, Gadag, Yadgir and Koppal districts. Table 3 summarizes the results of PTFs developed for estimating water retention at FC and PWP in NKP soils. The equations are as follows

$$FC = 13.82 + 0.205 (\text{clay}) - 0.088 (\text{sand}) + 0.316 (\text{CEC}),$$

$$PWP = -5.78 + 0.315 (\text{clay}) + 0.050 (\text{sand}) + 0.271 (\text{CEC}).$$

Clay with its large adsorption surface and CEC which reflects the negative charge of clay, greatly influence the soil water content due to adsorption of dipolar water molecules. The performance of PTF models in terms of  $R^2$  value was higher for PWP ( $R^2 = 88\%$ ) than for FC ( $R^2 = 83\%$ ), which indicates that variables used in the PTF model explained 88% variation for PWP and 83% for FC. Sand negatively influences the prediction of FC, whereas it positively influences the prediction of PWP. Tiwary *et al.*<sup>18</sup> developed PTFs for soil moisture content in basaltic region (black soil region), which is similar to NKP soils, using CEC, ESP and clay content of 75 soil layer observations of 14 soil profiles. The performance of PTFs were similar with  $R^2$  of 0.82 and 0.71 for FC and PWP respectively. The errors of estimations, RMSE, were also found very low for both FC (5.2%) and PWP (3.7%) in NKP soils. Bias (mean error) of the estimated values of FC and PWP was found smaller for this regression model than other established PTFs in India<sup>1</sup>. Negative bias in the NKP soils indicates that predicted values are larger than observed values.

Among the soil properties, clay content can be easily measured or judged using different methods. When only

clay content data are available, the following equation can be used to predict the FC and PWP in NKP soils (Figure 4, Table 4).

$$FC = 4.97 + 0.586 (\text{clay}),$$

$$PWP = -2.44 + 0.50 (\text{clay}).$$

The performance of regression model showed that  $R^2$  value was higher for PWP (80%) than FC (71%). RMSE values for FC (7.05%) and PWP (4.74%) which were comparatively higher than PTFs developed using clay + CEC + sand models.

Table 5 summarizes the results of PTFs developed for estimating the water retention at FC and PWP for SKP soils. The equations are as follows

$$FC = 39.18 - 0.041 (\text{clay}) - 0.371 (\text{sand}) + 0.257 (\text{CEC}),$$

$$PWP = 8.227 + 0.168 (\text{clay}) - 0.101 (\text{sand}) + 0.217 (\text{CEC}).$$

Like NKP soils, the performance of PTF models (Table 5) in SKP soils in terms of  $R^2$  value was higher for PWP (88%) than FC (84%), which indicates that variables explained more variation for PWP than FC. The relationship between predicted and observed soil moisture constants in NKP and SKP soils is depicted in Figure 5. Similar results were recorded by different researchers in India (Tiwary *et al.*<sup>18</sup>,  $R^2 = 67-82\%$ ; Mohanty *et al.*<sup>27</sup>,  $R^2 = 85\%$ ; Dabral and Pandey<sup>28</sup>,  $R^2 = 80\%$ ). In contrast to NKP soils, sand has negative influence on the prediction of both FC and PWP. RMSE values were also comparatively lower for both FC (3.05%) and PWP (2.17%) than NKP soils. Positive bias (mean error) was found for the prediction of PWP, whereas negative bias was observed for the prediction of FC (Tables 6 and 7).

The following equation can be used to predict soil moisture constants in SKP soils when only clay content data are available

$$FC = 3.72 + 0.581 (\text{clay}),$$

$$PWP = -1.98 + 0.43 (\text{clay}).$$

Like NKP soils, less performance was recorded for FC-clay ( $R^2 = 64\%$ ) and PWP-clay ( $R^2 = 73\%$ ) models compared to FC/PWP-clay + CEC + sand model (Table 8).



**Table 8.** Performance of PTFs developed using clay content in predicting water content at field capacity and permanent wilting point

| Property   | Northern Karnataka |              | Southern Karnataka |             |
|------------|--------------------|--------------|--------------------|-------------|
|            | FC                 | PWP          | FC                 | PWP         |
| $R^2$ (%)  | 71 ± 8.2           | 80 ± 4.9     | 64 ± 14            | 73 ± 10.7   |
| Mean error | 0.001 ± 1.0        | 0.002 ± 0.71 | 0.012 ± 1.3        | 0.006 ± 0.7 |
| RMSE       | 7.05 ± 1.01        | 4.74 ± 0.54  | 5.39 ± 1.2         | 3.13 ± 0.68 |

**Table 9.** Multiple regression analysis of infiltration rate in Karnataka

| Property  | Estimate | Standard error |
|-----------|----------|----------------|
| Intercept | 177.55   | 73.1*          |
| Clay      | -1.80    | 0.75*          |
| Sand      | -1.47    | 0.75*          |
| Silt      | -1.58    | 0.69*          |

\*Significant at 0.05.

Clayey soils retain more water than sandy soils. In both regions, i.e. NKP and SKP, higher  $R^2$  was recorded for PWP than FC. Shwetha and Varija<sup>29</sup> reported that water retention at lower tension (FC) does not mainly depend on soil texture like clay but on soil structure, but at higher tension (PWP) it depends on particle-size distribution and soil mineralogy.

Infiltration rate mainly depends on pore size and particle size. The PTFs for prediction of infiltration were developed from soil particles, viz. sand, silt and clay datasets of 100 observations in Karnataka (Figure 6 and Table 9). Infiltration rate varied from 2.3 to 35 mm/h, with mean and standard deviation of 15.69 and 8.75 mm/h respectively. Infiltration rate (mm/h) increased with decreasing clay content (Figure 7, clay (7.25) < sandy clay (14.69) < sandy clay loam (17.32) < sandy loam (18.80) < loamy sand (25.42)). The regression model developed showed minimum RMSE (6.71%) and acceptable  $R^2$  value (41%).

Infiltration rate = 177.55 - 1.47 (sand)

- 1.80 (clay) - 1.58 (silt).

Adhikary *et al.*<sup>26</sup> found that infiltration rate has a power function relationship with clay content ( $R^2 = 42\%$ ). The rate of decrease in infiltration rate is maximum till it reaches 20% clay, after which it reduces and becomes negligible. Mahdian *et al.*<sup>30</sup> developed PTFs for infiltration rate using silt, clay, sand, BD, FC and PWP as input variables. The performance of PTFs was highly significant with  $R^2$  of 74%. Unlike soil moisture constants, only limited research has been carried out on soil infiltration rate which might be due to the complex process and high variance.

Characterizing soil response to hydrology is a challenging task, particularly because of the difficulty in quantifying soil hydraulic properties and their spatial variability. For practical applications of PTFs, we need approaches that provide for hydraulic information in a

cost-effective manner, minimizing requirements for direct measurement of soil hydraulic properties. The PTFs developed in this study are improvised hydrologic predictions of semi-arid regions of southern India. Regular updation of PTFs with increased number of observations as well as increased number of independent variables like BD and aggregate stability will improve the results.

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## Impact of Pusa hydrogel application on yield and productivity of rainfed wheat in North West Himalayan region

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**Farmers in the North West Himalayan region generally practise rainfed agriculture and have very limited scope for irrigation. Water scarcity is a major constraint for crop production in these areas. This problem exacerbates further during the Rabi season where vagaries of winter rain result in complete crop failure. This study was conducted in the Raipur Block of Dehradun district in the farmer's field to study the impact of hydrogel on yield and productivity of wheat. Hydrogel is a hydrophilic polymer having high water holding capacity and can provide water to crops during moisture stress. Hydrogel was applied in the field in Rabi wheat with two broad treatments, i.e. with hydrogel (WH) and without hydrogel (WHO). Each treatment was replicated ten times, i.e. ten demonstrations were laid out in the field conditions. Hydrogel was applied at the rate of 5 kg ha<sup>-1</sup> and observations related to various plant growth parameters and yield were recorded. The plant population in hydrogel plots increased by 22% compared to the non-hydrogel treated plots. The effective tillers, plant height, ear length and grains per ear significantly improved due to hydrogel application. The total yield as well as grain yield increased significantly after hydrogel amendment. The improved performance of wheat upon hydrogel application was evident in the field. This technology could be promising in terms of productivity improvement of rainfed crops and in combating the moisture stress in agriculture.**

**Keywords:** Hydrogel, Northwest Himalayas, rainfed wheat, yield.

DESPITE the fast-paced development in agricultural sector, a majority of the arable area in our country (i.e. around 67% of the net sown area) still remains under rainfed condition<sup>1</sup>. Even after achievement of full irrigation potential of the country by various Government schemes like the 'Pradhan Mantri Krishi Sinchayi Yojna' and 'Har Khet Ko Pani' about 40% of the agricultural land is still in need of irrigation. Thus, a majority of the cultivated area across the length and breadth of the country is primarily dependent on the monsoon for livelihood

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