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Hydro-Mechanical Properties of Recently Developed Alkaline Soils of Sultanpur Village in Gurgaon District

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Abstract

Salinization and alkalization are the long recognized problem of agricultural in semi-arid and arid regions, both under rain fed and irrigated conditions. Hydro-mechanical characterization of recently turned alkaline soils of Sultanpur village of Gurgaon district, Haryana was done. Substantial increase in pH and decrease in electrical conductivity (EC) within a span of a decade were observed. The pH was in the range of 7.5 to 9.8 compared earlier report of <8.5. Similarly EC reduced to 0.2—0.7 dS/m compared to earlier report of 5–6 dS/m. Soil strength as measured through impact cone penetrometer was found to be more in higher pH of similar textured soil. Field saturated hydraulic conductivity was low on high pH sites. Cohesiveness, total porosity, matric potential, α-parameter and sorptivity were correlated with pH but the correlation was not as good as found in controlled condition. Because in field condition many of the parameters changes simultaneously. Field saturated hydraulic conductivity (steady state with constant head; measured by Guelph permeameter) in high pH region of moderate to fine textured soil was found to have positive linear permeameter) in high pH region of moderate to fine textured soil was found to have positive linear relationship with initial moisture content. New area put to cultivation under irrigation management were hot spot of development of high pH and lowering of EC.
Key words : Hydro-mechanical properties, Alkaline soils, Characterization.

Land degradation due to salinization and alkalization is a long recognized problem of agriculture in semiarid and arid regions; both under rain fed and irrigated conditions. The area under potential saline soils is much higher than that of the reported saline soils; the farmer may convert to later under intensive agriculture, when soil health is not taken care properly. Intensive agriculture supported by irrigation has rendered many productive soils infertile. To some extent soil salinity has already been taken care off by drainage with good quality irrigation water but the sodium concentrations in these soils kept on increasing and often these soils are recovered to have higher pH values which aggravate both physical and chemical soil properties. Sodicity-induced soil degradation is a major environmental constraint with severe negative impacts on agricultural productivity and sustainability in arid and semiarid regions. Excess levels of sodium ions (Na^+) in the soil solution phase and on the exchange complex, exhibiting unique structural problems as a result of certain physical processes (slaking, swelling, and dispersion of clay) and specific conditions like surface crusting and hard-setting (1). Soil strength that is directly affected by sodicity, plays a dominant role in soil management, soil erodibility, seedling emergence and root development, tration required to pull farm implements and soil compaction. Soil strength depends not only on the soil and the measuring conditions but also on the method of measurement itself (2). Penetrometer was used to detect the effect of bulk density on soil strength and to testify the measurement by new device, but not directly to compare the measured strength itself. Several laboratory methods have been

Table 1. Land use and physicochemical status of soils of study area in 1993 (5).

Soil type	BD (g/cm^3)	EC (dS/m)	pH	Land use
Clay	1.40	4.2	7.9	Mustard
Clay loam	1.44	5.0	7.5	Wheat/barley
Loam	1.54	4.8	7.2	Wheat/barley/gram
Clay loam	1.44	3.6	8.3	Wheat/barley
Sandy loam	1.62	2.9	7.5	Gram
Clay	1.40	5.2	8.4	Mustard

used to determine soil hydraulic conductivity and related parameters and extrapolate these to field conditions; however it is essential to determine these parameters under field conditions to minimize the effect of spatial variability (3). Many of the mechanical properties, their measurement and evaluations have been given importance by the civil engineers whose objective is altogether different than that of agricultural practitioners. The paper aims to quantify hydro mechanical properties of recently developed alkaline soils.

Methods

Study Area

The study area, Sultanpur village of Gurgaon district, Haryana comprises of sand dunes, dunal foot slopes, interdunal plains and basins. The area resembles to a locked type ponds without any natural outlet hence drainage is the major problem. Texture of the alluvial soils varies from sandy loam to loam in the uplands and caly in the relatively low lying areas and depressions. The area, formerly was a deep depression, has been filled up by sediments brought by Sahitri River and its tributaries. Different soil textural classes and land uses are given in Table 1.

Mode of Sampling

Tentative grid sampling with moderate field adjustment was carried out. Soil strength and penetration resistance parameters, were measured in fields at about 610 m and 544 m interval in N-S and E-W directions respectively (Fig. 1). The soil samples, for laboratory determination of bulk density, moisture, electrical conductivity and pH were also collected from the same sites. Soil moisture, pH, electrical conductivity and bulk density were measured in laboratory following standard procedure.

Measurement of Penetration Resistance (Soil Inpedance)

Soil strength depends not only on the soil and the measuring conditions but also on the method of measurement itself (2). Penetration was measured using impact cone penetrometer in which impact was provided by means of falling 1 kg weight by 50 cm (4). After placing the penetrometer at the predetermined location, cumulative strokes of 5, 10, 15, 20, 25, 30, 35, 40, 50 and 70 were given. The potential energy imparted in each stroke is 4.9 Joules. The amounts of penetration for a prefixed number of strokes were recorded until a cumulative penetration of at least 8 to 12 cm depth was achieved. The energy of impact versus depth of penetration was plotted for comparison of soil impedance under different conditions.

Measurement of Shear Strength

The shear strength of the study area was measured with the direct shear test apparatus developed by Sirohi (1987) (4). It consisted of a metallic platform with a central guide and a rotating screw. The proving ring was axially mounted with rotating screw to measure shear forces. The apparatus consisted of a rotating screw having a pitch of 20 TPI in combination with a proving ring and a shear box. The rotating screw was horizontally fitted on a machined platform, which could be firmly anchored to the soil. A uniform horizontal shearing displacement was imparted to the shear box by rotating the screw approximately 30 revolution per minute (RPM). The shear force corresponding to failure was read from the dial gauge fitted inside the proving ring. The direct shear tests were conducted at normal loads of 5, 8 and 10 kg on the metallic circular plate amounting to stress of 0.25, 0.41 and 0.516 kg/cm respectively. Shear stresses were calculated using shear force at the time of failure corresponding to each level of normal load.

Soil Water Transmission Coefficients

Guelph permeameter measures the steady state liquid recharge from a cylindrical well in which con-

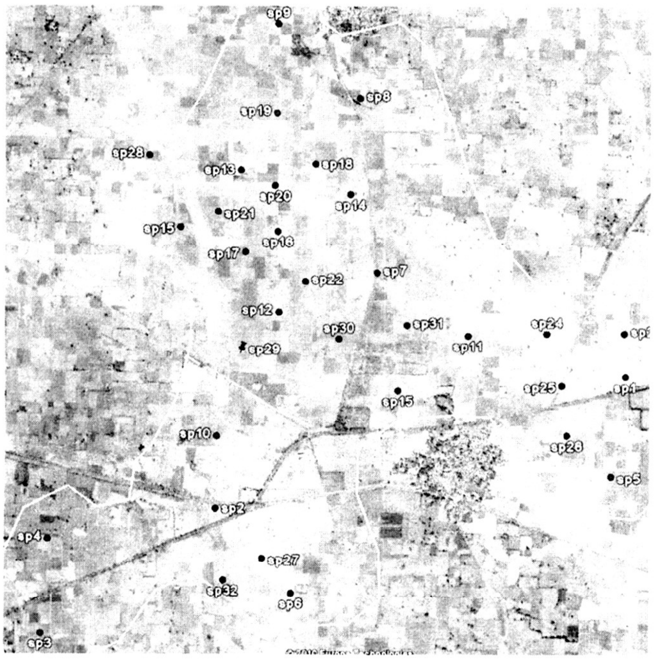

Figure 1. Sampling sites in the study area near village Sultanpur, Gurgaon, Haryana.

stant depth of water is maintained. Constant head level in the well hole is established and maintained by regulating the level of the bottom of air tube which is located in the centre of the permeameter. In the present investigation two depths of water level, 5 cm and 10 cm were maintained. The reservoir combination was used in coarse texture soil, while in case of fine texture soil inner reservoir was used to maintain constant depth of water. From the rate of fall of water head in the well the water transmission coefficient were calculated.

The soil water transmission coefficients were calculated for 5 cm (h_1) and 10 cm (h_2) head of water in the well using the following equations. Field saturated hydraulic conductivity (K_{fs}) and matric flux potential (φ_m) were computed as follows.
When reservoir combination is used

$$K_{fs}\ (cm/h) = (0.0041)\ (X)\ (R_2) - (0.0054)\ (X)\ (R_1) \quad (1)$$

$$\varphi_m\ (cm^2/h) = (0.0572)\ (X)\ (R_1) - (0.0237)\ (X)\ (R_2) \quad (2)$$

When inner reservoir is used

$$K_{fs} = (0.0041\ (y)\ (R_2) - (0.0054)\ (y)\ (R_1) \quad (3)$$

$$\varphi_m = (0.0572)\ (y)\ (R_1) - (0.0237)\ (y)\ (R_2) \quad (4)$$

where, R_1 and R_2 are the steady state rate of fall corresponding to h_1 and h_2, respectively, expressed in cm/sec. X (39.09 cm^2) is the reservoir constant provided by the manufacture when reservoir combination is selected, and Y (2.17 cm^2) is the reservoir constant provided by manufacture when inner reservoir is selected.

α-parameter

$$\alpha\ (cm^{-1}) = K_{fs} / \varphi_m \quad (5)$$

Sorptivity (s)

$$s\ (cm/sec^{1/2}) = [2\ \theta_{fs} - \theta_1)\ \varphi_m]^{1/2} \quad (6)$$

Where, θ_{fs} is the field saturated volumetric water content, and θ_i is the initial/instantaneous moisture content at the time of sampling.

Results and Discussion

Soil EC and pH

The Haryana Department of Agriculture has surveyed the study site long back in 1985 and was aware about salinity problem. Sharma (5) studied that EC (determined by suspension method 1:2.5) was in range

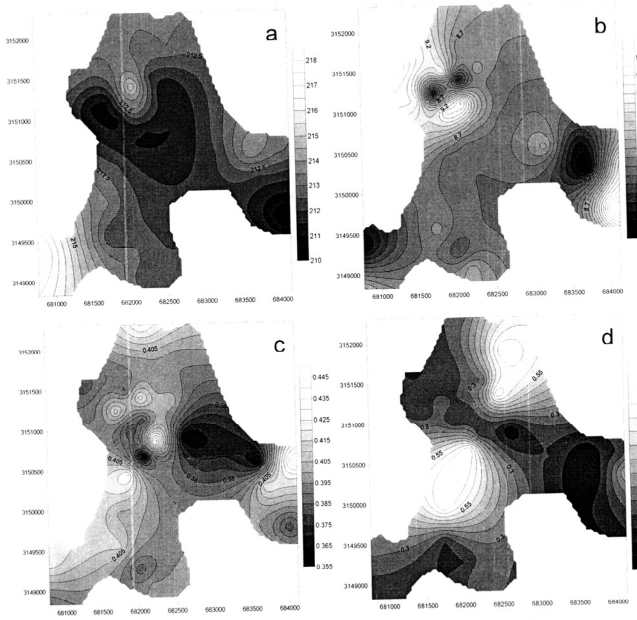

Figure 2. Spatial variation of (a) Elevation (m) (b) pH (c) Saturation moisture content (fraction) and (d) Electrical conductivity (dS/m) within the study area.

of 3 to 5 dS/m and pH less than 8.5 (Table 1). Present study was also aimed to see the temporal changes of EC and pH. EC was as low as 0.01 to 2.0 dS/m while pH (determined by suspension method 1:2.5) ranged from 7.1 to 9.8 (Fig. 2b and 2d). Out of total 76 samples collected across the study area, pH between 8—8.5, 8.5—9 and >9 comprised of 26, 20 and 9 samples respectively. Irrigation leached down excess salts of calcium and magnesium that were responsible for higher EC in the past, but sodium level might have been kept on building which resulted in shooting up of the pH. Hydraulic conductivity decreases with clay dispersion as caused by sodium ions (6). The reason may be increased duration of waterlogged period in low laying area.

Soil Strength by Impact Penetrometer Method

Mechanical impedance is the resistance offered by the soil matrix against deformation by a root growing in a homogeneous non-structural soil (7). Soil impedance determines whether a root will penetrate a given layer or grow horizontally until a weaker zone or structural interface is encountered (8, 9). Mechanical impedance to root growth is approximated by penetrometer measurements in soils (7, 10). *In situ* methods of soil strength measurement are to be preferred than laboratory techniques because they cause minimum disturbance to soil and are therefore more realistic both from crop emergence and establishment and agricultural vehicle and implements performance point of view (11).

Penetration resistance and pH of upper 10 cm layer of the study area varied from 7.84 to 128 J/cm (fig. 3d) and 7.1 to 9.8, respectively. The highest strength (penetration resistance) was obtained for the soil pH of 9.83 (Fig. 4d) but the main responsible factor for high strength was low moisture content (3.9%). Strength values as expected were higher for the soils where the natural conditions prevailed. Bulk density value ranged from 1.48 to 1.72 g/cm^3 (Fig. 3c); but its direct effect on strength could not be appreciated since it varied due to texture also. Penetration resistance and soil water content are highly interrelated, and both are affected by texture, structure, aggregation and bulk density (12). Since many of the factors vary simultaneously in the field condition, it is diffi-

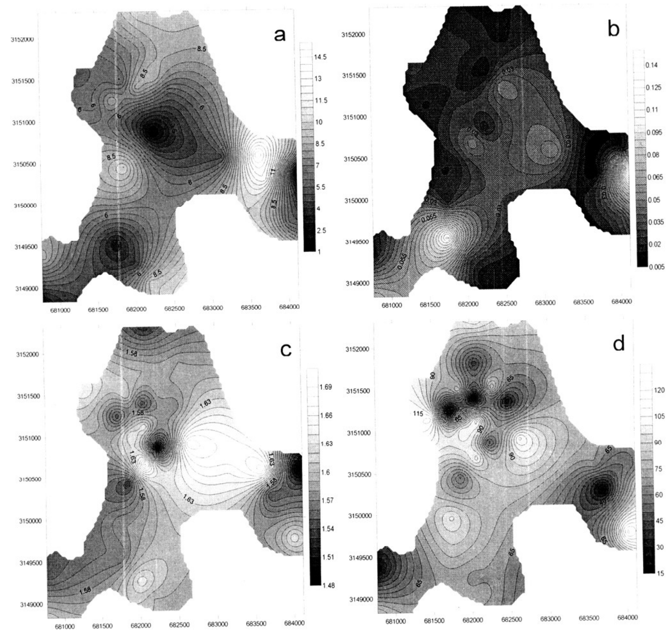

Figure 3. Spatil variation of (a) Sorptivity (cm/$^{1/2}$ sec) (b) α-parameter (per cm) (c) Bulk density (g/cm^3) and (d) Soil strength (J/cm) within the study area.

cult to corroborate theoretical relation obtained under controlled condition.

Higher moisture content at higher pH sites has buffering effect in minimizing the soil strength. The variation of penetration resistance as affected by soil moisture is illustrated in Figure 4e. The dispersing effect caused by sodium would be appreciable in case of fine textured soils as compared to coarse textured soils. This is well correlated with heavy reduction in the hydraulic conductivity of the soils. The bulk density in these sites ranged from 1.48 to 1.72 g/cm^3 and penetration resistance touched 130J/cm^1 in pH range greater than 8.5. The dispersion of the clay colloids decreases the pore size.

Soil Cohesiveness by Direct Shear Apparatus

Soil shear strength measured by the direct shear in salt affected part of the study area was low with cohesiveness ranging from 0 to 0.27 kg/cm^2. The pH value in these sites ranged from 6.9 to 9.1 and EC from 0.2 to 0.7 dS/m. The bulk density ranged from 1.54 to 1.75 g/cm^3. The soil cohesiveness, which is a direct measure of the ease of soil to be sheared, is found to be profoundly influenced of soil moisture, bulk density and pH. Coarse textured soils especially of sandy loam type situated near to the sand dunes were seen to have lower values of cohesiveness.

Dispersing effect of sodium on clay may be responsible for low values of cohesiveness. Increase in moisture levels in case of caly loam soils (fine texture) decreased the cohesiveness to values close to zero. No inference from bulk density to soil cohesiveness can be made due to simultaneous variation of texture, moisture and pH counteracting each others affect.

Soil Strength as Affected by Moisture and Bulk Density

For any soil at a given bulk density, PR increases as the soil dries and decreases as the soil becomes wet (13, 14). The sites with considerable higher pH (>9) having moisture content less than 5% exhibited higher value of soil strength (>80 J/cm) as compared to another site of almost similar pH but higher moisture content (around 10% or more). The influence of bulk density could not directly be appreciated due to textural variations in the soils. Results were segre-

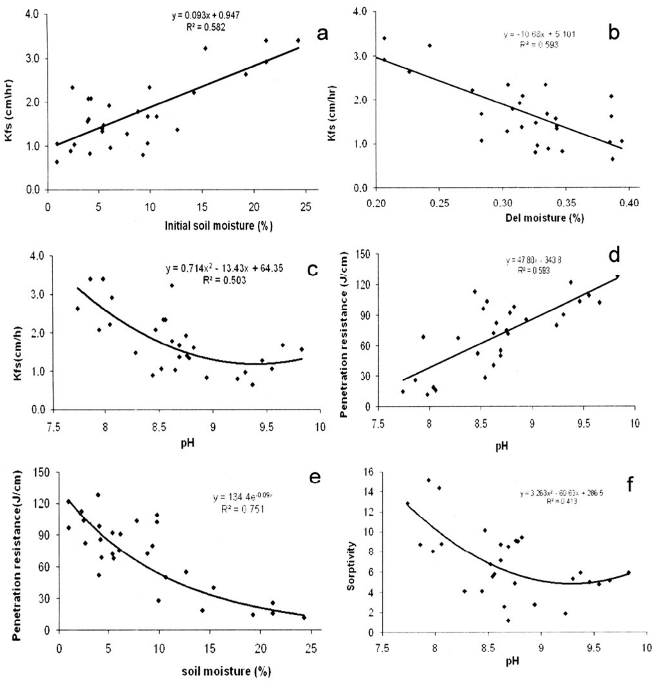

Figure 4. Relation between (a) Field saturated hydraulic conductivity (cm/h) and difference of saturation and instantaneous moisture content ($\Delta\theta$) (b) Field saturated hydraulic conductivity and initial moisture content (c) Field saturated hydraulic conductivity and pH (d) Penetration resistance and pH (e) Penetration resistance and soil moisture content and (f) Sorptivity and pH in the study area.

gated in two groups based on texture to study the relationship between bulk density and soil strength. The penetration resistance varied from 12 to 49 J/cm for sandy soils with bulk density varying from 1.54 to 1.79 g/cm^3 (Fig. 3d). For high pH driven compacted top soil the BD ranged from 1.48 to 1.7 g/cm^3 and penetration resistance varied from 38 to 128 J/cm.

Water Transmission Properties

Water transmission properties contain information about pore size distribution, effects of soil water availability to plant roots (15, 16). The field saturated hydraulic conductivity (K_{fs}) of this high pH (around 9.5) site is less than 0.6 cm/h. While for a normal to slightly alkaline soil of pH 7.5—7.8, it reached a very high value of 3.5 cm/h (Fig. 4c). Salinity and sodicity could affect soil structure, pore size distribution and continuity; and consequently alter soil hydraulic properties (1, 17). Water permeability of sodic soil decreases due to excess exchangeable sodium, which causes dispersion of the soil (16, 18).

Field saturated hydraulic conductivity was found to vary with initial moisture content and with saturation moisture content in fine textured soils (Fig. 4a and 4b). Similar observation was reported by Jabro et al. (19) for highly structured clay soil where he found a non linear logistic relationship between them. Field measured steady state hydraulic conductivity under a constant pressure head is not same as laboratory measured saturated hydraulic conductivity in which initial moisture content is highly defined. Saturated hydraulic conductivity vary with the initial soil water content in fine textured soil because of swelling and shrinking induced changes in soil structure and macro porosity that governs hysteresis phenomena.

Matric Flux Potential and α-Parameters of Salt Affected Soils

The matric potential varied from 2 to 370 cm^2/h at the time of measurement, matric potential (in situ measurement combines the matrix effect of salt) decreases with increase in pH in polynomial function with R^2 value of 0.65.

The α-parameter varied from 0.0038 to 0.1425/c (Fig. 3b). Though lower values of α-parameter (ratio of field saturated hydraulic conductivity and matric flux potential) was seen for soils with very high pH in range of 8.5 to 9.93, it showed week relation (as expected) with pH because saturated hydraulic conductivity and matric potential both varies with pH. The directional effect for α-parameter and K_{fs} as reported by Russo et al. (20) for natural condition, could not be appreciated because of different management practices at different site. The porosity varied from 35 to 46.5%. The miosture distribution can be correlated to study the field saturated hydraulic conductivity as it is influenced by the moisture content.

Sorptivity

Sorptivity is a derived soil property influenced both by soil solids and liquid medium for flow. The sorptivity values in the study ware varied from 1.23 to 16.76 cm/h. Generally lower values of sorptivity were found for soils with higher pH values (Fig. 4f). As sorptivity included the $\Delta\theta$ in its calculation, it is reported to vary with initial moisture content and texture. Sorptivity was found to be fairly related with saturated hydraulic conductivity.

Conclusion

New areas were brought under cultivation supplemented by tubewell irrigation was found to developed alkalinity, evidenced by lower EC (0.2-0.7 dS/m) as against earlier report of 3 to 5 dSm^{-1} and higher pH (8 to 9.83) as against earlier report of (<8.5). Also rain fed cultivation with no amendment inputs lead to leaching of salts leaving the sodium in the exchange complex. Soil strength in terms of penetration resistance was found to increase with pH in fine textured saline soil generally observed in low lying area. Higher value of penetration resistance (80 to 130 J/cm) was observed at relatively dryer site of fine textured soil. Hydraulic conductivity was lower (<0.6 cm/h) at the site of higher pH but general relation could not be established due to simultaneous variation of bulk density and moisture content. Considerable increase in waterlogged period was also evidence of alkalinity induced lower conductivity. The finding is field corroboration of development of alkaline soil from saline soils as effect of leaching with low SAR water.

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