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Assessment of the Role of different Soil Properties on Crust Strength by Linear Regression Models

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ABSTRACT

Soil crust strength influences seedling emergence, penetration and morphology of plant roots, and, consequently, crop yields. A study was carried out to assess the role of different soil properties on crust strength at Hisar, Haryana, India. The soil samples from 0-5 and 5-15 cm depths were collected from 21 locations from farmer's fields, having a wide range of texture. Soil properties were evaluated in the laboratory and their in fluence on the modulus of rupture (MOR), the measure of crust strength, was evaluated. The MOR of texturally different soils was significantly correlated with saturated hydraulic conductivity at both the depths. Dispersion ratio was found to decrease with an increase in fineness of the texture of soil and the lowest value was recorded in silty clay loam soil, which decreased with depth. The modulus of rupture was significantly negatively correlative with the dispersion ratio. There was no role of calcium carbonate in influencing the values of MOR of soils. Similarly, the influence of pH, EC and SAR of soil solution on MOR was non-significant.A perusal of the values of the correlations between MOR and different soil properties showed that the MOR of soils of Haryana are positively correlated with silt+clay (r=0.805) followed by water-stable aggregates (r = 0.774), organic carbon (r = 0.738), silt (r = 0.711), mean weight diameter (r = 0.608) and clay (r = 0.593) while negatively correlated with dispersion ratio (r = - 0.872), sand (r = -0.801) and hydraulic conductivity (r = -0.752) of soils.

KEYWORDS

Crust strength, Hydraulic conductivity, Linear Regression Models, Modulus of rupture, Soil Texture

INTRODUCTION

Soil Crusting is a surface phenomenon caused by the susceptibility of aggregates to disruptive forces of climate and agricultural practices (tillage and traffic). Dispersion of aggregates, reorientation of dispersed particles and hardening of soil material upon drying leads to the formation of the soil crust. Soil crusting influences seedling emergence, penetration and morphology of plant roots, and, consequently, crop yields. The extent to which seed emergence is affected depends on the crust strength. Crust strength is measured by many procedures such as shear strength, penetrometer resistance, tensile strength or modulus of rupture test.

Modulus of rupture is a measure of the breaking strength of the soil and is used to assess the physical status of the seedbed, especially the crust strength. Different properties of soil such as saturated hydraulic conductivity, dispersion ratio, pH, EC and exchangeable cations such as calcium and sodium, etc., affect the strength of crust. Crust strength increases with a decrease in saturated hydraulic conductivity and an increase in sodium absorption ratio, which consequently increases penetration resistance to roots and their development and reduces crop yield (Vrindts *et al*., 2005). The different worker has used multiple regression analysis for estimating soil penetration resistance (Grunwald *et al*., 2001; Aggarwal *et al*., 2006), therefore, in the present study,the role of different soil properties on crust strength has been assessed by using linear regression models.

MATERIALS AND METHODS

An experiment was conducted at CCSHAU, Hisar, Haryana, during 2016-17 by taking soil samples from different locations from the State of Haryana. The soil samples were collected from 0-5 cm and 5-15 cm depths and were analyzed for their different properties. The soil core samples (internal diameter = 5 cm and height = 5 cm) were used for measuring saturated hydraulic conductivity. After saturating the core for overnight saturated hydraulic conductivity was measured using a constant head method (Richard, 1954) in the laboratory.

For determination of dispersion ratio, known mass of soil samples were soaked in distilled water and a final volume of one liter was made in a sedimentation cylinder. The soil suspension was mixed thoroughly by end-over-end shaking for 20 times. A sample of soil suspension was taken at a given depth at a predetermined time according to temperature. Percent silt + clay was calculated from the suspension. Percent silt + clay was also determined from mechanical analysis. The dispersion ratio of the soils was estimated as follows (Piper, 1966):

Dispersion ratio =
X/Y, where X is percent silt plus clay dispersed in water and Y is percent silt plus clay from the mechanical analysis.

Calcium carbonate of soil samples was determined by titrating the soil suspension with 0.5N H_2SO_4 in the presence of bromothymol blue and bromocresol green indicators using rapid titration method Puri's (1930). Soil water suspension was prepared in 1:2::soil: water, i.e., 40 ml of water is added to 20 g of soil and stirred

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with glass rod intermittently for 30 minutes for analysis of pH and EC. pH meter was calibrated with a buffer solution of 7.0 and 9.2 pH. After allowing standing the suspension until clear supernatant liquid was obtained, the EC was measured using EC meter (Jackson, 1967).

After measuring the concentration of Na, Ca and Mg in the clear solution using standard methods, the sodium adsorption ratio (SAR) of soil solution was calculated as:

$$SAR = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} Mg^{2+})}}$$

For the determination of MOR, soil samples were ground and passed through 2 mm sieve. The samples were placed in a rectangular briquette mould set on a porous base and saturated with deionized water. After saturation, the soil is dried in an oven at 50 °C. The soil briquettes, thus, made were broken on a breaking machine. The dimensions of the briquettes fractured surface were measured and the modulus of rupture was calculated as follows:

$$S = \frac{3FL}{2bd^2}$$

Where S = modulus of rupture (dynes cm^{-1})
F = breaking force (dynes) = weight of water × 980
L = the distance between two lower bars (cm)
b = width of briquette (cm)
d = thickness of briquette (cm).

Karl Pearson correlation of modulus of rupture with different soil properties was calculated and the impact of various features on MOR was established using a step down regression.

RESULTS AND DISCUSSION

Saturated hydraulic conductivity

The mean values of saturated hydraulic conductivity (K_s) of different textured soils (Table 1) indicated that the K_s increased with an increase in coarseness in soil texture. The K_s was highest in the surface layer in all the texturally different soils and decreased with depth. It was observed highest in sand and lowest in silty clay loam soil. A significant positive & negative correlation was found with sand content and negatively with clay content. Shwetha and Varija (2015) found the highest saturated hydraulic conductivity for sandy soils (13.92 to 6.48 cm hr^{-1}) followed by loamy sand and sandy loam soils.

Table 1: Mean saturated hydraulic conductivity of different textured soils at 0-5 and 5-15 cm depths

Texture	Saturated hydraulic conductivity (cm hr^{-1})	
	0-5 cm	5-15 cm
Sand	14.68 ± 1.44	12.88 ± 1.61
Loamy sand	4.22 ± 0.43	3.88 ± 0.34
Sandy loam	1.98 ± 0.04	1.75 ± 0.04
Loam	0.72 ± 0.33	0.58 ± 0.27
Silty loam	0.61 ± 0.06	0.45 ± 0.05
Sandy clay loam	0.44 ± 0.02	0.30 ± 0.02
Clay loam	0.31 ± 0.05	0.28 ± 0.04
Silty clay loam	0.18 ± 0.06	0.15 ± 0.03

The modulus of rupture of texturally different soils was significantly negatively and exponentially correlated with saturated hydraulic conductivity with R^2 value of 0.76 and 0.81 (Fig. 1a and b) at 0-5 cm and 5-15 cm depths, respectively. The results show that as the saturated hydraulic conductivity increases, the modulus of rupture decreases and vice versa. This may be due to the different texture of the soil. Mullins *et al.*(1987) and Le Bissonnais (1996) indicated that particle size distribution resulting from the dispersion of aggregates determines the hydraulic properties. [It also shows that as soil organic carbon content increases, the volume of water transmitting pores decreases and consequently, K_s decreases exponentially.]

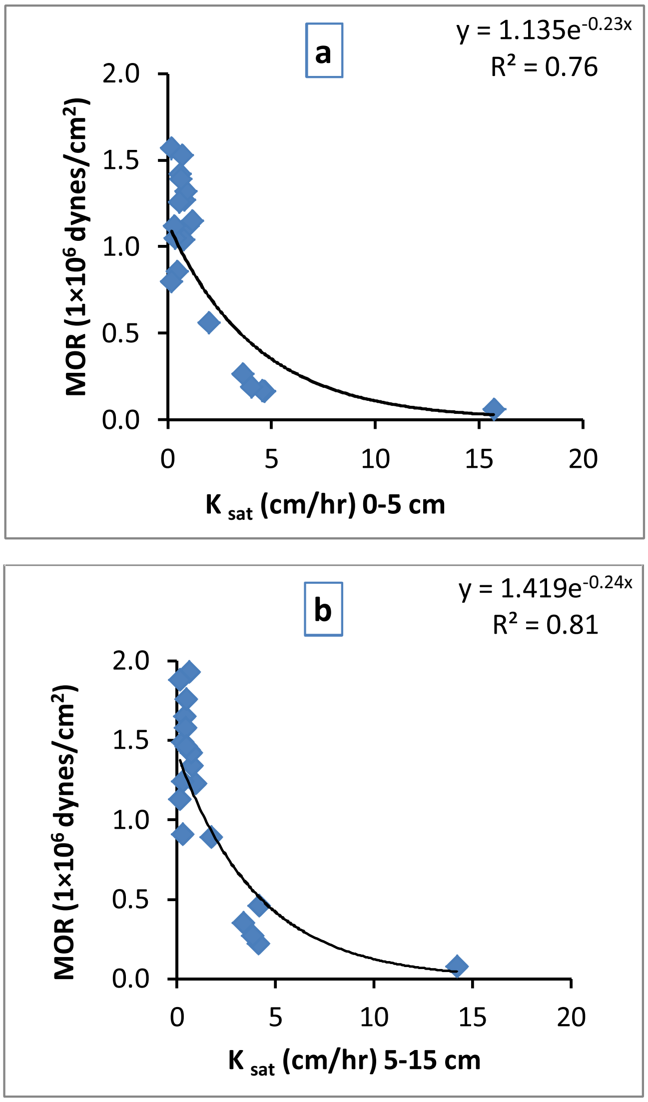

Fig.1: Relationship of Modulus of rupture (MOR) (a) 0-5 cm and (b) 5-15 cm depths with a saturated hydraulic conductivityof texturally different soils

Hydraulic conductivity was found significantly negatively and exponentially correlated with stable water aggregates with R^2 value of 0.90 (Fig. 2a and b) in both 0-5 and 5-15 cm depths. Yazdanpanah*et al.*(2016) found that soils with lower soil organic carbon compared to those with higher organic carbon resulted in higher hydraulic conductivity due to more water stable aggregates and macro pore fraction.

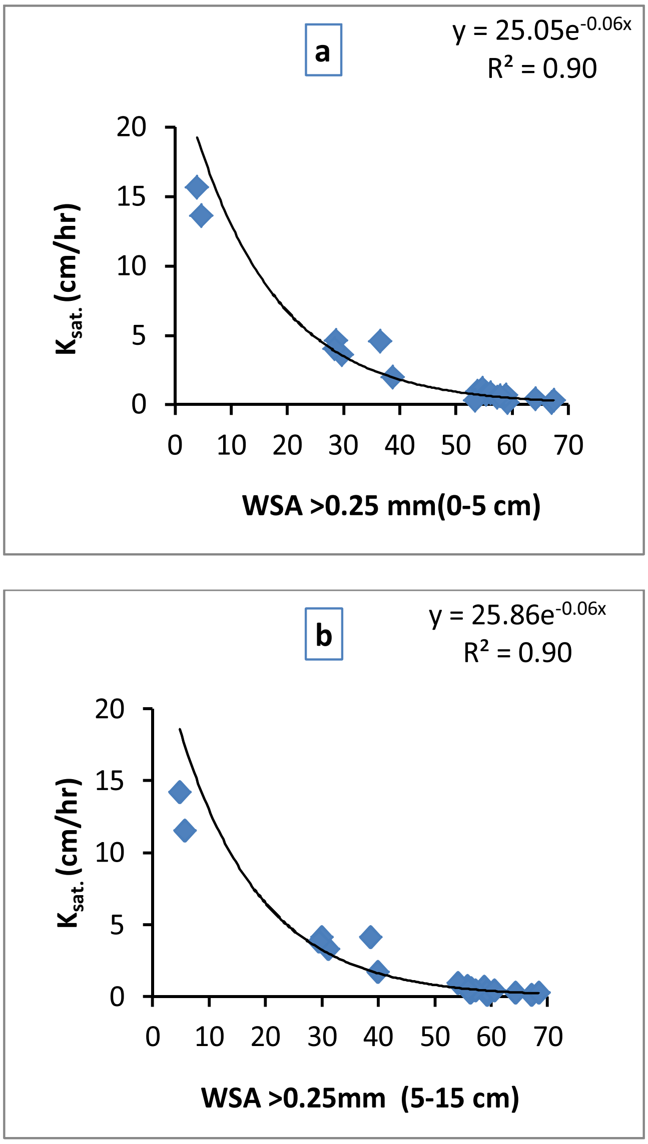

Fig.2: Relationship of saturated hydraulic conductivity (K_s) with water stable aggregates (> 0.25 mm) at 0-5 and 5-15 cm soil depths

Dispersion ratio

The data on dispersion ratio at different depths (Table 2) showed that sand soil was having the highest value of dispersion ratio while it was lowest in silty clay loam soil. The dispersion ratio found to decrease with an increase in depth and fineness of the texture.Gu and Doner (1993) also found the positive correlation between dispersion ratio with clay and negative correlation between dispersion ratio with sand, silt and calcium carbonate.

Table 2: Dispersion ratio of different textures soils at different depths

Texture	Dispersion ratio	
	0-5cm	5-15cm
Sand	1.00 ± 0.00	0.85 ± 0.04
Loamy sand	0.75 ± 0.05	0.75 ± 0.03
Sandy loam	0.67 ± 0.05	0.58 ± 0.04
Loam	0.46 ± 0.06	0.45 ± 0.07
Silty loam	0.41 ± 0.04	0.36 ± 0.06
Sandy clay loam	0.54 ± 0.02	0.46 ± 0.01
Clay loam	0.34 ± 0.00	0.27 ± 0.00
Silty clay loam	0.29 ± 0.00	0.25 ± 0.00

Modulus of rupture was found significantly negatively correlative with dispersion ratio at 0-5 and 5-15 cm depths, respectively (Fig. 3a and b). The dispersion ratio was found

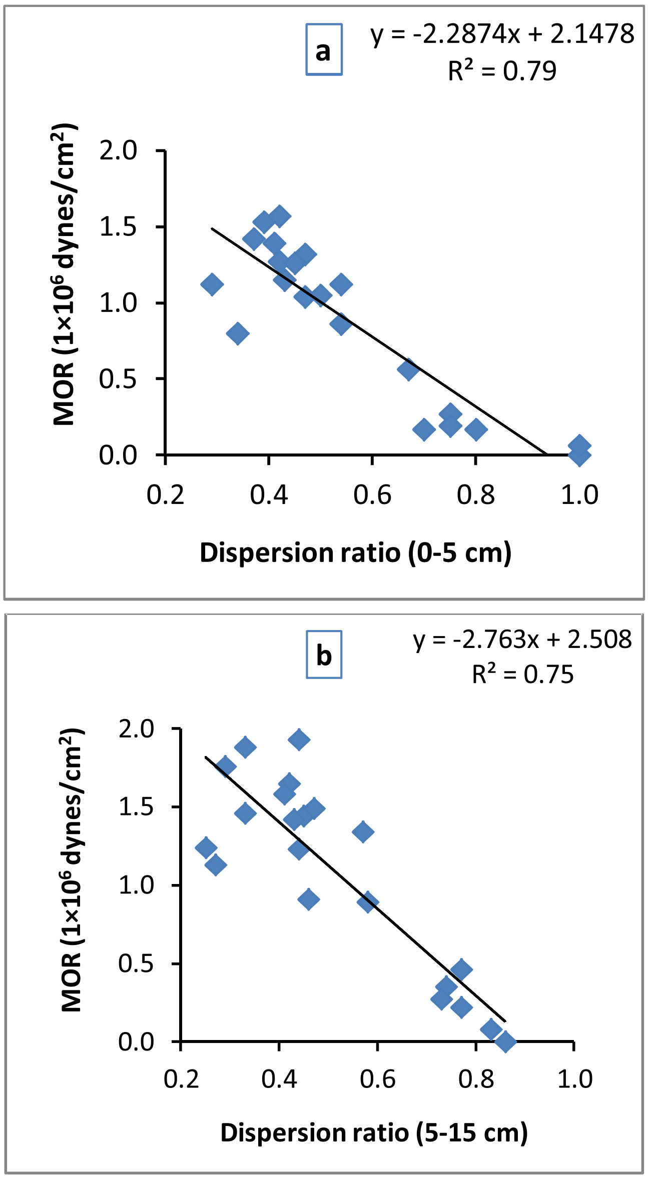

Fig.3: Relationship of modulus of rupture (MOR) with dispersion ratio at (a) 0-5 cm and (b) 5-15 cm depths

positively correlated with sand content and saturated hydraulic conductivity. In the absence of raindrop impact, clay swelling and dispersion are two major mechanisms that have been considered to cause a reduction in saturated hydraulic conductivity of soils when they are leached with deionized water (Shainberg and Letey, 1984). Less dispersive clay contains more aliphatic materials in the topsoils and carbohydrates in the subsoil. These compounds may act as 'glue' to hold particles together (Nelson *et al.*, 1999).

Calcium carbonate

Calcium carbonate for 0-5 and 5-15 cm depths of eight different textured soils is given in Table 3. No definite trend was observed in the calcium carbonate content of different textured soils at both the depths.

Calcium carbonate was found positively correlated with pH of soils, but it was not significantly correlated with any other properties studied including MOR. The use of soil amendments containing Ca^{2+} and Mg^{2+} such as lime and gypsum can have profound effects on aggregation. Canasveras *et al.*(2010) reported a close correlation of the contents of clay, calcium carbonate, and organic matter with soil aggregate stability. Increased aggregate stability in limed soils suggests the formation of strong bonding (Chan and Heenan, 1999).

Table 3: Mean calcium carbonate content in texturally different soils at 0-15 and 15-30 cm soil depths

Texture	Calcium carbonate (%)	
	0-5 cm	**5-15 cm**
Sand	0.00	0.00
Loamy sand	1.00	1.19
Sandy loam	0.25	0.30
Loam	0.67	0.78
Silty loam	1.04	0.93
Sandy clay loam	1.03	1.08
Clay loam	0.70	0.75
Silty clay loam	1.04	1.06

Soil pH, EC and SAR

The data on pH, EC and SAR of the soil solution (Table 4a, b, c) showed that the soils taken for the study were normal in soil reaction, i.e. neutral to slightly alkaline and there was not much change with depth (Table 4a). The data recorded for electrical conductivity showed that most of the soils were having EC < 4 dS m^{-1} ranging from 0.15 to 4.82 dS m^{-1} at 0-5 cm depth and 0.12 to 4.32 dS m^{-1} at 5-15 cm depth (Table 4b). The SAR values of texturally different soils showed variations and ranged from 5.05-11.54 in 0-5 cm and 5.12-11.84 in 5-15 cm depth (Table 4c).

The negative charge on clay particles increases with pH that leads to more repulsion of clay particles. Consequently, clay fragmentation is increased by increasing pH (Gupta *et al.*, 1984; Barzegar *et al.*, 1997). But modulus of rupture was not found significantly correlated with pH of soils collected for the present study. This may be due to a small change in soil pH_s. Barzegar *et al.* (1994) suggested that the dispersive effects of SAR on soil strength are modified by electrolyte concentration.The influence of soluble salts and SAR of soil solution was negligible on the modulus of rupture as the amount of soluble salts and SAR of the soil samples were within a safe range. Sodic soils occur mostly in arid and semi-arid regions and gypsum is used as a soil amendment to overcome sodicity by reducing dispersion, pH and exchangeable sodium percentage (Batra *et al.*, 1997).

Table 4 (a): pH range of texturally different soils at 0-5 and 5-15 cm soil depths

Texture	$pH_{(1:2)}$	
	- 0 5cm	**- 5 15cm**
Sand	7.75 - 7.97	7.45 - 7.89
Loamy sand	7.65 - 8.06	7.55 - 8.03
Sandy loam	7.71	7.65
Loam	7.35 - 8.04	7.33 - 8.10
Silty loam	7.44 -8.06	7.55 - 8.06
Sandy clay loam	7.85	7.93
Clay loam	7.37	7.38
Silty clay loam	7.42	7.23

Table 4 (b): EC range of texturally different soils at 0-5 and 5-15 cm soil depths

Texture	$EC_{(1:2)}$	
	0-5cm	**5-15cm**
Sand	0.15 - 0.32	0.13 - 0.26
Loamy sand	0.23 - 3.58	0.16 - 3.28
Sandy loam	4.02	4.32
Loam	0.25 - 4.82	0.18 - 3.04
Silty loam	0.28 - 0.57	0.27 - 0.47
Sandy clay loam	0.97	1.11
Clay loam	0.45	0.38
Silty clay loam	0.24	0.45

Table 4 (c): SAR range of texturally different soils at 0-5 and 5-15 cm soil depths

Texture	SAR $(me\ l^{-1})^{1/2}$	
	0-5cm	**5-15cm**
Sand	5.05 - 6.02	5.12 - 6.14
Loamy sand	6.22 - 11.34	6.45 - 10.88
Sandy loam	11.54	11.09
Loam	6.21 - 11.47	6.15 - 11.84
Silty loam	6.27 - 9.12	6.34 - 9.56
Sandy clay loam	10.06	10.22
Clay loam	8.25	8.15
Silty clay loam	7.22	7.44

To identify the soil properties which are sensitive to affect the modulus of rupture, stepwise regression analysis was done (Table 5). It MOR was found highly dependent on dispersion ratio, silt + clay, EC and water-stable aggregates

Table 5: Step wise regression correlation

Regression equation	R^2
MOR=2.310 -2.485 DR	0.715
MOR=3.804 - 3.669 DR - 1.554 MWD	0.785
MOR=3.250 - 3.415 DR -1.478 MWD + 0.0254 slit+clay	0.808
MOR=3.338 - 3.430 DR - 1.585 MWD+0.0288 silt+clay-0.066 EC	0.827
MOR=4.213 - 3.949 DR - 0.128 MWD +0.0296 silt+clay - 0.094 EC -0.025 WSA	0.845
MOR=4.243 - 3.961 DR+0.029 silt+clay - 0.0957 EC-0.0269 WSA	0.845

CONCLUSION

The different soil properties such as saturated hydraulic conductivity, calcium carbonate, dispersion ratio, pH, EC and SAR of soil solution influence the modulus of rupture (MOR) which is the measure of crust strength. Modulus of rupture was significantly positively correlated with saturated hydraulic conductivity and negatively correlatied with dispersion ratio at 0-5 and 5-15 cm depths. There was no role of calcium carbonate, pH, EC and SAR of soil solution in influencing the values of MOR of soil. Thus it may be concluded that values of MOR of soils of Haryana are positively correlated with silt + clay (r = 0.805) followed by water stable aggregates (r = 0.774), organic carbon (r = 0.738), silt (r = 0.711), mean weight diameter (r = 0.608) and clay (r = 0.593) while negatively correlated with dispersion ratio (r = -0.872), sand (r = -0.801) and hydraulic conductivity (r = -0.752) of soils.

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