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Saturated Hydraulic Conductivity, Dispersion Index and Water Retention Changes in Salt Affected Soils under Different Quality Water Irrigation

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Abstract

Impact of different quality irrigation water *viz.,* normal tap water (NTW, EC 0.7 dS m^{-1}), dilute saline water (DSW, EC 5.0 dS m^{-1}; SAR 5.0 $mmol^{½}$ $L^{-½}$), concentrated saline water (CSW, EC 10.0 dS m^{-1}; SAR 5.0 $mmol^{½}$ $L^{-½}$), dilute alkali water (DAW, RSC 2.5 me L^{-1}) and concentrated alkali water (CAW, RSC 10.0 me L^{-1}) was evaluated on the physical properties of normal (pHs 7.5, ECe 1.0 dS m^{-1}), saline (pHs 7.7, ECe 10.6 dS m^{-1}) and alkali (pHs 9.15, ECe 2.9 dS m^{-1}) sandy loam soils in the micro-lysimeters during growth of wheat (cv. KRL 213) and rice (cv. CSR 36). Initial saturated hydraulic conductivity (Ks) for normal, saline and alkali soil was 0.16, 0.23 and 0.005 cm h^{-1}, respectively. Ks was reduced significantly to one fifth of initial value under CAW while DSW and CSW caused 20 and 50% increase, respectively as compared to normal soil. In alkali soil, Ks decreased significantly i.e. > 50% under DAW from its initial value of 0.005 cm h^{-1} and reduced to about one-fifth (0.001), under CAW. While Ks increased significantly to 0.07 and 0.21 cm h^{-1} on the application of DSW and CSW, respectively. In post wheat samples, Ks increased by 10 to 15-times in normal soil while, 5 to 9-times in saline soil and 15 to 30-times in alkali soil under both DSW and CSW. But in comparison to post-rice soil, no effect was observed in alkali soil in post-wheat soil on alkali water application but Ks increased 5 to 10-times in normal and saline soil under saline water irrigations. Dispersion index (DI) and Ks found inversely proportional to each other in all water treatments in all three soils. Under DAW (31.3) and CAW (39.9), DI was increased significantly by 5 and 33%, respectively as compared to the initial soil. DI increased by 12 and 30% under dilute and concentrated alkali water application, respectively in saline soil. DI increased significantly with application of CAW (65.3) and decreased when irrigation was applied with DSW (37.0) and CSW (34.2), respectively. Under different quality water irrigation, soil water retention was the highest in alkali soil followed by normal and saline soils at all matric suctions. Under the application of saline water in all three soils, water retention either decreased or remains unchanged with increase in TEC of irrigation water as compared to normal tap water. Whereas under the application of alkali water, it increased in all the three soils with increase in TEC of irrigation water as compared to normal tap water application,.

Key words: Alkali soil, Dispersion index, Matric suction, RSC, Saline soil, Salt affected soils, Saturated hydraulic conductivity

Introduction

Change in solution composition had an impact on soil physical/hydraulic properties *viz.,* saturated and unsaturated conductivity, water content, dispersion index, exchange phase-solution phase relationships and soil-water diffusivity. Increase in SAR, sodium ion adsorption by colloidal surfaces and soil swelling-shrinkage damages soil micro-structure. Large hydrated Na^+ ions physically and chemically separate the soil particles. This separation occurs when hydrated Na^+ ions dominate the diffuse double layer (DDL) around the clay platelets resulting in high swelling pressure and single platelet becoming suspended in solution (Keren and Shainberg, 1981). The decrease in soil physical health means degradation of soil structure and lower physical quality (Dexter, 2004). The soil quality decreases when saline water application increases because of the counteracting effect of salinity (Yadav *et al.,* 2007). Hydraulic properties of irrigated soils are most sensitive to the irrigation water quality. Irrigated soils display varying physico-chemical behavior at temporal scales. Physical properties of irrigated soils limit its productivity. Irrigated soils, if not managed properly, deteriorate hydraulic properties, for example infiltration rate, saturated and unsaturated hydraulic conductivity, soil-water diffusivity and soil-water retention (Chaudhari and Somawanshi, 2004). The exchange phase-solution phase behavior of these soils is also sensitive to water management.

Sodium induced dispersion in soil causes clay particles to plug soil pores resulting in reduced soil permeability which may leads to reduced infiltration, reduced hydraulic conductivity and increased surface crusting. Moreover, sodium saturation and clay dispersion are often associated with salinization (Chaudhari, 2001). Lower hydraulic conductivity and void ratio were recorded in the soils leached with sodium salts compared to calcium salts (Waldron *et al.,* 1970). McBride (1994) observed decrease in soil hydraulic conductivity and permeability with increase in ESP, when electrolyte concentration was below a critical threshold level. Carvajal *et al.* (1999) studied the effects of salts on plant growth and found reduction in osmotic potential of the soil solution which reduces available water to the plants. Therefore the present study was planned and executed to understand the impact of different quality water irrigation on Ks, DI and water retention of normal, saline and alkali soils cultivated with rice and wheat.

Materials and Methods

The present study was conducted during the year 2014-15 in filled-in micro lysimeters (1.0 m deep and 0.3 m internal diameter) at the experimental farm of Central Soil Salinity Research Institute, Karnal located at latitude of 29°43′ N and longitude of 76°58′ E. Three different soils (Normal soil, collected from experimental farm of Central Soil Salinity Research Institute (CSSRI), Karnal; Saline soil, collected from experimental research farm Nain, Panipat and Alkali soil, collected from Saraswati farm - Kaithal) were used for this investigation. Experimental soils were sandy loam in texture with low clay content (14.3, 12.4 and 13.7%, respectively). Soil organic C content for normal soil was 0.50% followed by 0.45% for saline and 0.42% for alkali soil. Alkali soil had ECe, pH_s and ESP of 2.9 dS m^{-1}, 9.2 and 23.9% respectively. The degree of calcareousness was less than 1% for all the soils taken for investigations. Under these initial soil parameters rice crop was grown by applying different quality water and change in soil chemical properties and rice yield was recorded. Then wheat crop was raised under the same soil by applying the same quality water to see the add-on effect on soil properties and performance of wheat in comparison with initial soil.

Different quality waters used for irrigation

Five different quality waters (NTW, DSW, CSW, DAW and CAW) were prepared using bicarbonate, chloride and sulphate of calcium, magnesium and sodium (Table 1, 2). Table 3 described the ionic composition of different quality irrigation waters used in the study. Crops were irrigated every time with freshly prepared water quality combination. The following steps were used to calculate the ionic composition of the waters.

Table 1. Chemical composition of prepared saline waters

Total electrolyte conc (me L^{-1})	Ca^{2+}/Mg^{2+} and Cl^-/SO_4^{2-} ratio of 2:1	Ionic composition at SAR 5.0 $mmol^{1/2} L^{-1/2}$ Cl^-	SO_4^{2-}	Total
Dilute saline water (50 me L^{-1})	Na^+	13.01	6.506	19.519
	Ca^{2+}	20.32	–	20.32
	Mg^{2+}	–	10.16	10.16
	Total	33.33	16.67	50.00
Concentrate salinewater (100 me L^{-1})	Na^+	19.77	9.88	29.65
	Ca^{2+}	46.9	–	46.9
	Mg^{2+}	–	23.45	23.45
	Total	66.67	33.33	100.00

Table 2. Chemical composition of prepared alkali waters

RSC(me L^{-1})	Ca^{2+}/Mg^{2+} ratio of 2:1	Ionic composition (me L^{-1})			
		CO_3^{2-}	HCO_3^-	Cl^-	Total
Dilute alkaliwater (2.5 meL^{-1})	Na^+	–	5.00	–	5.00
	Ca^{2+}	–	–	1.67	1.67
	Mg^{2+}	–	–	0.83	0.83
	Total	–	5.00	2.50	2.50
Concentrate alkaliwater (10 meL^{-1})	Na^+	–	15.0	–	15.0
	Ca^{2+}	–	–	3.33	3.33
	Mg^{2+}	–	–	1.67	1.67
	Total	–	15.0	5.0	10.0

Table 3. Composition of irrigation waters

Characteristics	Normal tap water	Saline water		Alkali water	
	NTW	DSW	CSW	DAW	CAW
Electrical conductivity (dS m^{-1})	0.7	5.0	10.0	0.8	2.0
Ion concentration (me L^{-1})					
Ca^{2+}	1.0	20.3	46.9	1.7	3.3
Mg^{2+}	4.2	10.2	23.5	0.8	1.7
Na^+	3.0	19.5	29.7	5.0	15.0
Cl^-	0.8	33.3	66.7	4.0	5.6
$CO_3^{2-} + HCO_3^-$	0.0 + 6.2	5.8	5.6	5.0	15.0
SO_4^{2-}	0.5	16.7	33.3	2.0	2.8
Sodium adsorption ratio (SAR)	1.9	5.0	5.0	5.0	10.0
Residual sodium carbonate (RSC)	1.0	-ve	-ve	2.5	10.0
Total elctrolyte concentration (TEC)	7.0	50.0	100.0	8.0	20.0

[SAR = $Na^+/[(Ca^{2+}+Mg^{2+})/2]^{1/2}$ in $mmol^{1/2} L^{-1/2}$; RSC = $(CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+})$ and TEC in me L^{-1} (all ions expressed in me L^{-1}); ratio of Ca^{2+} and Mg^{2+} or Cl^- and SO_4^{2-} were maintained at 2:1]

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

Now, if SAR = A and TEC = $Na^+ + Ca^{2+} + Mg^{2+}$ = B

or, $Ca^{2+} + Mg^{2+} = B - Na^+$

SAR can be re-written as:

$$A = \frac{Na^+}{\sqrt{\frac{B-Na^+}{2}}} \qquad \ldots(2)$$

Or, $\frac{(B-Na^+)}{2} = \frac{(Na^+)^2}{A^2}$

Rearranging in a quadratic equation

$$2(Na^+)^2 + A^2Na^+ - A^2B = 0 \qquad \ldots(3)$$

Hence,

$$Na^+ = \frac{-A^2 \pm \sqrt{A^4+8A^2B}}{4} \text{ me } L^{-1}$$

If Na^+ (me L^{-1}) = x, then $Ca^{2+} + Mg^{2+}$ (me L^{-1}) = B – x,

But Ca : Mg = 2 : 1, Therefore

Ca^{2+} (me L^{-1}) = 2 (B-x) /3 and Mg^{2+} (me L^{-1}) = B – $(Na^+ + Ca^{2+})$

Experimental Design

The experiment was conducted in a completely randomizned factorial design with three replications. Soil pH_2, pHs, EC_2 and EC_e were measured in a 1:2 soil-water suspension and soil saturation paste and extract using a pH and conductivity meter, respectively. Ca^{2+} and Mg^{2+} were estimated by complexometric titration involving ethylene di-amine tetra-acetic acid (EDTA), Chloride (Cl^-) was measured by argentometric titration as described by Jackson (1973). Carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were determined by methyl red and phenolphthalein end point titration (USSL, 1954). Saturated hydraulic conductivity determined by constant head laboratory permeameter (Klute and Dirkson, 1986), water retention characteristics curves at and above 10 kPa (0.1 bar) determined using a pressure plate apparatus (Bruce and Luxmoore, 1986), while Dispersion index was determined using Chaudhari and Somawanshi (2004) method.

Results and Discussion

Saturated hydraulic conductivity (Ks)

Saturated hydraulic conductivity of post-rice soil remained unchanged under NTW and DAW in the normal soil, whereas it was reduced significantly to one fifth (0.03) of the initial values (0.16 cm h^{-1}) under CAW (Table 4 and 5) due to higher exchangeable Na and comparatively higher dispersion (Table 6). Swelling becomes a prominent process when dilute solutions were passed through the soil as reported earlier by McBride (1994). DSW and CSW caused 20 and 50%, respective increase in hydraulic conductivity

Table 5. Effect of water quality on saturated hydraulic conductivity of three soils under varying soil depths at post-harvest of wheat

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
Saturated hydraulic conductivity (Ks, cm h^{-1})						
Normal Soil						
0 -15	0.16	0.20	1.56	2.31	0.11	0.01
15-30		0.24	1.09	2.36	0.14	0.01
LSD $_{0.05}$ 0.1 and 0.1 for 0-15 and 15-30 cm soil depths, respectively						
Saline Soil						
0 -15	0.23	0.89	1.13	2.55	0.77	0.12
15-30		0.78	0.90	2.43	0.66	0.18
LSD $_{0.05}$ 0.1 and 0.1 for 0-15 and 15-30 cm soil depths, respectively						
Alkali Soil						
0 -15	0.005	0.004	0.09	0.17	0.002	0.001
15-30		0.004	0.09	0.15	0.002	0.001
LSD $_{0.05}$ 0.0 and 0.0 for 0-15 and 15-30 cm soil depths, respectively						

Table 4. Effect of water quality on saturated hydraulic conductivity of three soils under varying soil depths at post-harvest of rice

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
Saturated hydraulic conductivity (Ks, cm h^{-1})						
Normal Soil						
0 -15	0.16	0.15	0.19	0.23	0.15	0.03
15-30		0.25	0.21	0.25	0.17	0.07
$LSD_{0.05}$ 0.0 and 0.1 for 0-15 and 15-30 cm soil depths, respectively						
Saline Soil						
0 -15	0.23	0.20	0.24	0.30	0.19	0.04
15-30		0.22	0.26	0.28	0.20	0.09
$LSD_{0.05}$ 0.0 and 0.1 for 0-15 and 15-30 cm soil depths, respectively						
Alkali Soil						
0 -15	0.005	0.004	0.07	0.21	0.002	0.001
15-30		0.003	0.04	0.07	0.003	0.001
$LSD_{0.05}$ 0.0 and 0.0 for 0-15 and 15-30 cm soil depths, respectively						

Table 6. Effect of water quality on dispersion index (%) of three soils under two soil depths at post-harvest of rice

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
			Dispersion Index (%)			
			Normal Soil			
0-15	29.9	30.5	29.5	28.5	31.3	39.9
15-30		30.1	28.8	27.6	32.1	38.3
LSD $_{0.05}$ 4.5 and 3.2 for 0-15 and 15-30 cm soil depths, respectively						
			Saline Soil			
0-15	27.6	29.5	27.1	26.0	31.0	34.9
15-30		28.8	28.2	27.1	31.2	34.9
LSD $_{0.05}$ 2.3 and 1.9 for 0-15 and 15-30 cm soil depths, respectively						
			Alkali Soil			
0-15	50.4	50.9	37.0	34.2	52.5	65.3
15-30		52.5	38.4	36.3	50.0	62.8
LSD $_{0.05}$ 3.6 and 3.2 for 0-15 and 15-30 cm soil depths, respectively						

as compared to initial soil due to aggregation and flocculation of soil clay. Saline soil maintained higher initial Ks under different water treatments as compared to normal soil, due to low dispersion and followed the same trend as in normal soil under different water treatments. Curtin *et al*. (1994) and Balpande *et al*. (1997) recorded equal contribution of dispersion and swelling in reducing the Ks of soils. Cheng *et al*. (1987) also considered dispersion as an important process in governing changes in Ks of soils.

Ks decreased significantly to 0.19 and 0.04 cm h^{-1} from its initial value of 0.23 under the application of DAW and CAW, respectively. Ks of initial alkali soil was observed 0.005 cm h^{-1}. It decreased significantly to 0.002 cm h^{-1} when irrigation was applied with NTW and DAW in each case. It was further decreased significantly to 0.001 cm h^{-1} when irrigation was applied with CAW (Table 4). Hydraulic conductivity reduction is difficult to restore, because of soil matrix changes caused by swelling and dispersion. Internal swelling and dispersion decrease pore size, particularly large pores, quickly reducing the hydraulic conductivity of the soil (Chaudhari, 2001). Under the application of DSW and CSW, Ks increased significantly to 0.07 and 0.21, respectively in the alkali soil. There was slight variation in the value of Ks in lower depths (15 - 30 cm) in all studied soils. Ks increased in post wheat samples under DSW and CSW as compared to corresponding post rice samples in all three studied soils (Table 5). Change in Ks was compared by taking saline water and alkali water application separately in three studied soils as compared to NTW in post rice and post wheat soils. Ks increased in all three soils under saline water irrigation, while it decreased in alkali water application as compared to NTW (Fig 1a; 1b). Ks experienced maximum increase under CSW, while it decreased maximum under CAW in saline soil as compared to NTW. While in comparison to post rice, magnitude of increase in Ks was more in post wheat samples in all three studied soils.

Dispersion index

Dispersion index in post-rice surface samples (0-15cm) under NTW, DSW, CSW, DAW and CAW was 30.5, 29.5, 28.5, 31.3 and 39.9%, respectively (Table 6). Dispersion index increased insignificantly as compared to initial soil (29.9) by application of NTW and DAW in normal soil, whereas under CAW it was increased significantly by 33% as compared to the initial soil due to low Ks and de-flocculation of the soil clay (Shainberg and Letey, 1984, Basak *et al*., 2015). Under DSW and CSW, it was decreased by about 2% and 5%, respectively, as compared to initial soil due to aggregation and flocculation of the soil clay. Lower initial DI of 27.6 was observed in saline soil as compared to normal soil (29.9). In saline soil, DI increased to 29.5, 31.0 and 34.9 with NTW, DAW and CAW application as compared 27.6 in initial soil while it slightly decreased to

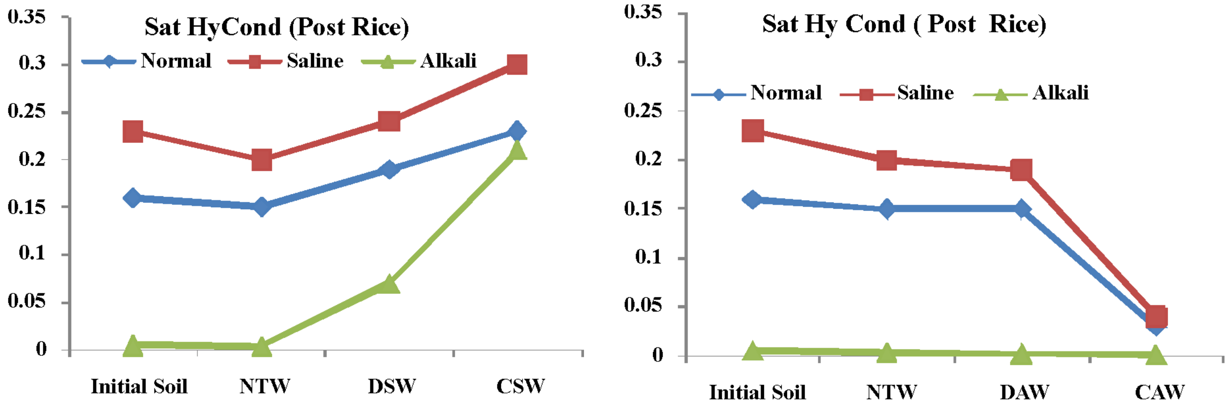

Fig. 1a Effect of saline water quality on sat hydraulic conductivity of three soils under rice

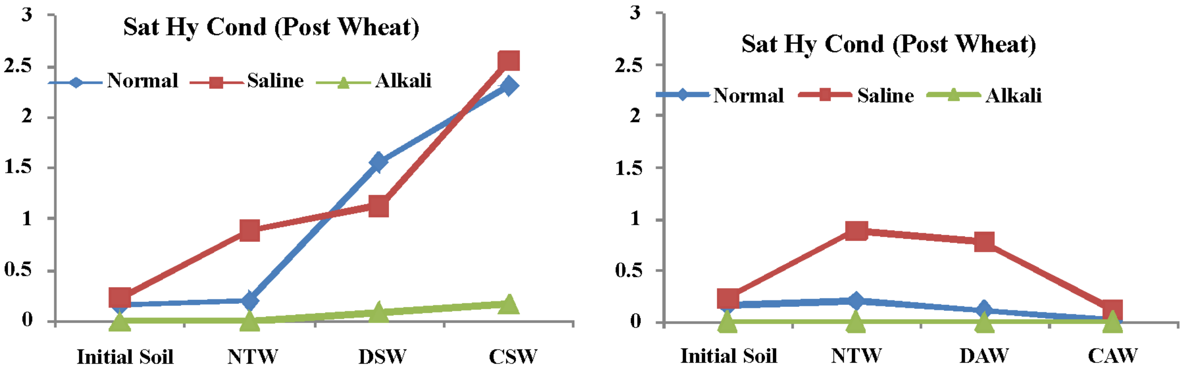

Fig. 1b Effect of alkali water quality on sat hydraulic conductivity of three soils under wheat

27.1 and 26.0 under DSW and CSW, respectively. Saline soil observed lesser DI as compared to normal soil under corresponding water treatments due to its higher Ks and followed the same trend as normal soil under different water treatments. Slight variation in DI value was observed in lower depths (15 -30 cm) in all the studied soils. With the application of NTW and DAW, DI increased to 50.9 and 52.5, respectively as compared to initial alkali soil (50.4), whereas it was increased significantly to 65.3 with application of CAW. It decreased significantly to 37.0 and 34.2 under DSW and CSW, respectively. Slight variation was found in DI value in lower depths (15-30 cm) in alkali soils (Table 6). For post-wheat samples DI decreased in each treatment under NTW, DSW, CSW, DAW and CAW (Table 7) alkali soils as compared to post-rice samples.

DI variation was compared by taking saline water and alkali water application separately in three studied soils as compared to NTW in post rice and post wheat soils. DI decreased in all three soils under saline water irrigation and it was found minimum in saline soil under CSW as compared to NTW. DI increased in alkali water application and it was observed maximum in alkali soil under CAW as compared to NTW. DI experienced maximum increased under CAW, while it decreased maximum under CSW in saline soil (Fig 2a; 2b). Dispersion increases with increase in soil pH (>7) (Regea *et al.,* 1997)**.** Dispersion of clay followed by migration of clay particles and plugging of water-conducting pores is regarded as one of the major process causing structural problems in irrigated soils.

Water retention

On applying different quality water, water retention was found to be the highest in alkali soil followed by normal and saline soil in all matric suction points (Fig 3, 4 & 5). It increased with increase in SAR of the applied irrigation water at a given suction in each of the three studied soils. Under the application of saline water, in all three soils, water retention decreased or remains unchanged with increase in TEC of the irrigation

Table 7. Effect of water quality on dispersion index (%) of three soils under two soil depth at post-harvest of wheat

Depth (cm)	Ini Exp soil	NTW	DSW	CSW	DAW	CAW
			Dispersion Index (%)			
			Normal Soil			
0-15	29.9	29.7	27.2	23.4	32.4	38.5
15-30		29.1	26.5	26.1	33.1	36.1
LSD $_{0.05}$ 3.5 and 3.1 for 0-15 and 15-30 cm soil depths, respectively						
			Saline Soil			
0-15	27.6	27.0	25.6	24.1	29.6	33.9
15-30		26.0	25.1	23.1	29.1	33.8
LSD $_{0.05}$ 2.3 and 1.6 for 0-15 and 15-30 cm soil depths, respectively						
			Alkali Soil			
0-15	50.4	48.3	34.3	31.8	50.0	63.3
15-30		47.2	33.4	32.8	50.8	62.0
LSD $_{0.05}$ 3.1 and 3.1 for 0-15 and 15-30 cm soil depths, respectively						

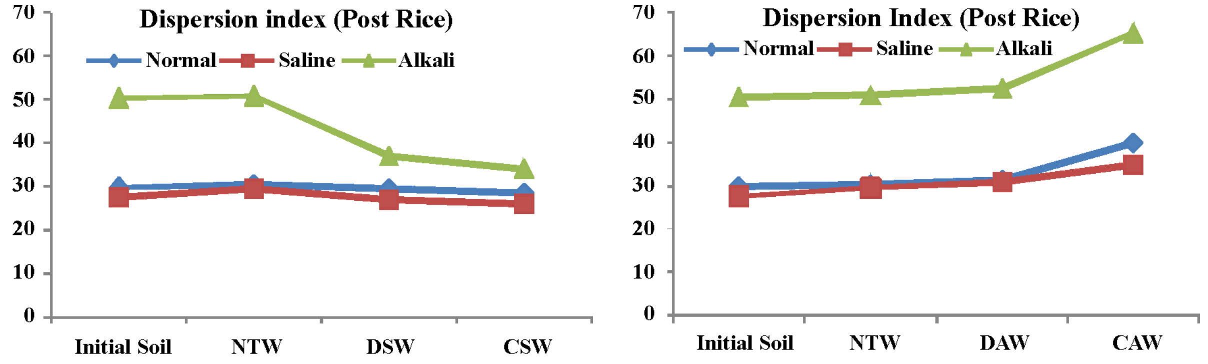

Fig. 2a Effect of saline water quality on dispersion index of three soils under rice

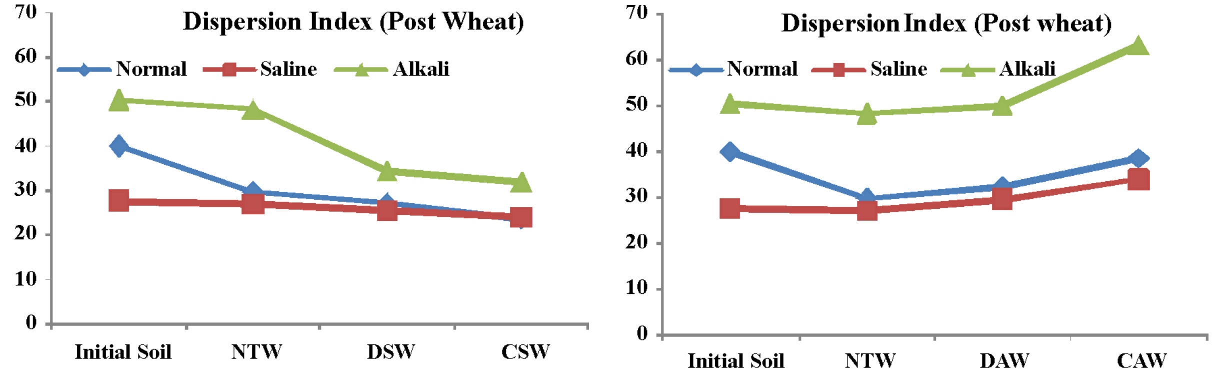

Fig. 2b Effect of alkali water quality on dispersion index of three soils under wheat

water (Malik *et al.,* 1992) as compared to application of normal tap water. Whereas with the application of alkali water, in all three soils, water retention increased with increase in TEC of the irrigation water as compared to normal tap water application.

At all suction points, water retention was observed highest in CAW (SAR 10.0 mmol$^{1/2}$L$^{-1/2}$ and TEC 20 me L^{-1}) in alkali soil and least under CSW (SAR 5.0 and TEC 100 mmol$^{1/2}$L$^{-1/2}$) in saline soil. At low suction (0.1 bar), wider difference in water retention was observed in alkali and normal soils. However, difference in water retention was narrowed down in higher suction range (3-15 bar). Russo and Bresler (1980) also found that at a fixed SAR, when TEC was low,

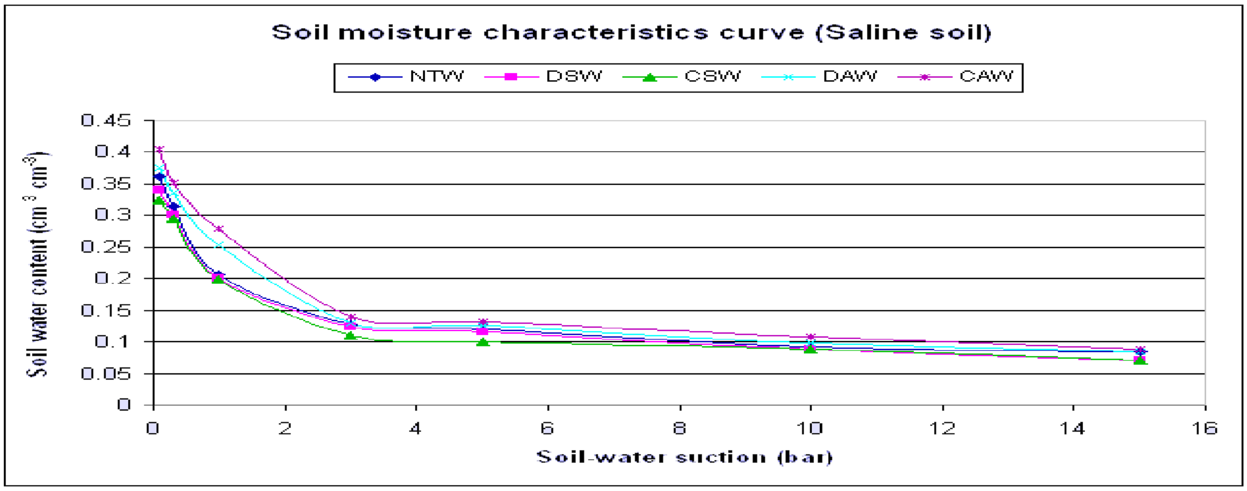

Fig. 3 Water quality effect on soil-water content in saline soil

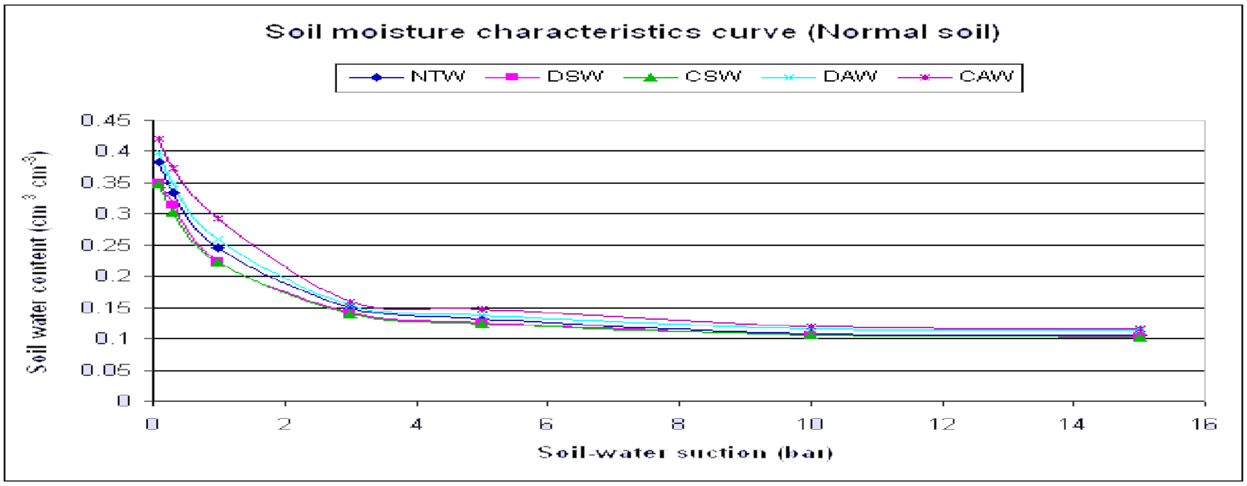

Fig. 4 Water quality effect on soil-water content in normal soil

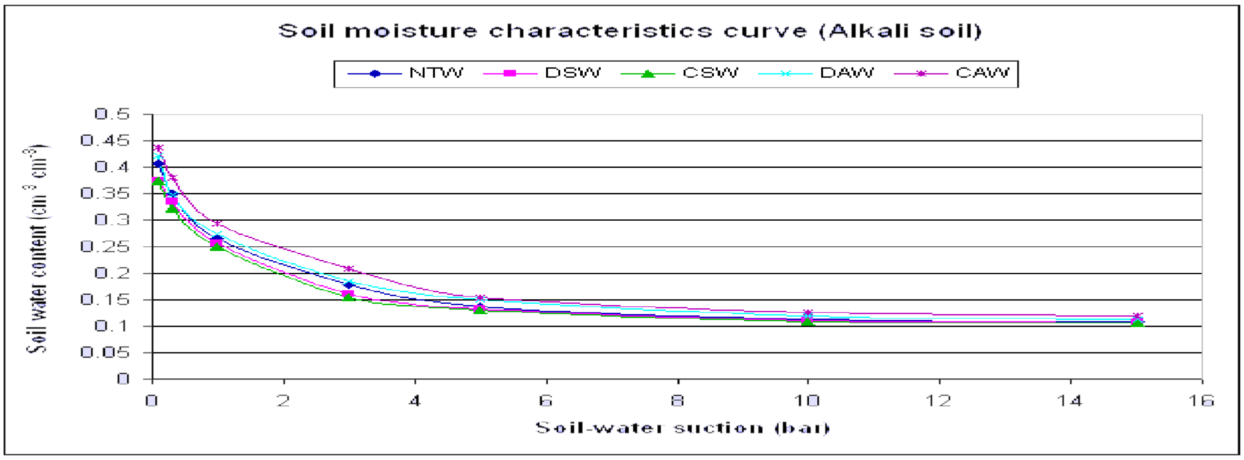

Fig. 5 Water quality effect on soil-water content in alkali soil

the macropores and mesopores collapsed and became micropores. Water content was found to be varied in the order as saline soil < normal soil < alkali soil with respect to the corresponding quality water applied.

The highest water content was observed under CAW (0.44 cm^3 cm^{-3}) and least under CSW (0.36 cm^3 cm^{-3}) in the alkali soil. In the normal soil, water content was 0.42 and 0.35 cm^3 cm^{-3} under CAW and CSW, respectively. Water content was highest when irrigation was applied with CAW (0.41 $cm^3\ cm^{-3}$) and least under CSW application (0.33 $cm^3\ cm^{-3}$) at low suction range (0.1 bar) in saline soil. At high suction range (15 bar), effect of water quality on water content was not significant in all three studied soils (Fig 3, 4 & 5). Tetsu *et al.* (2003) mentioned that water retention relations were obtained with respect to water retained in intra-granular pores and along particles surfaces.

Conclusions

On application of poor quality water, salinity and alkalinity were more pronounced in normal soil leading to more risk of normal soil degradation. Ks of soils, irrespective of water quality were quite high in soils of post-wheat crop compared to soils of post-rice. However, irrigation with concentrated saline water increased Ks, whereas Irrigation with concentrated alkali water decreased Ks. DI of soil, irrespective of water quality was lower in soils of post-wheat crop compared to soils of post-rice. Water retention was highest in alkali soil, followed by normal and saline soil at all matric suction. In all three studied soils, water retention was found lowest in CSW and highest in CAW.

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