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Effect of Irrigation Water Quality on Saturated Hydraulic Conductivity of Typic Haplustert, Vertic Haplustept, and Lithic Ustorthent Soils

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ABSTRACT

Present paper analyses water quality effects on saturated hydraulic conductivity (Ks) and other soil properties viz; pH, ECe, exchangeable sodium percentage and dispersion index of Typic Haplustert, Vertic Haplustept and Lithic Ustorthent soils of Bilaspur and Jahami in Orissa, India. Nine water quality combinations consisting of three sodium adsorption ratios (SAR) i.e. 10, 20 and 30 m mol$^{1/2}$ L$^{-1/2}$ and three total electrolyte concentrations (TEC) i.e. 10, 20 and 30 me L^{-1} have been used in the study. Pure A.R. grade carbonate salts of Ca, Mg and Na were used to synthesize various combinations at Ca:Mg 1:2, 1.5:2 and 1:1. Saturated hydraulic conductivity (HC) ranged from 0.02 to 0.32, 0.28 to 0.83, 0.92 to 2.74 cm h^{-1} in clay, clay loam and sandy loam soils, respectively. The exchangeable sodium percentage ranged from 17.55 to 70.85, 14.98 to 40.76, 14.30 to 33.49; and dispersion index from 48.88 to 71.38, 36.75 to 61.75, 32.38 to 50.88 in clay, clay loam and sandy loam soils, respectively. Equilibrated clay and clay loam soils exhibited saline-sodic/sodic nature with pH ranging from 8.51 to 9.98, and 8.52 to 9.66, respectively. Sandy loam showed highly sodic reaction with pH ranging from 9.05 to 9.96. Multiple regression developed to study the dependence of Ks on solution and soil parameters were Ks = - 0.003SAR + 0.013TEC + 0.001pH - 0.131ECe – 4.705DI – 0.001ESP + 0.128 ($R^2 = 0.674$), Ks = - 0.009SAR + 0.023TEC – 0.190 pH + 0.001ECe – 0.010ESP + 0.004DI + 2.184 ($R^2 = 0.948$), and Ks = - 0.324SAR – 0.028TEC + 0.107pH + 0.001ECe + 0.317ESP + 0.060DI – 2.078 ($R^2 = 0.958$) for clay, clay loam and sandy loam soils, respectively. Result of the analysis showed that the Ks values were significantly dependent on SAR and TEC of equilibrating solution and pH of the soil.

Key words: SAR, TEC, ESP, Saturated hydraulic conductivity, clay soil, dispersion, flocculation

In most irrigated areas of the world in adequate supply of good quality irrigation water, or the high cost of water compel the growers to look for alternatives such as shallow groundwater or drainage water. Often, poor quality of groundwater/drainage water increases soil salinity, and with decreased crop yields besides causing structural deterioration of agricultural lands. The poor quality of the irrigation water applied will also affect the soil chemical properties which further influence soil dispersion, aggregate breakdown, surface sealing and crust formation (Shainberg and Letey 1984).

Sodic soils are associated with structural changes that principally affect permeability of soils. Effect of salinity and alkalinity of water are widely studied under saturated (Chaudhari and Somawanshi 2004, Dane and Klute 1977) and unsaturated conditions (Levy et. al., 2005, Quirk and Schofield 1955, Shainberg *et al*., 2001, Mclntyre 1979). Soil aggregate stability, slaking and dispersion were related to SAR and electrolyte concentration by Abu-Sharar *et al.* (1987). Suarez *et al.* (2006) found that a SAR increase caused by irrigation water had an adverse impact on water infiltration for two types of soil, clay and loam. Increasing sodicity and decreasing the concentration of the applied water enhances physico-chemical dispersion. This dispersion, in turn, leads to a reduction in soil hydraulic conductivity (Frenkel *et al.*, 1978, Pupisky and Shainberg, 1979, Shainberg and Letey, 1984). If the level of Na^+ in the soil is high, the colloidal fraction behavior will be affected. High carbonate ($CO_3^=$) and bicarbonate (HCO_3^-) in water essentially increases the sodium hazard of the water to a level greater than that indicated by the SAR. High $CO_3^=$ and HCO_3^- tend to precipitate calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) when the soil solution concentrates during soil drying. The concentrations of calcium and magnesium in soil solution are reduced relative to sodium and the SAR of the soil solution tends to increase. When high concentrations of sodium affect a soil, the subsequent loss of structure reduces the hydraulic conductivity. (Shainberg and Letey, 1984, Hanson *et al.*, 1999, Hardy *et al.*, 1983 and Levy *et al.*, 1999).

Limited freshwater availability and increasing demand on food are making even marginal and poor quality waters, an important source for irrigation. The salt effect on soil hydraulic properties should not be ignored because it can lead to serious degradation of irrigated soils (Dane and Klute 1977). Present paper describes the effect of water quality with different concentration and composition on saturated hydraulic conductivity (Ks) and structure of Typic Haplustert, Vertic Haplustept, and Lithic Ustorthent.

Materials and Methods

Three different textured soils (clay, clay loam, sandy loam) were selected for the present study. Bulk soil samples were collected from 0-30cm layer from A or Ap horizon of *Typic Haplustert* (clay) from Bilaspur in Chhattisgarh, *Vertic Haplustep* (clay loam) from Diandehi and *Lithic Ustorthent* (sandy loam) from Jahami in Orissa, India. These samples were brought to the ‘Soil-Water Plant Relationship’ laboratory of Water Technology Centre for Eastern Region, Chandrasekharpur, Bhubaneswar, India. Air dried soil samples (>2mm) were equilibrated with different solutions of Sodium adsorption ratio (SAR) and total electrolyte concentration (TEC). Solution combinations consisted of three SAR levels (10, 20, and 30 $mmol^{1/2}L^{-1/2}$) and three TEC levels (10, 20, and 30 meL^{-1}). Solutions were prepared using pure air-grade Carbonate salts of calcium, magnesium and sodium at Ca:Mg = 1:2, 1.5:2, and 1:1. Soil samples were placed in buchner funnel (15cm diameter and 7.5cm height) and poured with 1 pore volume of the solution. After complete leaching, subsequent pore volume was poured till the time effluent solution had the same SAR and TEC as that of influent solution. Equilibrated soil samples were allowed to air dry and ground to pass through a 2mm brass-sieve and stored for analytical purpose. The basic physical and chemical properties of these three textured soil (Table 1, 2, and 3) were determined using standard methods.

Table 1. Effect of water quality on pH, ECe, ESP and dispersion index (DI) of clay

Water Quality			Carbonate series		
SAR ($mol^{1/2}L^{-1/2}$)	TEC (meL^{-1})	pH	ECe (dSm^{-1})	ESP	DI (%)
At Ca: Mg = 1: 2					
10	10	9.51	0.93	40.44	64.50
10	20	9.71	1.25	56.36	52.00
10	30	9.75	1.55	68.82	48.88
20	10	9.78	0.95	46.81	67.63
20	20	9.89	1.38	59.07	61.38
20	30	9.98	1.80	70.85	45.75
30	10	9.74	1.00	45.36	64.50
30	20	9.84	1.40	57.76	58.25
30	30	9.94	1.88	69.03	42.63
At Ca: Mg = 1.5: 2					
10	10	8.51	0.85	17.55	60.25
10	20	8.77	1.15	35.29	54.00
10	30	8.96	1.28	53.98	44.63
20	10	8.90	0.90	26.43	63.38
20	20	8.94	1.18	39.26	57.13
20	30	9.08	1.68	51.12	54.00
30	10	9.56	0.93	42.17	63.38
30	20	9.63	1.25	54.97	57.13
30	30	9.72	1.70	66.37	57.13
At Ca :Mg = 1:1					
10	10	9.00	1.13	25.18	58.88
10	20	9.21	1.40	42.10	55.75
10	30	9.32	1.60	56.06	52.63
20	10	9.05	1.15	26.27	58.88
20	20	9.24	1.43	42.71	58.88
20	30	9.37	1.68	56.88	52.63
30	10	9.23	1.18	30.48	71.38
30	20	9.30	1.53	42.91	65.13
30	30	9.32	1.70	57.97	52.63

Table 2. Effect of water quality on pH, ECe, ESP and dispersion index (DI) of clay loam

Water Quality		Carbonate series			
SAR ($mol^{1/2}L^{-1/2}$)	TEC (meL^{-1})	pH	ECe (dSm^{-1})	ESP	DI (%)
At Ca: Mg = 1: 2					
10	10	8.52	0.68	15.78	43.00
10	20	8.99	1.05	26.73	39.88
10	30	9.23	1.40	36.59	36.75
20	10	8.54	0.75	18.95	46.13
20	20	9.03	1.18	29.40	43.00
20	30	9.34	1.63	38.45	39.88
30	10	8.92	0.83	24.30	49.25
30	20	9.46	1.23	35.37	46.13
30	30	9.63	1.80	42.01	43.00
At Ca: Mg = 1.5: 2					
10	10	9.11	0.73	18.75	41.00
10	20	9.46	1.10	28.97	37.88
10	30	9.57	1.30	39.90	34.75
20	10	9.16	0.75	22.72	44.13
20	20	9.58	1.20	32.44	41.00
20	30	9.72	1.63	40.76	37.88
30	10	9.23	0.80	26.50	47.25
30	20	9.61	1.33	35.04	44.13
30	30	9.78	1.75	43.55	41.00
At Ca :Mg = 1:1					
10	10	8.54	0.75	14.98	55.50
10	20	9.06	1.23	24.99	52.38
10	30	9.24	1.60	34.18	49.25
20	10	8.64	0.83	18.63	58.63
20	20	9.21	1.30	28.95	55.50
20	30	9.39	1.75	37.20	52.38
30	10	8.70	0.88	22.34	61.75
30	20	9.31	1.35	32.91	58.63
30	30	9.66	2.00	39.72	55.50

Table 3. Effect of water quality on pH, ECe, ESP and dispersion index (DI) of sandy loam

Water Quality		Carbonate series			
SAR ($mol^{1/2}L^{-1/2}$)	TEC (meL^{-1})	pH	ECe (dSm^{-1})	ESP	DI (%)
At Ca: Mg = 1: 2					
10	10	9.19	0.60	14.22	41.75
10	20	9.42	0.90	16.08	38.63
10	30	9.51	1.11	17.98	35.50
20	10	9.62	0.78	21.94	44.88
20	20	9.66	0.93	23.89	41.75
20	30	9.68	1.20	25.70	38.63
30	10	9.73	0.84	29.66	48.00
30	20	9.83	0.99	31.64	44.88
30	30	9.88	1.23	33.49	41.75
At Ca: Mg = 1.5: 2					
10	10	9.18	0.48	14.35	38.63
10	20	9.63	0.81	16.27	35.50
10	30	9.72	1.14	18.04	32.38
20	10	9.22	0.51	22.08	41.75
20	20	9.66	0.84	24.00	38.63
20	30	9.78	1.17	25.77	35.50
30	10	9.29	0.54	29.82	44.88
30	20	9.69	0.93	31.65	41.75
30	30	9.94	1.68	32.99	38.63
At Ca :Mg = 1:1					
10	10	9.05	0.48	14.30	44.63
10	20	9.76	0.93	16.19	41.50
10	30	9.92	1.38	17.84	38.38
20	10	9.43	0.54	22.14	47.75
20	20	9.85	1.02	23.87	44.63
20	30	9.94	1.41	25.56	41.50
30	10	9.48	0.63	29.80	50.88
30	20	9.89	1.14	31.49	47.75
30	30	9.96	1.62	33.07	44.63

The pH and Electrical conductivity (ECe) of the equilibrated soil samples were measured using pH meter and electrical conductivity meter in 1:2.5 soil distilled water suspension (Jakson 1973). Exchangeable sodium percentages (ESP) of soil samples were indirectly estimated from some of the easily measurable soil and solution parameters using standard ESR-SAR relationships previously determined by Chaudhari and Somawanshi (2002). We used the same equations of ESR-SAR relationships. Dispersion index as defined by Mustafa and Letey (1969) was calculated using the relationship;

$$Dispersion\,index\,(\%) = \frac{Water\,dispersible\,(silt + clay)}{Total\,(silt + clay)} \times 100 \quad \ldots(1)$$

Twenty grams of equilibrated soil (<2mm) was placed in a 1 litre cylinder and a given solution combination of SAR and TEC was slowly added. The soil suspension was stroked twenty times with a long plunger. The percentage of silt+clay size particulates was determined by the hydrometer method (Day 1965) and this was termed as water dispersible silt+clay. Total silt+clay was also determined by the hydrometer method after completely dispersing the soil. Complete dispersion was achieved by both the chemical and physical means. For achieving complete dispersion, the following procedure was used. Twenty grams of equilibrated soil was taken in a 1-litre long beaker, to this 30ml of 30 percent

H_2O_2 was added in two installments of 15ml each and the contents were allowed to react for six hours. After the complete oxidation of organic matter, 15-ml of 0.1*N* HCl was added to the beaker and allowed to react for one hour. To the organic matter and $CaCO_3$ free soil, 200 ml of 5 percent sodium hexa-meta-phosphate solution was added and soil was allowed to deflocculate for 12 hours. Soil was then stirred by an electrical stirrer at 2500 rpm for 3 minutes and transferred to a 1-litre cylinder. Volume in the cylinder was made up to 1-litre. Using a long plunger, 20 gentle strokes were applied to the suspension and hydrometer readings were carefully recorded after 60 seconds and 2 hours. Simultaneously a blank was also run and temperatures were noted at each determination. Final readings were corrected for the temperature. The hydrometer used in these determination was a standard hydrometer, a ASTM No. 152H, with Bouyoucos scale, calibrated at 68 ^{0}F. All the determinations were replicated five times.

Saturated hydraulic conductivity (Ks) of the equilibrated soil samples were determined by constant head method. Ks determination was carried out in a closed permeameter. Equilibrated soil samples were packed at bulk density 1.20 (clay), 1.25 (clay loam), and 1.3 Mgm^{-3} (sandy loam) of in cylindrical cores having internal diameter 6.25 cm and height 5 cm. Soil cores were tightened into the ring holders and transferred to the permeameter. The soil samples were allowed to saturate for 12 hours. Siphons and wells of the permeameter were filled with the same solution combination. Constant head was adjusted using a constant head device. Flow rate was determined until the steady state condition was attained. Procedure followed for Ks determination was similar to that described by Klute and Drikson (1986). All determinations were repeated two times under identical conditions. Ks were calculated by rearranging Darcy's equation for constant head condition as below;

$$Ks = \frac{V \times L}{A \times t \times H} \qquad \dots(2)$$

where,

V = Volume of water collected at steady state, mL
L = Length of the soil sample, cm
A = Cross sectional area, cm^2
T = Time, h
H = Hydraulic head difference, cm

Multiple regression analysis of the data were carried out using standard procedure given by Panse and Sukhatme (1995).

Results and Discussion

The three soils differed in physical, chemical and mineralogical properties. The effect of water quality with different composition and concentration (SAR 10, 20, 30 m mol$^{1/2}$ L$^{-1/2}$ and TEC 10, 20, 30 me L^{-1}) along with three Ca:Mg ratios such as 1:2, 1.5:2, and 1:1 on soil basic properties namely pH, ECe and DI of clay, clay loam and sandy loam soils are illustrated in Table 1, 2, 3, respectively.

The pH of the soils were sodic in nature and greatly influenced by the SAR and TEC of the applied solution. The pH of clay, clay loam and sandy loam soils ranged from 8.51 to 9.98, 8.52 to 9.78, and 9.05 to 9.96 respectively. Values were increased with increase in SAR and TEC of the equilibrating solution. Average value of pH was 9.38, 9.21, and 9.63 in clay, clay loam and sandy loam soils (Table 5). In clay soil pH values were lower in Ca:Mg = 1.5:2 as compared with Ca:Mg = 1:2 and 1:1. Whereas in clay loam and sandy loam showed the lower pH value in Ca:Mg = 1:2, respectively. The highest pH value was observed at (SAR 10 m mol$^{1/2}$ L$^{-1/2}$ and TEC 10 me L^{-1}) and the lowest was at (SAR 30 m mol$^{1/2}$ L$^{-1/2}$ and TEC 30 me L^{-1}) in all the three textured clay, clay loam and sandy loam soils. Electrical conductivity of extract solution (ECe) increased with increase in SAR and TEC of the equilibrating solution. In clay soil ECe ranged from 0.85 to 1.88, whereas in clay loam and sandy loam soil it was ranged from 0.68 to 2.0 and 0.48 to 1.68 dS m^{-1}. The average values of ECe were 1.33, 1.21, and 0.96 dS m^{-1} in clay, clay loam and sandy loam soil respectively. High sodium levels combined with low soil-water electrical conductivity can lower a soil's permeability through the swelling and dispersion of clays and the slaking of the aggregates. As the EC decreases and the ESP increases, the reduction in infiltration rate due to seal formation is usually more pronounced (Kazman *et al.*, 1983, Shainberg and Letey, 1984).

The ESP of these soils increased with increase in both SAR and TEC of the equilibrating solution. ESP of clay, clay loam and sandy loam soils ranged from 17.55 to 70.85, 14.98 to 43.55, and 14.22 to 33.49, respectively. The average value of ESP was 47.55, 46.50, and 41.67 in respect to three soil i.e. clay, clay loam and sandy loam. A combination of SAR and TEC i.e. (10 m mol$^{1/2}$ L$^{-1/2}$ and 10 me L^{-1}) yielded lowest ESP values, whereas SAR 30 m mol$^{1/2}$ L$^{-1/2}$ and TEC 30 me L^{-1} yielded highest ESP in all three textured soils. Higher ESP build-up in clay over clay loam and sandy loam soils due to higher clay swelling. (Curtin et. al., 1994) observed higher swelling with higher ESP of the soils. Shainberg and Letey (1984) proposed a "Cation demixing" theory and explained that when only about 10 percent of divalent cations are replaced by Na$^+$, most of the Na$^+$ is absorbed on the external surface of clay tactoids and little swelling occurs, but as ESP increases further Na$^+$ penetrates into internal surface and causes clay platelets to move apart. Similar mechanism seems to be effective in the present study.

In all the soils, dispersion index (DI) increased with increase in SAR and decreased in TEC of the equilibrating solution. DI of clay, clay loam and sandy loam soils ranged from 42.63 to 67.63, 34.75 to 58.63, and 32.38 to 50.88 %, respectively. The average value of DI was 57.16, 30.00, and 23.85 % in respect to three soil (clay, clay loam and sandy loam). The DI of normal clay, clay loam and sandy loam soil was 14.5, 11.7 and 5.8 per cent respectively. In general the highest dispersion index was observed in combination of (SAR 30 m mol$^{1/2}$ L$^{-1/2}$ and TEC 10 me L^{-1}) and lowest was of (SAR 10 m mol$^{1/2}$ L$^{-1/2}$ and TEC 30 me L^{-1}). The highest DI values in three Ca:Mg 1:2, 1.5:2 and 1:1 were 77.51, 77.12, and 80.0 ; 76.24, 75.23, and 81.05 ; 87.07, 87.07, and 88.6 % higher over normal DI of clay, clay loam and sandy loam soils respectively. (Velasco-Molina *et al*. 1971) found clay and clay loam equally sensitive to dispersion with increasing SAR of water and ESP of soil. The three main problems caused by sodium-induced dispersion are reduced infiltration, reduced hydraulic conductivity, and surface crusting. Formation Surface crusting due to water quality is greatly enhanced by sodium induced clay dispersion. Agassi and associates (1981) found that crust formation due to water quality is greatly enhanced by clay dispersion and movement in the soil. This makes it very difficult for water movement and for plant roots to break through this surface crust (Hanson et. al., 1999, Barbour *et al.*, 1998, Buckman and Brady, 1967, Miller and Donahue, 1995, Rhoades, 1977, Saskatchewan, 1987, Western Fertilizer Handbook, 1995).

Saturated hydraulic conductivity (Ks) of these soils decreased with increase in SAR and decrease in TEC of the equilibrating solutions. The average value of Ks was observed to be 0.08, 0.58, and 1.98 cm h^{-1} in respect to three soils i.e. clay, clay loam, and sandy loam. Ks value in clay, clay loam and sandy loam soils ranged from 0.03 to 0.38, 0.28 to 0.83, and 0.92 to 2.74 cm h^{-1} respectively (Table 4). Highest value of Ks was recorded from the combination of (SAR 10 m mol$^{1/2}$ L$^{-1/2}$ and TEC 30 me L^{-1}) and lower value from (SAR 30 m mol$^{1/2}$ L$^{-1/2}$ and TEC me L^{-1}) in all the soils (Figure 1). Most of the Ks data was not detected at SAR (20 m mol$^{1/2}$ L$^{-1/2}$ and 30 m mol$^{1/2}$ L$^{-1/2}$) with TEC (10 me L^{-1}) in Ca:Mg = 1:2 and 1.5:2 under clay soil only. The Ks of the normal soil was 0.13, 0.20 and 12.3 cm h^{-1} in clay, clay loam and sandy loam soil respectively. The highest Ks value in Ca:Mg = 1:2, 1.5:2 and 1:1 were 7.14, 7.7 and 65.78 per cent; 75.3, 68.0 and 76.0 per cent higher over the Ks of normal clay and clay loam soil. In case of sandy loam soil, highest Ks value were 78.0, 79.2 and 77.7 per cent lower than Ks of normal sandy loam soil in Ca:Mg 1:2, 1.5:2 and 1:1. The HC decreases with an increase in the ESP (McIntyre 1979) and the decrease in the total electrolyte concentration of the soil solution. The reduction in the HC has been attributed mainly to swelling and dispersion of the soil clays (Quirk and Schofield 1955). It is generally recognized that high levels of exchangeable Na

Table 4. Effect of water quality on hydraulic conductivity (Ks) of Clay, Clay loam, and Sandy loam soil

Soil type	TEC	SAR (m mol$^{1/2}$ L$^{-1/2}$)								
	(me L^{-1})	10	20	30	10	20	30	10	20	30
		Ca:Mg =1:2			Ca:Mg =1.5:2			Ca:Mg =1:1		
Clay	10	0.07	-	-	0.04	-	-	0.15	0.08	0.04
	20	0.09	0.07	0.06	0.08	0.04	0.03	0.20	0.12	0.08
	30	0.14	0.11	0.08	0.12	0.09	0.07	0.38	0.32	0.21
Clay loam	10	0.69	0.58	0.35	0.55	0.42	0.28	0.76	0.66	0.45
	20	0.75	0.64	0.46	0.59	0.49	0.35	0.80	0.69	0.49
	30	0.81	0.69	0.52	0.62	0.52	0.38	0.83	0.73	0.52
Sandy loam	10	2.48	1.92	1.40	2.32	1.80	0.92	2.50	1.98	1.42
	20	2.60	2.08	1.52	2.44	1.92	0.96	2.65	2.17	1.56
	30	2.72	2.12	1.64	2.56	2.00	1.00	2.74	2.22	1.80

Table 5. Mean physico-chemical properties of three different textured soils with their ranges

Soil type	pH		ECe (dSm^{-1})		ESP		DI (%)		Ks (cmh^{-1})	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Clay	9.38	8.51-9.98	1.33	0.90-1.88	57.16	17.55-70.85	47.55	48.88-71.38	0.08	0.02-0.32
Clay loam	9.21	8.52-9.66	1.21	0.68-2.00	30.00	14.98-40.76	46.50	36.75-61.75	0.58	0.28-0.83
Sandy loam	9.63	9.05-9.96	0.96	0.48-1.62	23.85	14.30-33.49	41.67	32.38-50.88	1.98	0.92-2.74

lead to soil structural deterioration, which is accompanied by a reduction in water movement through the soil profile.

Multiple regression of water quality parameters on Ks in three soils indicated that Ks was very significantly affected by SAR in clay, while TEC significant in clay loam and sandy loam soil (Table 6). Considering the soil properties, influence of pH, ECe and DI was highly significant in clay loam soil only, whereas pH, ESP was significant in clay and clay loam, and ECe, ESP, DI in sandy loam soil respectively. Ks was highly significantly affected by SAR and DI in clay; SAR, TEC, pH, and ESP in clay loam;

Table 6. Multiple Regression of Saturated Hydraulic conductivity (Ks) on solution parameters (SAR and TEC), soil parameters (pH, ECe, ESP and DI); and solution and soil parameters together in three soil type.

Multiple Regression Equation	r^2
Clay	
Ks = 0.032741 – 0.00336** SAR + 0.00595 TEC	$r^2 = 0.63$
Ks = 0.954637 – 0.11446* pH + 0.071251 ECe + 0.003185 *ESP – 0.00075 DI	$r^2 = 0.51$
Ks = 0.128 – 0.003** SAR + 0.013 TEC + 0.001 pH + 0.131 ECe – 0.001 *ESP – 4.705** DI	$r^2 = 0.67$
Clay loam	
Ks = 0.770421 – 0.01457 SAR + 0.00941* TEC	$r^2 = 0.68$
Ks = 4. 307854 – 0.37541** pH + 0.682519** ECe – 0.01895 *ESP – 0.01146** DI	$r^2 = 0.60$
Ks = 2.184204 – 0.00957** SAR + 0.023032** TEC – 0.19088** pH + 0.0001 ECe – 0.01077 **ESP + 0.004416* DI	$r^2 = 0.95$
Sandy loam	
Ks = 2.950338 – 0.05997 SAR + 0.011388* TEC	$r^2 = 0.88$
Ks = - 0.84162 + 0.407868 pH + 0.537742* ECe – 0.09667 *ESP + 0.016436 *DI	$r^2 = 0.89$
Ks = -2.07809 – 0.32439* SAR – 0.02893 TEC + 0.107304 pH + 0.0001 ECe + 0.317683 **ESP + 0.060353* *DI	$r^2 = 0.96$

Ks = saturated hydraulic conductivity, cmh-1, SAR = sodium adsorption ratio, m mlo$^{1/2}$L$^{-1/2}$, TEC = total electrolyte concentration, meL^{-1}, ESP = exchangeable sodium percentage, DI = Dispersion index, %, * = Significant at P = 0.05 and ** = significant at P = 0.01.

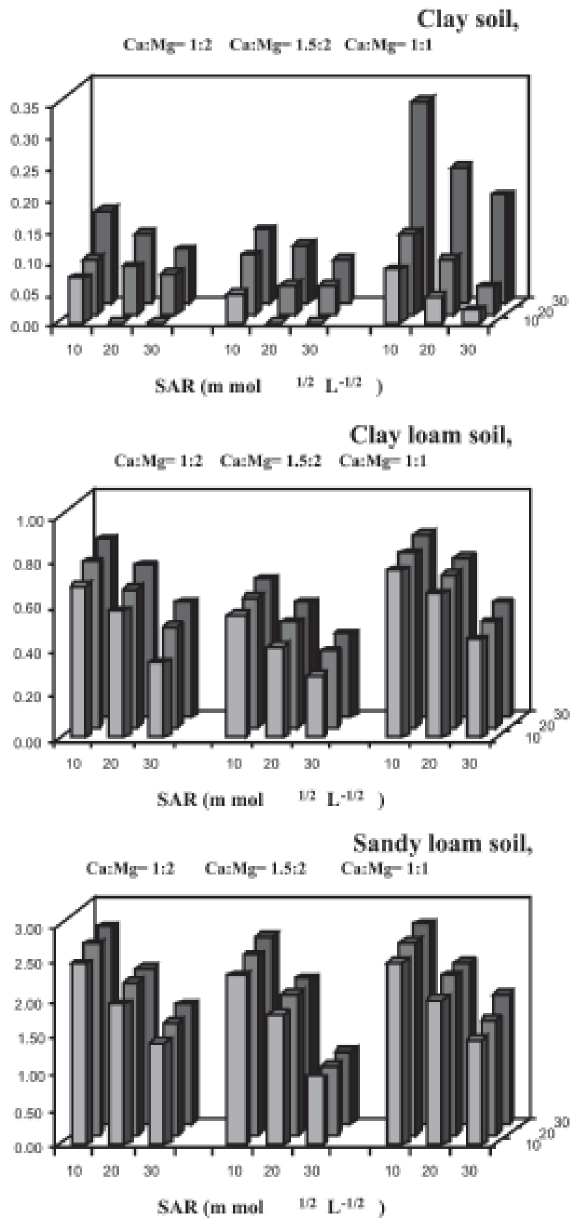

Fig. 1. Saturated hydraulic conductivity (Ks) as a function of SAR and TEC at three Ca:Mg ratios in three textured (clay, clay loam and sandy loam) soils.

and ESP, DI in sandy loam soil respectively considering both water quality and soil properties. However the predictability of multiple regression equation was very high (R^2= 0.67, 0.95 and 0.96 for clay, clay loam and sandy loam soil respectively) when water quality parameters and soil properties considered together. This indicates that the exchangeable sodium build-up in the soil was most effective for changes in Ks. Although, the process governing changes were dispersion and swelling in clay and clay loam, and only dispersion in sandy loam soil. This indicates that saturated hydraulic conductivity of the soil is not only dependent on water quality parameters, but also on soil properties i.e. dispersion, swelling behavior, and exchangeable sodium percentage of the soil.

It is shown that decreases in permeability at higher concentration of sodium adsorption ratio (SAR) solution are occasioned by increased clay-particle interaction owing to the extensive development of diffuse double layers which give rise to enhanced swelling. The exchangeable sodium percentage (ESP) is the major influence in the dispersibility of soils. The effects of clay type and content, exchangeable sodium percentage, and electrolyte concentration on clay dispersion and soil hydraulic conductivity was studied by Frenkel *et al*. (1977) and found that plugging of pores by dispersed clay particles is the major cause in reduced hydraulic conductivity of montmorillonitic, vermiculitic and kaolinitic soils of SAR's of 10 to 30 and salt concentration of 0 to 10 meL^{-1}. Gupta, *et al*. (1984) in evaluating the relative role of sodicity and pH on the dispersive behavior of a representative soil in relation to calcium carbonate and organic matter found that increasing alkalinity (pH) or SAR increased clay dispersion.

Conclusions

Poor and marginal quality water along with industrial effluents are emerging as a fourth important water resource throughout the globe. However, irrigation with poor quality waters may lead to poor soil physical health. Present paper analyses water quality effects on saturated hydraulic conductivity (Ks) and other soil properties of Typic Haplustert, Vertic Haplustept and Lithic Ustorthent soil subgroups. Nine solution combinations consisting of three levels each of sodium adsorption ratio (SAR) and total electrolyte concentrations (TEC) at Ca:Mg 1:2, 1.5:2 and 1:1 have been tried in the study. Saturated hydraulic conductivity (HC) ranged from 0.02 to 0.32, 0.28 to 0.83, 0.92 to 2.74 cm h^{-1} in clay, clay loam and sandy loam soils, respectively. The exchangeable sodium percentage ranged from 17.55 to 70.85, 14.98 to 40.76, 14.30 to 33.49; and dispersion index from 48.88 to 71.38, 36.75 to 61.75, 32.38 to 50.88 in clay, clay loam and sandy loam soils, respectively. Equilibrated clay and clay loam soils exhibited saline-sodic/sodic nature. Sandy loam showed highly sodic reaction with pH ranging from 9.05 to 9.96. Multiple regression developed to study the dependence of Ks on solution and soil parameters showed that the Ks values were significantly dependent on SAR and TEC of equilibrating solution and pH of the soil.

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