Journal of the Indian Society of Soil Science, Vol. 66, No. 3, pp 258-267 (2018)
DOI: 10.5958/0974-0228.2018.00032.4

Chemical Properties of the Salt-affected Soils and Performance of Wheat (*Triticum aestivum*) with Saline and Alkali Water Irrigation

N.K. Arora*, S.K. Chaudhari[1], J.A. Farooqi[2], A.K. Rai and Manisha

Division of Soil and Crop Management, ICAR-Central Soil Salinity Research Institute, Karnal, 132 001, Haryana

Effect of different quality of 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}) on the soil chemical properties and its impact on growth and yield of wheat (cv.KRL 213) was evaluated in 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-lysimeter. The ECe increased by 9.5, 12.5 and 5.5, 7.0 times due to DSW and CSW irrigation in normal and alkali soils, respectively as compared to initial values, whereas decrease in ECe was observed in all water treatments except CSW in saline soil. Increase in pHs of normal and saline soils was more pronounced in case of NTW, DAW and CAW as compared to alkali soil. On application of DSW and CSW, decrease in pHs was observed in alkali soil, whereas it remained constant in normal and saline soils as compared to initial. Exchangeable sodium percentage (ESP) increased with all water treatments in normal, saline and alkali soils. This increase was more pronounced under NTW, DAW and CAW in alkali soil as compared to normal and saline soils. Sodium concentration in saturation paste increased by 15 to 17 times in normal soil, 3.5 to 4.5 times in alkali soil under DSW and CSW, respectively. Sodium leaching was observed in saline soil under all water treatments except under CSW where it increased to 1.2 times. Sodium build-up was increased 1.5 to 2.0 times under all water treatments in normal, saline and alkali soils as compared to post rice sodium concentration. Increase in organic carbon content was observed in surface samples in normal soil, whereas it was not as pronounced in saline and alkali soils. Calcium carbonate increased significantly in all depths in three soils under DAW and CAW. Wheat yield reduced approximately by 4, 11 and 34 per cent under normal, saline and alkali soils, respectively in DAW as compared to NTW, whereas CAW reduced grain yield by 31 per cent in normal, 87 per cent in saline and near total loss of crop was observed in case of alkali soil as compared to NTW. The DSW reduced yield by about 22 per cent each in normal and saline soils and about 70 per cent in alkali soil. Application of CSW reduced yield by 70 per cent in normal soil, whereas near complete loss of crop was observed in saline and alkali soils as compared to NTW.

Key words: Saline water, alkali water, salt-affected soils, wheat, exchangeable sodium percentage, residual sodium carbonate, sodium adsorption ratio

Rice-wheat is the pre-dominant cropping system of Indo-Gangetic plains and both these crops need ample amount of water for optimum growth and yield. Irrigation with poor quality waters deteriorates the soil properties and creates condition unfavorable for economic growth of crops, with normal farming practices. Amount and kind of salts in irrigation waters determine the nature of hindrance in crop growth. The most common problems resulting from irrigation with poor quality waters can be arising due to salinity, alkalinity and toxicity hazards (Minhas and Bajwa 2001). The total concentration of soluble salts and its ionic composition is one of the most important criteria which have been used for determining the quality of irrigation water. Relative concentration of specific cations and anions present

*Corresponding author (Email: nk.arora@icar.gov.in)
[1]Division of Natural Resource Management, Indian Council of Agricultural Research, Krishi Anusandhan Bhawan-II, IARI, Campus, New Delhi, 110 012
[2]Department of Chemistry, School of Sciences, IGNOU, New Delhi, 110 012

in the water also play important role in development of the irrigation induced alkalinity or salinity in the soil. When soils are irrigated with bicarbonate type water dominated by sodium (Na) ions, soil usually accumulate excessive amounts of Na on the exchange complex. Sodicity build-up in soils depends on the amounts of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions in the irrigation water. Large areas in Rajasthan, Haryana, Uttar Pradesh, Karnataka, Punjab and Gujarat are underlain with saline and high residual sodium carbonate (RSC) groundwater (Manchanda *et al.* 1989) and due to prolonged use of poor quality water these areas develops sodicity and salinity problems which induces changes in physicochemical properties leading to reduced crop yield (Manchanda *et al.* 1982; Bajwa and Josan 1989; Bajwa *et al.* 1992; Choudhary *et al.* 2004). High concentration of Na^+, CO_3^{2-}, HCO_3^- and chloride (Cl^-) present in irrigation water leads to increase in soil pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP) (Minhas and Bajwa 2001; Choudhary *et al.* 2011). Keeping all this in view, an attempt has been made to study the chemical properties of saline and alkali soils and yield of rice and wheat under saline and alkali irrigation water.

Materials and Methods

Soil sampling and analysis

The present study was conducted in micro-lysimeter (1.0 m deep and 0.3 m internal diameter) at the experimental farm of ICAR-Central Soil Salinity Research Institute (CSSRI), Karnal located at latitude of 29º43' N and longitude of 76º58' E. Three different soils (normal soil, collected from experimental farm of ICAR-CSSRI, Karnal; saline soil, collected from experimental research farm Nain-Panipat and alkali soil, collected from Saraswati farm-Kaithal) were used for this investigation. Initial soil characteristics and ionic composition of soil saturation extract are given in table 1 and 2.

The experiment was conducted in a completely randomized factorial design with three replications. Rice and wheat were grown in rotation by applying different quality water and change in soil chemical properties and performance of wheat was recorded in comparison with initial soil. Soil pH_2, EC_2, pHs, and ECe were measured in a 1:2 soil:water suspension and soil saturation paste and extract using pH and conductivity meters, respectively (USSL 1954; Page *et al.* 1982). Soil ESP was determined by alcoholic ammonium acetate method described by Tucker (1971) and soil organic carbon (OC) was determined by wet oxidation method (Walkley and Black 1934). Soil texture was determined by International pipette method (Gee and Bauder 2006). Calcium carbonate was measured by neutralization with HCl (Richards 1954) and cation exchange capacity (CEC) by extracting the sample with sodium acetate solution of pH 8.5 (Gupta *et al.* 1985). The Ca^{2+} and Mg^{2+} were estimated as described in USDA handbook 60. Chloride was measured by argentometric titration as described by Jackson (1973). Carbonate and bicarbonate were determined using methyl red and phenolphthalein end point titration (Richards 1954).

Crop growth and water quality treatments

Wheat (cv. KRL 213) was sown during *rabi* season (November-April) in the third week of November, 2013. After the harvesting of rice crop, wheat was raised in the same lysimeters by applying normal water at the pre-sowing stage. No quality water

Table 1. Initial physicochemical properties of experimental soils

Soils	pHs	EC_2	ECe	CEC	ESP	OC	Sand	Fine sand	Silt	Clay	$CaCO_3$
		(dS m^{-1})		cmol(p^+)kg^{-1}	%						
Normal soil	7.5	0.3	1.0	15.2	4.2	0.50	39.9	21.4	24.3	15.3	0.3
Saline soil	7.7	2.8	10.6	13.2	11.2	0.45	47.5	17.7	22.4	12.4	0.3
Alkali soil	9.2	0.8	2.9	15.0	23.9	0.42	44.1	19.7	22.5	15.7	0.5

[Textural class: sandy loam; pH_2 and EC_2: pH and electrical conductivity at 1:2 soil-water suspensions; ECe: Electrical conductivity of saturation paste; ESP: Exchangeable Na percentage]

Table 2. Ionic composition of saturation extract (me L^{-1}) of experimental soils

Soils	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	SO_4^{2-}	CO_3^{2-}	HCO_3^-
Normal soil	3.7	1.8	4.6	0.2	4.0	3.2	0.0	1.0
Saline soil	28.5	19.5	88.6	0.7	58.0	46.3	0.0	3.0
Alkali soil	2.1	1.4	31.3	0.1	10.0	9.6	2.0	8.0

Table 3. Amount of chemical required for the preparation of different quality waters

Chemical name	Amount of chemical dissolved per litre (g)			
	EC 5.0 dS m^{-1}	EC 10.0 dS m^{-1}	RSC 2.5 me L^{-1}	RSC 10.0 me L^{-1}
NaCl	0.761	1.156	NA	NA
Na_2SO_4	0.462	0.702	NA	NA
$NaHCO_3$	NA	NA	0.422	1.26
$CaCl_2.2H_2O$	1.49	3.45	0.123	0.245
$MgSO_4.7H_2O$	1.252	2.889	NA	NA
$MgCl_2.6H_2O$	NA	NA	0.085	0.17

NA: not applicable; Amount of the chemical was calculated on the basis of putting the TEC value in SAR quadratic equation on taking Ca : Mg ratio 2:1.

Table 3A. Composition of irrigation waters

Characteristic	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	-	-	2.5	10.0

SAR = $Na^+/[(Ca^{2+}+ Mg^{2+})/ 2]^{1/2}$ in $mmol^{1/2} L^{-1/2}$; RSC = $(CO_3^{2-}+HCO_3^-) - (Ca^{2+}+Mg^{2+})$ 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; DSW: Dilute saline water; CSW: Concentrated saline water; DAW: Dilute alkali water; CAW: Concentrated alkali water

was applied in the lysimeter up to 3 weeks after sowing. A basal dose of 75 kg N, 60 kg P_2O_5, 30 kg K_2O and 25 kg Zn ha^{-1} was applied to the wheat crop. Lateron, remaining 75 kg N ha^{-1} was applied after 21 and 45 days after sowing (DAS) in equal splits. After establishment of crown root initiation stage (CRI), total 5 irrigation were imposed at 21, 45, 65, 85 and 105 DAS with five different quality waters *viz.,* normal tap water (NTW), diluted saline water of EC_w 5.0 dS m^{-1}, SAR 5.0 $mmol^{1/2}$ $L^{-1/2}$ (DSW), concentrated saline water of EC_w 10 dS m^{-1}, SAR 5.0 $mmol^{1/2}$ $L^{-1/2}$ (CSW) and diluted alkali water of RSC 2.5 me L^{-1} (DAW) and concentrated alkali water of RSC 10 me L^{-1} (CAW). These quality waters were synthesized freshly every time using bicarbonate, chloride and sulphate of calcium, magnesium and sodium in the syntax water tank. Amount of the chemical required for the preparation of different quality waters (Arora *et al.* 2012; Basak *et al.* 2015) and chemical compositions of saline and alkali water are presented in table 3 and 3A.

Soil samples were collected depth-wise (0-15 and 15-30 cm) after harvesting the rice and wheat crop and analyzed for different chemical properties. Various biometric observations like plant height, panicle length and yield were also recorded (Data not shown).

Results and Discussion

Electrical conductivity

Salt load declined under saline soils, on application of normal tap water (NTW) but slight increase in salt load was observed in normal and alkali soils (Arora *et al.* 2012). Under normal soil, ECe was 9.5 and 12.6 times higher from initial values when 5-irrigation cycles were applied under dilute (DSW) and concentrated saline water (CSW) in 0-15 cm soil depth. It is the obvious effect of cations and anions present in saline irrigation water which led to increase in the EC_2 and ECe (Choudhary *et al.* 2004; Ould Ahmed *et al.* 2010). The ECe was increased to 2.3 and 3.9 dS m^{-1} from 1.0 dS m^{-1} upon irrigation with dilute and concentrated alkali water (DAW and CAW) in the surface layer of normal soil. Same alkali water increased ECe nearly 2 to 3 times in the 15-30 cm

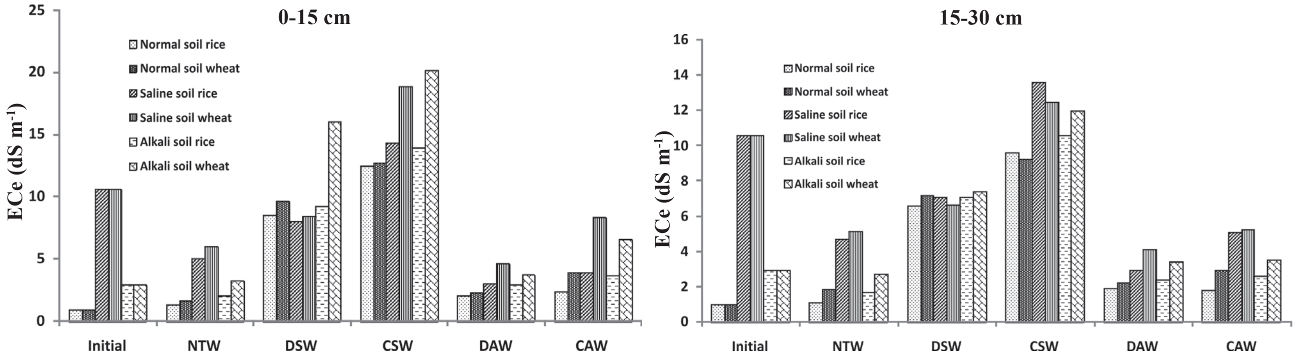

Fig. 1. Effect of irrigation treatments on ECe of post rice and post wheat soils at two soil depths

layer for normal soil, respectively. A build-up of ECe (5.5 and 7.0 times) was also recorded in alkali soil when irrigated with two saline water treatments as compared to normal soil. Both alkali water increased ECe by 33 to 100 per cent in the surface soil layer in alkali soil as compared to initial level. In the lower depth, alkali soil remained unaffected in respect to salt load upon irrigation with alkali water. Effect of salt load was relatively lower due to other water treatments under saline soil, while it increased to ~75 per cent from initial level when irrigated with CSW. Substantially lower ECe were observed in both the soil depths when irrigated with DAW and CAW in saline soil as compared to initial values. Lower salt build-up was observed in 15-30 cm soil depth for normal, saline and alkali soil upon irrigation with normal and saline water compared to 0-15 cm soil depth. But, on application of NTW, ECe remained nearly same or slightly higher at 15-30 cm depth compared to surface soil in normal soil. Arora *et al.* (2012) reported the change in the chemical properties of the different soils by growing rice crop in the same experiment. On comparing ECe data for rice-wheat crop soil samples for consecutive years, trend of increase in ECe was observed in normal, saline and alkali soils under all water treatments. This build-up was found more pronounced in saline and alkali soil under DSW, CSW and CAW and was observed particularly in surface soil (Fig.1). It is evident from fig. 1, increase in ECe was more in post-wheat than rice harvesting at 0-15 cm soil depth.

Soil ECe in the normal soil reached to the threshold level of salinity (3.0 dS m^{-1}) under alkali water (Grattan *et al.* 2002). Choudhary *et al.* (2011) also reported a doubling ECe in 0-15 cm layer, under alkali water irrigation (EC_{iw} 2.1 dS m^{-1}, RSC_{iw} 12.5 me L^{-1}, SAR_{iw} 10.6 $mmol^{1/2} L^{-1/2}$) in rice-wheat rotation in calcareous soil in Punjab state.

Soil pH

Normal tap water (NTW) irrigation increased soil pH by 0.5 unit in both the soil depths in normal soil whereas, imposing of five irrigations of DAW caused significant increase in soil pH of normal soil (Fig. 2). The highest pH increment at both soil depths were 1.2 unit for normal soil under CAW. The presence of Na^+ and HCO_3^- in irrigation water can lead to increases in pH (Minhas and Bajwa 2001; Jalali and Ranjbar 2009). However, soil pH of the normal soil largely remained unaffected on application with DSW and CSW. Alkali soil pH also remained unaffected under DAW and a decrement of 0.15 unit was noticed under NTW as compared to initial value. Soil was extremely alkali in nature and leaching of $CO_3^{2-} + HCO_3^-$ did not happen due to low permeability (Table 5). Application of saline water (DSW and CSW) significantly reduced soil pH for alkali soil whereas it remained more or less same for normal and saline soil. The highest degree in decrement under DSW and CSW was around 1.4, 1.2 and 1.25, 1.1 unit in two respective depths (0-15 and 15-30 cm) for alkali soil. Data revealed that more the salinity of the water applied, more reduction in the soil pH was observed in all soils. Presence of soluble salts prevents the alkaline hydrolysis due to common ion effect (Minhas and Bajwa 2001). A significant increase in soil pH of 0.4 unit under NTW, 0.65 unit under DAW and 0.9 unit under CAW for saline soil at respective soil depths were recorded. But, change in soil pH was significantly unaffected in saline soil under both saline waters. A significant increase in soil pH was observed for all soils irrigated with concentrated alkali water (RSC 10.0 me L^{-1}). Greater rise in soil pH was noticed for normal soil with 1.2 unit for both soil depths followed by saline soil with 0.9 and 0.7 unit and 0.2 unit for alkali soil in both soil depths. Soil pH showed a decreasing trend when comparing soil samples at

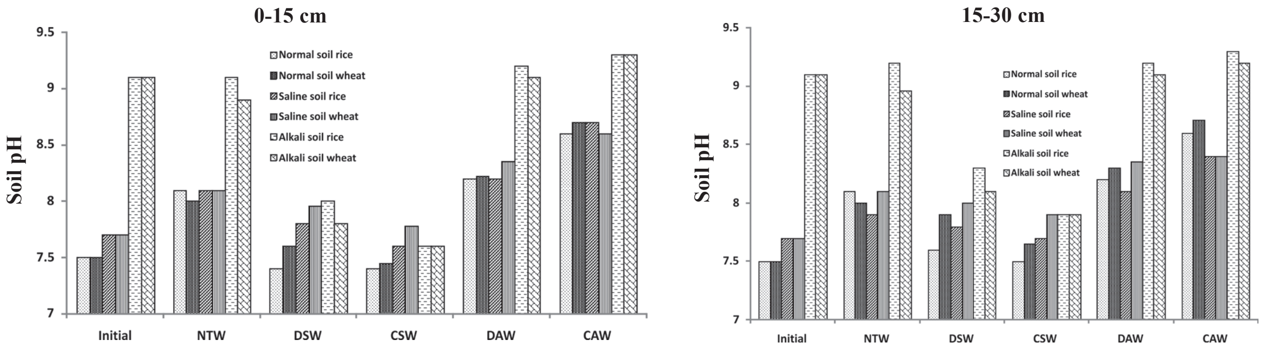

Fig. 2. Effect of irrigation treatments on pHs of post-rice and post-wheat soils at two soil depths

two depths (0-15 and 15-30 cm) of post-wheat to post-rice crop under alkali soils, whereas slight increase in soil pH was observed in post-wheat samples as compared to post-rice under normal soil in all water treatments (Arora *et al.* 2012)**.** Both these effects were more pronounced in saline water application as compared to alkali water application (Fig. 2). This was owing to increased sodium concentration in both cases but at the same time decreased carbonate and bicarbonate concentration in alkali soil, while increased carbonate and bicarbonate concentration in normal soil (Table 5). Soil pH increment of about 2.2 and 1.9 unit was recorded by Choudhary *et al.* (2011) on a long-term rice-wheat rotation with alkali water irrigation (EC_{iw} 2.1 me L^{-1}; RSC_{iw} 12.5 me L^{-1}) in normal soil (pH_2 7.9, EC_2 0.2 dS m^{-1}) in Punjab.

Exchangeable sodium percentage

The ESP for respective water quality irrigation in all three studied soils followed nearly similar trend in both depths (Fig. 3). The ESP became double in normal soil upon irrigation with normal tap water and diluted alkali water as compared to initial soil, it increased by 4 times upon irrigation with both dilute and concentrated saline water, while it increased 6 times on application of concentrated alkali water. These results corroborate with the earlier reports of increased soil ESP due to application of saline and sodic water to soil that did not receive any chemical/ organic amendments (Choudhary *et al*. 2004; Jalali and Ranjbar 2009; Bajwa and Choudhary 2014). The ESP of saline soil remained under safe range (≤15) when treated with other quality water except the concentrated alkali water in which it was elevated around three times compared with the initial value. Upon irrigation with concentrated alkali water (RSC 10.0 me L^{-1}), ESP increased to around 6.2 and 6.0 times for normal; 3.2 and 1.8 times for saline and 2.3 and 2.0 times for alkali soil for two soil depths as compared to initial ESP of the respected soil. The rate of increase was more due to prior establishment of quasi-equilibrium. It was observed that ESP was highest for alkali soil (27.3-55.3 and 25.0-47.9) followed by saline soil (16.9-35.3 and 15.6-28.9) and normal soil (9.8-26.4 and 9.5-25.3) in two soil depths. The soil salinity depend on nature of salts and its load, soil characteristics, nature of crops grown and rainfall frequency and evaporation demands. So, sodicity built-up (ESP>15) is not attained as residual alkalinity (RSC) of the quality water, which was ≤ 2.5 me L^{-1} for NTW and DAW and RSC was nil for saline water. Therefore, RSC of 2.5 me L^{-1} is prescribed by most for safe use of irrigation water without its deleterious effects (USSL 1954). Additionally, it was visualized that saline waters irrigation with moderate SAR (5.0 $mmol^{1/2}\,L^{-1/2}$) would not have any adverse effects like sodification. But long-term use of saline water with moderate SAR (~6) leads to high ESP (USSL 1954). Irrigation water with high residual alkalinity had a priming effect to build-up sodicity in alkali soil as shown in fig. 3 where ESP values of around ~50 was observed in two soil depths. Several reports also highlighted the sodicity build-up in soils due to short/prolong irrigation with waters having residual alkalinity. The ESP build-up continued from post rice to post wheat in all three soils under all water treatments (Fig. 3) due to increase in exchangeable sodium concentration as compared to exchangeable calcium and magnesium owing to addition of sodium in all water treatments (Choudhary *et al*. 2006; Minhas *et al*. 2007; Choudhary *et al*. 2011).

Ion analysis

Appreciable amount of Na^+ along with Ca^{2+} and Mg^{2+} was recorded under dilute and concentrated saline waters in normal soil, whereas comparatively lesser amount of Na^+ and Mg^{2+} build-up and absence

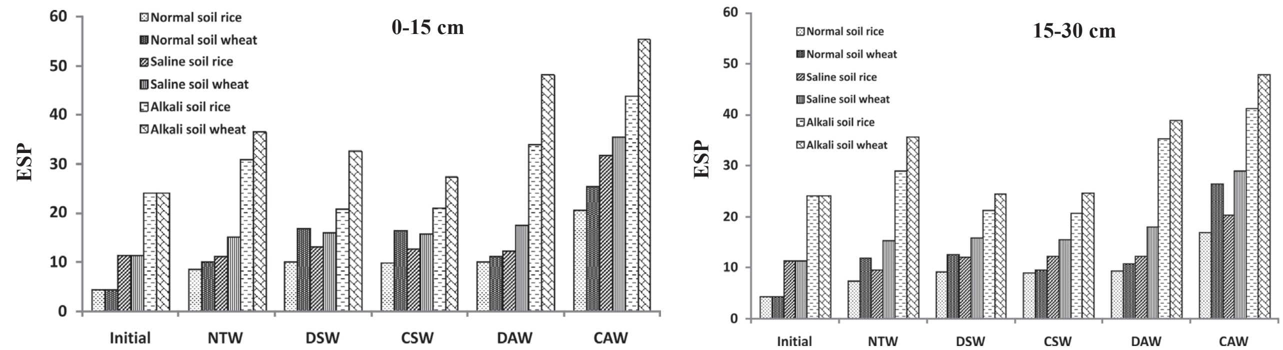

Fig. 3. Effect of irrigation treatments on ESP of post rice and post wheat soils at two soil depths

of Ca^{2+} build-up was found under NTW, DAW and CAW in normal soil. Substantial amount of Na^+ in irrigation water (EC_{iw} 5.0 and 10.0 dS m^{-1}; SAR 5.0 $mmol^{1/2}$ $L^{-1/2}$) can increase Na^+ in normal (71.4 and 82.3 me L^{-1}), saline (39.0 and 114.8 me L^{-1}) and alkali soil (113 and 136.6 me L^{-1}) under DSW and CSW application, respectively (Table 4 and 5). The occurrence of Na^+ was higher under CAW compared to DAW. Continuous irrigation with both alkali waters (Na^+ 5.0 and 15.0 me L^{-1}) can increase the holding capacity of Na^+ in alkali soil. An appreciable amount of Na^+ in soil solution was also reported by Basak *et al.* (2015) when saline-alkali and alkali soils were fed with saline water (EC_{iw} 6.0 and 12. dS m^{-1}; SAR 5.0 $mmol^{1/2}$ $L^{-1/2}$) in column-leaching experiment. Furthermore, continuous use of alkali waters caused poor soil permeability and reduced leaching of Na^+ (Bajwa *et al*. 1998; Choudhary *et al.* 2004). The Ca^{2+} content decreases under NTW specifically for saline soil, whereas it remains unaffected for normal and alkali soils when compared with initial soil. The 8 fold increase in Ca^{2+} and 20 and 30 fold increase in Mg^{2+} content were found under DSW and CSW in normal soil whereas; 10 and 17 fold increase in Ca^{2+} content and 40 and 54 fold increase in Mg^{2+} content were recorded upon irrigation with DSW and CSW for alkali soil in surface layer. Substantially lower amounts of Na^+, Ca^{2+} and Mg^{2+} were observed under 15-30 cm soil depth in these soils (Table 4). Enrichment of HCO_3^- was observed in normal soil under all water treatments with CO_3^{2-} remain unaffected, whereas CO_3^{2-} concentration reduced to 25% to 50% in alkali soil irrigated with normal, dilute and concentrated alkali water, whereas HCO_3^- concentration more or less remain unaffected. Wash out of the HCO_3^- was also reported in saline soil under all water treatments (Table 5). Poor permeability, decrease in infiltration had significant impact on CO_3^{2-}

Table 4. Effect of different water quality treatments on water soluble cations (me L^{-1}) at two soil depths

Soils	Initial	NTW	DSW	CSW	DAW	CAW	$LSD_{0.05}$
				Ca^{2+}			
0-15 cm							
Normal soil	3.7	3.5	26.5	28.0	3.5	3.7	2.5
Saline soil	28.5	7.2	7.0	35.0	7.0	11.0	2.7
Alkali soil	2.1	2.5	21.0	35.5	3.2	3.0	2.3
15-30 cm							
Normal soil	3.7	3.2	14.5	27.0	3.5	3.0	2.7
Saline soil	28.5	7.5	4.0	12.0	6.0	11.0	2.0
Alkali soil	2.1	2.5	11.0	19.0	3.0	2.2	2.8
				Mg^{2+}			
0-15 cm							
Normal soil	1.8	6.4	34.5	54.0	6.0	5.8	2.6
Saline soil	19.5	33.0	40.0	90.5	18.5	32.0	5.5
Alkali soil	1.4	3.5	55.5	76.5	5.2	3.0	4.0
15-30 cm							
Normal soil	1.8	6.0	24.5	34.2	7.0	3.0	2.4
Saline soil	19.5	29.0	34.5	63.0	16.5	14.0	7.8
Alkali soil	1.4	3.0	20.5	50.0	3.5	2.3	4.8

Table 5. Effect of different water quality treatments on water soluble anions (me L^{-1}) at two soil depths

Soils	Initial	NTW	DSW	CSW	DAW	CAW	$LSD_{0.05}$
				CO_3^{2-}			
0-15 cm							
Normal soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Saline soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkali soil	2.0	0.5	0.0	0.0	1.0	1.0	0.0
15-30 cm							
Normal soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Saline soil	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alkali soil	2.0	0.5	0.0	0.0	0.5	1.0	0.0
				HCO_3^-			
0-15 cm							
Normal soil	1.0	3.7	3.0	2.5	4.7	4.5	0.3
Saline soil	3.0	1.2	1.2	2.0	1.7	1.7	0.4
Alkali soil	8.0	2.5	1.2	2.0	6.7	5.7	1.1
15-30 cm							
Normal soil	1.0	4.2	3.2	2.2	4.7	3.0	0.4
Saline soil	3.0	1.2	1.2	1.0	1.2	2.0	0.1
Alkali soil	8.0	2.7	1.2	2.0	6.5	6.1	0.4

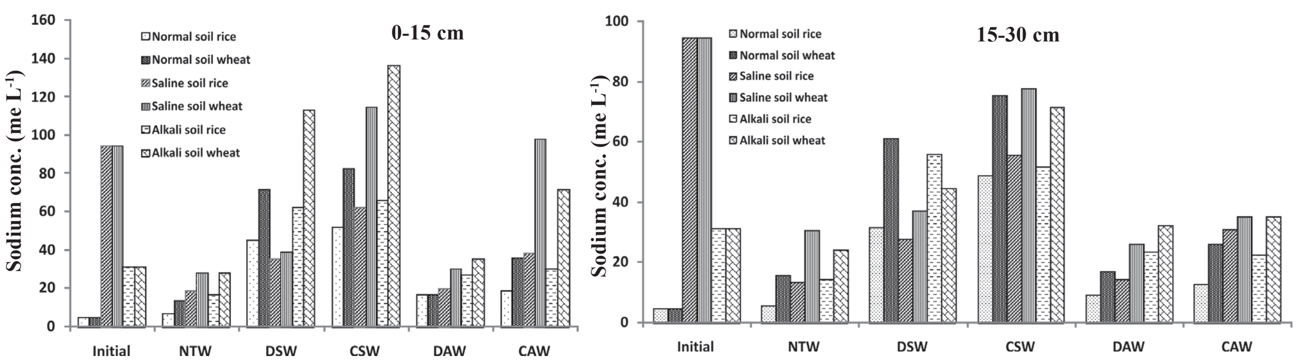

Fig. 4. Effect of irrigation treatments on sodium conc. of post rice and post wheat soils at two soil depths

+ HCO_3^- loading in alkali soil when fed with water having residual alkalinity (Minhas *et al.* 2007). Concentration of carbonate plus bicarbonate decreased under saline and alkali soils whereas, it increased under normal soil. Sodium build-up continued in all three soils, while increase in calcium plus magnesium concentration was observed in saline and alkali soil, whereas it decreased slightly in normal soil under post-wheat soils as compared to post-rice soils (Arora *et al.* 2012) under all water treatments (Fig. 4).

Organic carbon

Organic carbon slightly increased in the surface layer in all three soils under all water treatments, although this increase was higher under NTW and lowest under CAW in normal soil. Similar trend was followed in other two soils but of slightly lower magnitude (Table 6). Higher value of OC can be explained on the basis of accumulation of residues of leaves and roots in the lysimeter and slight lower value of OC under alkali soil was due to dissolution of OC owing to higher pH of alkali soil (Singh and Totawat 1994). Tavakkoli *et al*. (2014) also reported the enhanced solubility of OC at high pH. The OC increased (about 15%) in post-wheat soils as compared to post-rice soils under all water treatments in all three soils (Arora *et al*. 2012) owing to decomposition of leaves and roots residues but this increase (~8%) was hampered under CAW in alkali soil at two soil depths.

Calcium carbonate

There was general increase in calcium carbonates concentration under all treatments in all three soils. But it increased more on the application of DAW and CAW under normal and alkali soils as compared to saline soil (Table 7). Under application of DSW, it increased about 1.5-times whereas it

Table 6. Effect of water quality on organic carbon (%) of three soils at two soil depths

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
			Normal Soil			
0 -15	0.50	0.74	0.69	0.69	0.72	0.65
15-30		0.52	0.49	0.56	0.53	0.50
LSD (P=0.05): 0.0 and 0.0 for 0-15 and 15-30 cm soil depths, respectively						
			Saline Soil			
0 -15	0.45	0.58	0.56	0.55	0.58	0.56
15-30		0.52	0.49	0.56	0.56	0.56
LSD (P=0.05): 0.0 and 0.0 for 0-15 and 15-30cm soil depths, respectively						
			Alkali Soil			
0 -15	0.42	0.56	0.53	0.53	0.55	0.50
15-30		0.55	0.52	0.53	0.51	0.51
LSD (P=0.05): 0.1 and 0.1 for 0-15 and 15-30 cm soil depths, respectively						

Table 7. Effect of water quality on calcium carbonate (%) of three soils at two soil depths

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
			Normal Soil			
0 -15	0.30	0.6	0.5	0.5	0.9	1.0
15-30		0.6	0.6	0.5	0.8	1.1
LSD (P=0.05): 0.2 and 0.2 for 0-15 and 15-30 cm soil depths, respectively						
			Saline Soil			
0 -15	0.30	0.7	0.6	0.5	0.6	0.7
15-30		0.7	0.6	0.5	0.8	1.0
LSD (P=0.05): 0.1 and 0.1 for 0-15 and15-30 cm soil depths, respectively						
			Alkali Soil			
0 -15	0.50	0.8	0.8	0.5	1.3	1.3
15-30		1.1	0.8	0.6	1.0	1.4
LSD (P=0.05): 0.2 and 0.3 for 0-15 and 15-30 cm soil depths, respectively						

increased least under CSW application. Increase in $CaCO_3$ concentration may be because of precipitation of calcium as calcium carbonate on application of alkali waters in alkali soil (Singh and Bajwa 1991). This increment under post-rice samples were restricted under CAW only, while under post-wheat samples, this increment was for all, irrespective of water treatments and kind of soils.

Cation exchange capacity

There exists a relationship between CEC, soil texture and organic matter content (Saidi Djamel 2012). The CEC depends mainly on clay content of different soils. Clay content of normal, saline and alkali soils were determined as 15.3, 12.4 and 15.7% respectively (Table 8). Because of very little difference in clay content of three soils and similar

Table 8. Effect of water quality on cation exchange capacity [cmol(p^+)kg^{-1}) of three soils at two soil depths

Depth (cm)	Initial soil	NTW	DSW	CSW	DAW	CAW
			Normal Soil			
0 -15	15.2	11.6	10.9	10.7	11.9	12.2
15-30		10.9	12.1	11.2	9.6	10.0
LSD (P=0.05): 0.5 and 0.5 for 0-15 and 15-30 cm soil depths, respectively						
			Saline Soil			
0 -15	13.2	9.6	9.0	9.7	8.6	8.3
15-30		9.0	9.4	9.6	8.6	8.2
LSD (P=0.05): 0.4 and 0.4 for 0-15 and 15-30 cm soil depths, respectively						
			Alkali Soil			
0 -15	15.0	10.2	10.2	9.8	9.7	10.0
15-30		10.7	10.5	9.8	9.6	10.2
LSD (P=0.05): 0.6 and 0.3 for 0-15 and 15-30 cm soil depths, respectively						

soil texture, no appreciable change in CEC values were observed from rice to wheat samples in all three soils under all water treatments.

Crop yield

Application of saline and alkali water adversely affected the yield (Fig. 5) contributing parameters of wheat including plant height, leaf area and numbers of panicles, straw and grain weight (data not shown). Concentrated saline water irrigation made these adverse effects relatively more severe as compared to alkali water (CAW). Nearly total loss in crop emergence was recorded for saline and alkali soil and 30 per cent less grain yield was recorded for normal soil under CSW as compared to NTW. Normal soil recorded around 70 per cent yield under CAW, whereas around 13 per cent grain yield was recorded under saline soil and nearby total loss of crop recorded for alkali soil as compared to NTW. Grains in saline soil observed around 7 per cent yield penalty, whereas it was around 11 per cent in alkali soil under NTW as compared to normal soil. Whereas, 14 per cent yield penalty for saline and 40 per cent yield penalty in alkali soil were observed under DAW as compared to normal soil which concluded that wheat is less alkali tolerant. Around 4 per cent yield penalty was observed under DAW in normal soil and 11 per cent penalty for saline soil whereas, 35 per cent yield penalty was observed in alkali soil as compared to NTW. Under DSW, 22 per cent less grain yield recorded in normal soil, 23 per cent less under saline soil and around 70 per cent less yield in alkali soil as compared to NTW. Plant mortality up to 67% was reported with CSW in saline soil and 81% mortality was recorded in alkali soils, whereas in case of CAW, 7% plant mortality was recorded in saline soil and 53% was observed in alkali soil. No plant mortality was recorded in normal soil under CSW and CAW. Increase in soil pH, ECe and ESP due to irrigation with alkali water caused a significant reduction in crop yields for all type of soils (Minhas *et al.* 2007). In specific case for alkali soil the reported ESP build-up is 55.3 which is close to ESP 60 for 50% yield decline in rice/ wheat as coined by Choudhary *et al.* (2011). Extreme salinity and alkalinity can appear as nearly total crop mortality in saline and alkali soils, whereas yield penalty of 70% in CSW and 30% in CAW was recorded under normal soil.

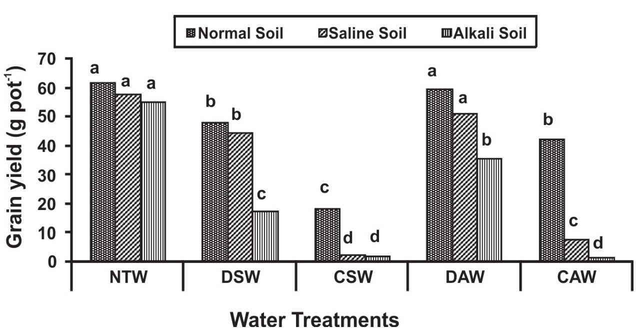

Fig. 5. Effect of irrigation treatments on grain yield in different soils

LSD (P=0.05): 6.0, 5.1 and 7.1 for normal, saline and alkali soil respectively; Numbers followed by different lower case letters are significantly different between C pools at $P \leq 0.05$ by Duncan's multiple-range test

Conclusions

On application of poor quality water, salinity and alkalinity build-up was observed in normal soil compared to alkali and saline soils. Continuous irrigation with CSW increased ECe of root zone soil that caused deleterious effect on crop productivity, severity in saline and alkali soils. Alkali water irrigation substantially increased the soil pH and ESP of all soils under consideration. Grain mortality was found maximum in CSW followed by CAW and DSW but has little affected by DAW as compared to NTW. Combined effect of salinity and alkalinity can lead to near total plant mortality. Rice was found less tolerant to saline water irrigation in three soils than wheat, while wheat was less tolerant to alkali water irrigation particularly in saline and alkali soil than rice.

References

Arora, N.K., Chaudhari, S.K., Farooqi, J.A. and Basak, N. (2012) Effect of poor quality water on the chemical properties of the salt affected soils and performance of rice. *Journal of Soil Salinity and Water Quality* **4,** 114-121.

Bajwa, M.S., Choudhary, O.P. and Josan, A.S. (1992) Effect of continuous irrigation with sodic and saline-sodic waters on soil properties and crop yields under cotton-wheat in north-western India. *Agricultural Water Management* **22,** 345-356.

Bajwa, M.S. and Choudhary, O.P. (2014) Sodic irrigation management for sustaining productivity. In *Efficient Water Management for Sustainable Agriculture* (R.K. Rattan and D.R. Biswas, Eds.). *Bulletin of the Indian Society of Soil Science* **29**, 59-86.

Bajwa, M.S., Choudhary, O.P. and Josan, A.S. (1998) Sodic waters and their management. In *Agricultural Salinity Management in India* (N.K. Tyagi and P.S. Minhas, Eds.). ICAR Publication, New Delhi, India, pp. 431-450.

Bajwa, M.S. and Josan, A.S. (1989) Effect of alternating sodic and non-sodic irrigations on the buildup of sodium in the soil and crop yields in northern India, *Experimental Agriculture* **25**, 199-205.

Basak, N., Chaudhari, S.K. and Sharma, D.K. (2015) Impact of varying Ca:Mg waters on ionic balance, dispersion, and clay flocculation of salt affected soils. *Communications in Soil Science and Plant Analysis* **46**, 827-844.

Choudhary, O.P., Ghuman, B.S., Bijoy-Singh, Thuy, N. and Buresh, R.J. (2011) Effect of long-term use of sodic water irrigation, amendment and crop residues on soil properties and crop yields in rice-wheat cropping system in a calcarous soil. *Field Crops Research* **121**, 363-372.

Choudhary, O.P., Ghuman, B.S., Josan, A.S. and Bajwa, M.S. (2006) Effect of alternating irrigation with sodic and non-sodic waters on soil properties and sunflower yield. *Agricultural Water Management* **85**, 151-156.

Choudhary, O.P., Josan, A.S., Bajwa, M.S. and Kapur, M.L. (2004) Effect of sustained sodic and saline-sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. *Field Crops Research* **87**, 103-116.

Gee, G.W. and Bauder, J.W. (2006) Particle-size analysis. In *Methods of Soil Analysis* (A. Klute, Ed.). Part 1. 2nd ed. Agronomy Monograph 9. ASA and SSSA, Madison, WI, pp. 383-409.

Grattan, S.R., Michael, L.Z., Shannon, M.C. and Roberts, S.R. (2002) Rice is more sensitive to salinity than previously thought. *California Agriculture* **56**, 189-195.

Gupta, R.K., Singh, C.P. and Abrol, I.P. (1985) Determining cation exchange capacity and exchangeable sodium in alkali soils. *Soil Science* **139**, 326-331.

Jackson, M.L. (1973) *Soil Chemical Analysis*. Prentice Hall India (Pvt.) Ltd., New Delhi.

Jalali, M. and Ranjbar, F. (2009) Effects of sodic water on soil sodicity and nutrient leaching in poultry and sheep manure amended soils. *Geoderma* **153**, 194-204.

Manchanda, H.R., Gupta, I.C. and Jain, B.L. (1989) Use of poor quality waters. In *Reviews of Research on Sandy Soils of India*, February 6-10, 1989, International Symposium on Managing Sandy Soils of India, CAZRI, held at Jodhpur, pp. 362-383.

Manchanda, H.R., Verma, S.L. and Khanna, S.S. (1982) Identification of some factors for use of sodic waters with high residual sodium carbonate. *Journal of the Indian Society of Soil Science* **30**, 353-360.

Minhas, P.S. and Bajwa, M.S. (2001) Use and management of poor quality waters for the rice-wheat based production system. *Journal of Crop Production* **4**, 273-305.

Minhas, P.S., Dubey, S.K. and Sharma, D.R. (2007) Comparative effects of blending, intra / inter-seasonal cyclic uses of alkali and good quality waters on soil properties and yield of paddy and wheat. *Agricultural Water Management* **87**, 83-90.

Ould Ahmed, B.A., Inoue, M. and Moritani, S. (2010) Effect of saline water irrigation and manure application on the available water content, soil salinity and growth of wheat. *Agricultural Water Management* **97**, 165-170.

Page, A.L., Miller, R.H. and Keeney, D.R. (Eds.) (1982) *Methods of Soil Analysis*, Part-2, Second Edition, Soil Science Society of America, Madison, Wisconsin, USA.

Richards, L.A. (1954) *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Handbook **60**, Washington, DC.

Saidi, Djamel (2012) Importance and role of cation exchange capacity on the physicals properties of the Cheliff saline soils (Algeria). *Procedia Engineering* **33**, 435-449.

Singh, H. and Bajwa, M.S. (1991)Effect of sodic irrigation and gypsum on the reclamation of sodic soil and growth of rice and wheat plants. *Agricultural Water Management* **20**, 163-171.

Singh, L. and Totawat, K.L. (1994) Effect of sodium to calcium activity ratio and residual sodium carbonate in irrigation water on physico-chemical properties of the Haplustabfs and performance of wheat (*Triticum aestiuvm*) *Annals Arid Zone* **33,** 23-27.

Tavakkoli, E., Rengasamy, P. and McDonald, G.K. (2014) Characterising the functional relationships of stable forms of organic carbon in micro- and nano-aggregates of soils with a focus on high pH soils. 20th World Congress of Soil Science. 8-13th June 2014, Jeju Island, South Korea.

Tucker, B.M. (1971) The partitioning of exchangeable magnesium, calcium and sodium in relation to their effects on the dispersion of Australian clay sub-soils. *Australian Journal of Soil Research* **23**, 405-416.

USSL (1954) Diagnosis and improvement of saline and alkali soils. USDA Handbook No. 60, Washington D.C.

Walkley, A. and Black, I.A. (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science* **37**, 29-38.

Received 09 March 2018; Accepted 02 September 2018