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# Inter-relationship between water retention, transmission and some soil parameters of typical saline black soils of Gujarat state

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**Abstract:** An attempt was made to establish a quantifiable relationship between sand, silt, clay, ECe, CEC and ESP and field capacity (FC), wilting point (WP), available water content (AWC) and saturated hydraulic conductivity (Ks). Water retention was lower in surface horizon than subsurface horizons. The clay, silt + clay and CEC had significant positive relationship with FC, WP and AWC, whereas sand and ECe had significant negative correlation. The saturated hydraulic conductivity had significant positive correlation with sand and EC and significant negative correlation with clay, ECe, CEC and ESP. The clay influenced 52.3 per cent variation in saturated hydraulic conductivity. Similarly ECe caused 89.4 and 72.0 per cent variation on FC and AWC, respectively, while CEC had 86.6 per cent variation in WP. Clay, CEC, ECe and ESP jointly accounted for highest variation (89.4 %) in saturated hydraulic conductivity and among them clay shared 52.3 per cent variation.

***Additional keywords:*** *Field capacity, wilting point, available water content, saturated hydraulic conductivity, regression*

## Introduction

Saline black soils are quite prevalent in Surendranagar, Bhavnagar, Ahmedabad, Kheda, Bharuch and Surat district of Gujarat. The soils of this region have developed over variety of parent materials and display wide variation in characteristics. Under semi-arid tropical climate, the profile water retention and their transmission characteristics in saline black soils are crucial for the success of crop production. Attempts have been made in the past (Bhavanarayana *et al.* 1986; Das and Datta 1997; Mathan and Mahendran 1997; Yadav and Vyas 1998) to develop interrelationship between soil parameters and moisture retentions but information related to saline black soils of Gujarat is lacking and hence present investigation was carried out.

## Materials and methods

Horizon-wise soil samples were collected and processed for laboratory analysis. Undisturbed core samples were taken for water retention and hydraulic conductivity study. The water retention characteristics were estimated using Pressure Plate apparatus at 33, 100, 500, 700 and 1500 kPa suctions as per the method described by Richards (1954). The gravimetric water content was converted to volumetric water by multiplying it with bulk density. The saturated hydraulic conductivity was determined by the constant head method. The difference between water content at 1500 kPa and 33 kPa was taken as available water content. International Pipette Method was followed for estimation of soil separates (Piper 1950). The cation exchange capacity (CEC) and exchangeable sodium were estimated by the method prescribed by Jackson (1973). The correlation between the relevant parameters were worked out and contribution of the above parameters to the moisture retention characteristics was determined by linear multiple regression analysis.

## Results and discussion

The relevant data pertaining to physical and chemical properties of soils, water retention and saturated hydraulic conductivity are presented in Table 1. The pedon 5 had higher clay ranging from 49.5 to 53.1 per cent but lower clay values were recorded for pedon 2 . The ECe value ranged from as low as 1.2 to 3.8 dS $m^{-1}$ in pedon 5 to as high as 76.0 to 132.0 dS $m^{-1}$ in pedon 3. The cation exchange capacity ranged from 19.0 to 40.3 cmol (p+) $kg^{-1}$ in different horizons.

The water retention at 33 kPa varied between 0.236 to 0.483 $cm^3$ $cm^{-3}$ whereas at 1500 kPa it ranged from 0.121 to 0.265 $cm^3$ $cm^{-3}$. The available water content varied widely among the pedons ranging from 0.114 to 0.230 $cm^3$ $cm^{-3}$. In general, surface soils at field capacity and wilting point had less water retentions owing to less clay and CEC, which are the major contributing factors for water retention at field capacity and wilting point. Similar observations were also reported by Prasad *et al.* (1998). High water retention at low tension (33 kPa) and *vice versa* is due to variation in structure and pore geometry of soil (Chatterji *et al.* 1995). The loosely bound water at 300 to 500 kPa is accumulated in structural pores (Yule and Ritchie 1980) is positively correlated with silt and clay. Pedon 1, 4 and 5 had higher values of moisture retention both at FC and WP because of higher clay and CEC than the other two pedons. The saturated hydraulic conductivity (Ks) ranged from 0.04 to 1.04 cm $h^{-1}$. Though the pedon 2 and 3 had more or less same clay content throughout the horizons, the pedon 2 showed higher Ks value as compared to pedon 3. Of all

**Table 1. Important soil properties and water retentions**

| Horizon | Depth (m) | Sand (%) | Silt (%) | Clay (%) | ECe ($dSm^{-1}$) | CEC [cmol (p+)$kg^{-1}$] | ESP | Water retention ($cm^{-3}$ $cm^{-3}$) 33 kPa | 1500 kPa | AWC | Ks cm $h^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Pedon 1: Orra : Fine, smectitic, hyperthermic Typic Haplusterts** | | | | | | | | | | | |
| Ap | 0-0.15 | 32.5 | 25.0 | 42.5 | 7.5 | 36.0 | 1.9 | 0.39 | 0.235 | 0.155 | 0.12 |
| Bw1 | 0.15-0.38 | 30.0 | 22.0 | 48.0 | 7.0 | 38.2 | 2.9 | 0.40 | 0.245 | 0.157 | 0.12 |
| Bss2 | 0.38-0.82 | 19.5 | 28.5 | 52.0 | 6.2 | 39.8 | 2.8 | 0.45 | 0.255 | 0.195 | 0.10 |
| Bss3 | 0.82-1.50 | 21.0 | 29.0 | 50.0 | 5.9 | 40.3 | 3.7 | 0.48 | 0.265 | 0.218 | 0.10 |
| BC | 1.50-1.80 | 20.0 | 42.0 | 38.0 | 6.1 | 36.2 | 4.4 | nd | nd | nd | 0.12 |
| **Pedon 2: Kalamsar : Fine–loamy, mixed, hyperthermic Fluventic Haplustepts** | | | | | | | | | | | |
| Ap | 0-0.20 | 46.0 | 23.3 | 31.7 | 70.0 | 18.6 | 2.6 | 0.32 | 0.144 | 0.161 | 1.04 |
| A12 | 0.20-0.40 | 41.3 | 25.5 | 31.4 | 50.0 | 19.2 | 2.9 | 0.33 | 0.161 | 0.167 | 0.92 |
| Bw1 | 0.40-0.70 | 31.7 | 25.8 | 32.5 | 54.0 | 19.6 | 3.4 | 0.34 | 0.168 | 0.168 | 0.82 |
| Bw2 | 0.70-1.05 | 39.4 | 26.2 | 34.4 | 56.0 | 20.3 | 3.9 | 0.32 | 0.150 | 0.171 | 0.76 |
| C | 1.05-1.50 | 37.5 | 27.5 | 35.0 | 49.0 | 19.9 | 4.2 | 0.35 | 0.175 | 0.170 | 0.74 |
| **Pedon 3: Saragwada : Fine–loamy, mixed, hyperthermic Typic Ustorthents** | | | | | | | | | | | |
| Ap | 0-0.15 | 48.0 | 20.0 | 32.6 | 132.0 | 19.0 | 9.5 | 0.24 | 0.121 | 0.115 | 0.26 |
| A2 | 0.15-0.35 | 43.6 | 23.9 | 32.5 | 86.0 | 19.6 | 10.3 | 0.24 | 0.128 | 0.114 | 0.25 |
| A3 | 0.35-0.80 | 42.5 | 23.5 | 34.0 | 80.0 | 20.2 | 12.0 | 0.25 | 0.132 | 0.120 | 0.24 |
| C | 0.80-1.50 | 40.4 | 24.6 | 35.0 | 76.0 | 22.1 | 14.5 | 0.25 | 0.136 | 0.118 | 0.22 |
| **Pedon 4: Traj : Fine, mixed, hyperthermic Typic Halaquepts** | | | | | | | | | | | |
| A1 | 0-0.10 | 36.8 | 21.4 | 41.8 | 7.3 | 32.2 | 9.2 | 0.42 | 0.224 | 0.191 | 0.16 |
| Bw1 | 0.10-0.36 | 38.8 | 18.0 | 43.2 | 7.8 | 34.9 | 9.5 | 0.43 | 0.233 | 0.185 | 0.16 |
| Bw2 | 0.36-0.55 | 34.0 | 26.0 | 40.0 | 8.9 | 36.2 | 10.0 | 0.45 | 0.251 | 0.199 | 0.15 |
| Bw3 | 0.55-0.85 | 35.2 | 26.2 | 38.6 | 6.3 | 35.2 | 8.8 | 0.45 | 0.257 | 0.196 | 0.14 |
| Bw4 | 0.85-1.10 | 35.4 | 23.8 | 40.8 | 5.4 | 33.5 | 8.7 | 0.45 | 0.255 | 0.197 | 0.14 |
| C | 1.10-1.30 | 37.0 | 23.9 | 39.1 | 4.3 | 32.1 | 8.8 | nd | nd | nd | 0.14 |
| **Pedon 5: Vejalka : Fine, smectitic, hyperthermic Vertic Haplustepts** | | | | | | | | | | | |
| Ap | 0-0.25 | 24.9 | 24.6 | 50.0 | 1.2 | 28.5 | 9.5 | 0.43 | 0.230 | 0.200 | 0.05 |
| Bw1 | 0.25-0.40 | 23.7 | 26.8 | 49.5 | 1.5 | 29.0 | 9.8 | 0.43 | 0.220 | 0.210 | 0.04 |
| Bw2 | 0.40-0.80 | 21.0 | 25.7 | 53.3 | 2.2 | 28.5 | 10.0 | 0.44 | 0.240 | 0.200 | 0.04 |
| Bw3 | 0.80-1.00 | 18.4 | 28.3 | 53.3 | 3.6 | 30.5 | 10.5 | 0.45 | 0.220 | 0.230 | 0.04 |
| BC | 1.00-1.50 | 22.4 | 28.8 | 49.8 | 3.8 | 28.0 | 10.8 | 0.42 | 0.220 | 0.200 | 0.04 |

nd - not detected.

**Table 2. Relationship (correlation coefficient, r) between different soil properties and water retention**

| Soil parameters | Water retention ($cm^3$ $cm^{-3}$) at different kPa 33 | 100 | 300 | 500 | 700 | 1500 | AWC | Ks |
|---|---|---|---|---|---|---|---|---|
| Sand | -0.766** | -0.842** | -0.766** | -0.860** | -0.773** | -0.717** | -0.766** | 0.560** |
| Silt | 0.361 | 0.338 | 0.361 | 0.370 | 0.308 | 0.274 | 0.487* | -0.068 |
| Clay | 0.791** | 0.899** | 0.791** | 0.853** | 0.825** | 0.774** | 0.727** | -0.723** |
| Silt+Clay | 0.778** | 0.863** | 0.778** | 0.833** | 0.790** | 0.737** | 0.762** | -0.632** |
| EC | -0.945** | -0.945** | -0.945** | -0.923** | -0.915** | -0.930** | -0.849** | 0.510* |
| CEC | 0.834** | 0.866** | 0.837** | 0.807** | 0.915** | 0.925** | 0.596** | -0.681** |
| ESP | -0.112 | -0.405* | -0.112 | -0.074 | -0.135 | -0.114 | -0.085 | -0.532** |

**Table 3. Stepwise multiple linear regression equation showing contribution of soil parameters to water retentions**

| Regression equation | $R^2$ |
|---|---|
| **33 kPa** | |
| $Y = 0.598 - 0.007$ Sand ($X_1$) | 58.75** |
| $Y = 0.130 + 0.010$ Silt ($X_2$) | 13.03 |
| $Y = 0.053 + 0.008$ Clay ($X_3$) | 62.64** |
| $Y = -0.055 + 0.007$ (Silt + Clay) ($X_4$) | 60.59** |
| $Y = 0.442 - 0.0020$ EC (X5) | 89.36** |
| $Y = 0.138 + 0.009$ CEC ($X_6$) | 69.53** |
| $Y = 0.397 - 0.002$ ESP ($X_7$) | 1.26 |
| $Y = 0.370 - 0.002 X_5 + 0.002 X_6$ | 90.04** |
| $Y = 0.394 - 0.001 X_1 - 0.002 X_5 + 0.002 X_6$ | 90.07** |
| $Y= 0.030 - 0.002 X_3 + 0.002 X_4 - 0.002 X_5 + 0.002 X_6$ | 89.52** |
| **1500 kPa** | |
| $Y = 0.331 - 0.004 X_1$ | 51.36** |
| $Y = 0.084 + 0.005 X_2$ | 7.50 |
| $Y = 0.002 + 0.005 X_3$ | 59.87** |
| $Y = 0.006 + 0.004 X_4$ | 54.31** |
| $Y = 0.242 - 0.001 X_5$ | 86.53** |
| $Y = 0.035 + 0.006 X_6$ | 86.61** |
| $Y = 0.214 - 0.002 X_7$ | 1.30 |
| $Y = 0.134 - 0.001 X_5 + 0.003 X_6$ | 95.05** |
| $Y = 0.137 - 0.0001X_1 - 0.001X_5 + 0.003 X_6$ | 94.82** |
| $Y = 0.182 - 0.001 X_1 - 0.001 X_3 - 0.001 X_5 + 0.003 X_6$ | 94.74** |
| $Y = 0.220 - 0.001 X_1 - 0.001 X_2 - 0.001 X_3 - 0.001 X_5 + 0.003 X_6$ | 94.47** |
| **AWC** | |
| $Y = 0.269 - 0.003 X_1$ | 58.70** |
| $Y = 0.032 + 0.006 X_2$ | 23.76* |
| $Y = 0.047 + 0.003 X_3$ | 52.86** |
| $Y = - 0.007 + 0.003 X_4$ | 58.15** |
| $Y = 0.200 - 0.001 X_5$ | 72.04** |
| $Y = 0.102 + 0.003 X_6$ | 35.52* |
| $Y = 0.181 - 0.001 X_7$ | 0.72 |
| $Y = 0.228 - 0.001 X_1 - 0.001 X_5$ | 72.79** |
| $Y = 0.165 + 0.002 X_2 - 0.001 X_5 - 0.001 X_6$ | 73.52** |
| $Y = 0.151 + 0.002 X_2 + 0.001X_3 - 0.001 X_5 - 0.001 X_6$ | 72.68** |
| $Y = 0.216 - 0.001 X_1 + 0.001 X_2 - 0.0001 X_3 - 0.001 X_5 - 0.001 X_6$ | 71.29** |

** Significant at 1 per cent, * significant at 5 per cent level.

**Table 4. Stepwise multiple regression equation showing contribution of the soil parameters to saturated hydraulic conductivity (Ks)**

| Regression equation (Y=Ks) | $R^2$ |
|---|---|
| $Y = -8.576 + 0.466$ Sand $(X_1)$ | 31.33* |
| $Y = 11.531 - 0.184$ Silt $(X_2)$ | 0.47 |
| $Y = 35.903 - 0.700$ Clay $(X_3)$ | 52.33** |
| $Y = 41.189 - 0.517$ (Clay+Silt) $(X_4)$ | 39.93** |
| $Y = 3.629 + 0.105$ EC $(X_5)$ | 26.05* |
| $Y = 26.066 - 0.676$ CEC $(X_6)$ | 46.40** |
| $Y = 15.031 - 1.084$ ESP $(X_7)$ | 28.25* |
| $Y = 37.046 - 0.738 X_6 - 1.239 X_7$ | 81.21** |
| $Y = 42.021 - 0.284 X_3 - 0.525 X_6 - 1.138 X_7$ | 84.83** |
| $Y = 57.860 - 0.485 X_3 - 0.087 X_5 - 0.712 X_6 -1.067 X_7$ | 89.36** |
| $Y = 56.729 + 0.017 X_1 - 0.467 X_3 - 0.088 X_5 - 0.716 X_6 - 1.072 X_7$ | 88.74** |
| $Y = 56.62 + 0.017X_1 + 0.001 X_2 - 0.466 X_3 - 0.088 X_5 - 0.716 X_6 - 1.072 X_7$ | 88.03** |

** Significant at 1 per cent, * significant at 5 per cent level

the pedons, pedon 5 showed the lowest Ks value which ranged from 0.04 to 0.05 cm $h^{-1}$. This may be due to high clay content, vertic nature, low ECe and high ESP.

Water retention at different tensions showed highly positive and significant correlation with clay, silt + clay and CEC of soils. Silt showed significant and positive correlation whereas sand and EC showed highly negative and significant correlation with available water content. Such behaviour of moisture retention is largely attributed to pore-size distribution resulting from sand and silt content. The moisture retention is largely controlled by the swelling and adsorptive forces associated with clay, silt and soluble salts. The correlation with ESP was non-significant. Under both the tension levels (FC and WP), the highest correlation was recorded with EC followed by CEC, clay, silt + clay, sand, silt and ESP. Thus it is revealed that moisture retention at FC and WP in saline black soils was a resultant of two sets of factors influencing in opposite direction (Table 2). The interactive effect of ECe and ESP on Ks was contradictory to each other. The sand and ECe of soils had significant positive correlation but clay, CEC and ESP had significant negative correlation with saturated hydraulic conductivity. The dispersion and swelling are observed to be important processes, affected by the electrolyte concentration and exchangeable sodium, and govern the Ks of clay and clay loam soils (Choudhary 2001)

Stepwise multiple regressions were worked out for accounting the variations in water retention at FC, WP and AWC. Of the six, three variables *viz.* sand, ECe and CEC significantly influenced the water retention (90.1 per cent) at 33 kPa (Table 3). Individually, ECe contributed the most to the variation accounting 89.4 per cent. The contribution of CEC and ECe play a major role in determining the water retention at 1500 kPa. Mathan and Mahendran (1997) reported that the soluble salt concentration of the soils play a major role in determining the water retention at 1500 kPa. Both ECe and CEC contributed 95.0 per cent variation. Inclusions of sand, silt, clay, silt + clay and ESP did not increase $R^2$ value. The contribution of ECe alone to prediction equation was 72.0 per cent for AWC. The silt, ECe and CEC jointly contributed 73.5 per cent to the prediction equation. Further inclusion of any other parameter was not found useful. The clay content is the main contributing factor for the variation in the saturated hydraulic conductivity followed by CEC and ESP out of the six variables, clay, CEC, ECe and ESP jointly accounted for highest per cent (89.4) of variation to the saturated hydraulic conductivity. Clay alone contributed towards 52.3 per cent variation in the prediction of Ks.

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