

Effect of saline irrigation water on the leachability of salts, growth and chemical composition of wheat (*Triticum aestivum* L.) in saline-sodic soil supplemented with phosphorus and potassium

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Abstract

Salinity-fertility interaction has not been properly explored especially in saline-sodic soils. Therefore, the current study investigated the response of wheat (*Triticum aestivum* L.) to saline irrigation water in saline-sodic soil supplemented with potassium (K) and phosphorus (P). Wheat was grown in pots filled with saline-sodic soil which were irrigated either with normal or saline water. Potassium and P fertilizers were applied at two levels. Results indicated that growth of wheat plants was impaired by saline irrigation resulting in a decreased grain and dry matter yield. The P application had significant effect on the dry matter yield and other yield components. Potassium application significantly increased dry matter yield and root mass. Wheat yield increased by 14 and 7% with the application of 150 kg K₂O ha⁻¹ and 120 kg P₂O₅ ha⁻¹ over the control soil under saline irrigation. The higher yield was obtained with combined P and K treatment under non-saline irrigation. The P addition significantly affected shoot and root [P] and [Na], [K] and [Mg] in the shoot tissue while the K:Na ratio produced non-significant effects under both irrigation waters. The addition of K significantly affected [Na], [K] and K:Na ratio in shoot. All other root parameters were significantly affected by the K addition. The Ca uptake by roots increased with saline irrigation. The P addition increased [P] in plant tissue. The Na uptake by root and shoot tissues was depressed with the addition of P and K fertilizers. The higher K uptake increased K:Na ratio in both shoot and root tissues. The values of EC, SAR and [P], [Na], [Ca], [Mg], [Cl] and ratios of Na:K, Ca:P, Cl:P and SO₄:P in the soil leachates significantly increased with saline irrigation. The P addition had significant bearing on the soil pH, SAR, [P], [SO₄], [CO₃] and [HCO₃] and Ca:P, Cl:P and SO₄:P ratios in leachates. Saline irrigation significantly increased ECe, [Na], [K], [Ca], [Mg], [Cl], [CO₃], SAR and ratios of Ca:P, Cl:P and SO₄:Cl in saturated extracts of post-harvest soils. This study could suggest

that the addition of P and K under saline-sodic conditions may affect salts and nutrients dynamics of the soil and was useful for crop productivity.

Keywords: Saline irrigation water, wheat crop, nutrient concentration, leachability of salts, saline-sodic soil, fertilizers application

1. Introduction

Water scarcity has been observed for agriculture sector in the arid regions of the world. Such situation deems necessary to utilize marginal water quality for crop irrigation. The use of saline drainage waters in such environments shows promise for growing agricultural crops (Rhoades, 1987). Salinity is a severe problem which not only reduces the agricultural potential, but also creates serious effects on livelihood of farmers (Haider and Hossain, 2013). Salinity affects plants by depressing the external water potential along physical effects; additionally specific ions may have chemical effects. Growth is suppressed when salinity exceeds beyond a threshold (TH) value (Tanji, 1990). The higher is the electrical conductivity (EC), the less is the water available to plants, even though a field may appear wet. The amount of water transpired through a crop is directly related to its yield and irrigation water with higher EC reduces yield potential. Saline water resources are abundant than fresh water. Bringing these resources into sustainable productive use will offer opportunities to increase food security especially in developing countries. Several physical, chemical and biological soil management measures help to facilitate the safe use of saline water in crop production. The benefits anticipated from soil management practices to facilitate the safe use of saline water for irrigation will not be realized unless adequate supply of plant nutrients as fertilizers. Saline water irrigation containing phosphorus and potassium is essential for optimum crop productivity.

A general consensus about the excessive accumulation of soluble salts in the rhizosphere being a major reason for reduced osmotic potential of soil or nutrient solution and for unbalanced nutrition and specific ion phytotoxicity in salt affected soils. In plants, salinity can induce damages in proteins, lipids and nucleic acids, and alterations in photosynthesis and respiration which affect plant growth and development (Manai *et al.*, 2014). The extent of growth inhibition caused by salinity on may be influenced by the nutritional status of plants. Constraints to crop productivity in salt affected soils may be overcome by leaching soluble salts from soil profiles by excess irrigation. This practice is no longer acceptable due to higher salinity in the streams and accumulation of salts in the deeper soil profile. The recycling of drainage water for irrigation is being considered as a best management practice.

Nutrient deficiency is yet another most prevalent constraint to agricultural production in saline or non-saline soils. Sustained and profitable crops production of on salt-affected soils is feasible if appropriate on-farm management practices are used. Under low fertility status of soil, proper fertilizer applications can increase crop yields regardless of the soil salinity (Mass, 1990).

Therefore, investigating the fertilizer management to maximize crop production under existing salinity is of greater importance.

Among the plant nutrients, potassium plays an important role to tolerate/mitigate ill effects of high salt contents in soils. It also helps to conserve water within plant itself. Its adequate levels in plants also enable roots to absorb/extract water from soils even under low moisture conditions. The K fertilizer application increased K movement from soil to root-surface and improved its availability to wheat roots (Ali *et al.*, 1999). Phosphorus, like K and N, is an important macronutrient involved in many essential functions in plant life especially in energy storage and transfer. The salinity x P interaction in plant nutrition is highly complex and sometimes confusing depending on the plant species, growth stage, salt types, degree of salinity and P content of growth media (Zhukovskaya, 1973).

Salinity and fertility interaction showed an improvement in the crop yield by addition of fertilizer to the soil irrigated with saline water (Muhammad and Khattak, 2009). The research studies on the response of wheat crop to the potassium and phosphate fertilizers in a saline-sodic soil irrigated with saline water is not well documented. Therefore, the objective of this study was to evaluate the influence of saline irrigation water on wheat crop in saline-sodic soil applied with K and P fertilizers.

2. Materials and Methods

An experiment was conducted at research farm of Agricultural University Peshawar-Pakistan. Wheat (*Triticum aestivum* L. cv. Inqilab-91) was grown in pots filled with saline-sodic soil. Each pot contained 6 kg soil collected from a saline-sodic field. Pots were irrigated either with normal tap water ($EC_{tw} = 0.6 \text{ dS m}^{-1}$) or saline water ($EC_{sw} = 5.7 \text{ dS m}^{-1}$). Saline water was collected from a dug well of arid zone field. Two levels of K_2O (0 and 150 kg ha^{-1} denoted as K_0 and K_1) as K_2SO_4 and two levels of P_2O_5 (0 and 120 kg ha^{-1} denoted as P0 and P1) in the form of diammonium phosphate (DAP) were applied.

The experiment was laid out in 3-factorial randomized complete block design (RCBD) with four replications [$2P_2O_5 \times 2K_2O \times 2EC_{iw} \times 4R$]. Each pot received 3.5L of water and total of six leachates were collected from each pot and analyzed for their chemical composition. The irrigation waters had two EC levels [saline and non-saline]. The values of pH, EC and SAR were averaged for six leachates, while the concentrations of leached salts were also calculated. Post-harvest soil, plant and leachates samples were analyzed. Soil samples were air dried, gently crushed and sieved (2 mm). Soil texture was determined by hydrometric method (Gee and Bauder, 1986). Similarly, plant shoot and roots were collected, washed with distilled water and oven-dried at 70°C for 48 h and ground in Wiley-Mill. The samples were analyzed for cations and anions following the methods described by Yoshida *et al.* (1976) and Benton *et al.* (1991). AB-DTPA-extractable P in the soil was determined colorimetrically (Soultanpour and Schwab, 1977). The pH values of soil suspension (1:5) and water samples were determined using pH meter (McLean, 1982; Thomas, 1996). Electrical conductivity (EC) was measured using a digital EC meter, Wiss. Techn. Werkstätten (WTW) D12 Weilheim. Potassium (K) and sodium (Na) in the soil extract, plant and water samples were analyzed by Perken-Elmer flame photometer (Richards, 1954). Calcium (Ca) and magnesium (Mg) were determined in soil, plant and water samples by titration with EDTA. Carbonates and bicarbonates were determined by titration method. Chloride (Cl) was determined by titration with silver nitrate (Richards, 1954). Sulfate content was determined using a turbidity method. Lime ($CaCO_3$) content of the soil was measured following Nelson and Sommers (1982). Sodium adsorption ratio (SAR) was determined using values of Na and Ca+Mg concentrations [mmol (+) L^{-1}] in soil saturation extracts and water samples. SAR of the soils and waters was calculated using the formula 1.

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca + Mg]}{2}}}$$

The properties of soil and saline irrigation water are given in Table 1.

The data were analyzed using Microsoft Excel 2007 and the factorial analysis was done using MSTATC program. Means were separated using least significance test (LSD) test at probability of 0.05.

Table 1. Chemical properties of saline-sodic soil and irrigation water

Soil/water	pH _(1:5)	EC	P	Na	Ca+Mg	K	SAR	Texture
		dS m ⁻¹	mg kg ⁻¹		mmol L ⁻¹			
Soil	8.24	6.22	2.1	53.8	13.5	0.27	20.7	Silty clay loam
Irrigation water	8.1	5.70	-	36.7	23.0	0.08	10.8	---

Table 2. Yield and yield components of wheat as affected by the application of K and P under saline irrigation water

P ₂ O ₅	K ₂ O	Grain yield	DM yield	Stem	Roots	Spike	Spike length	Plant height	Tillers plant ⁻¹
kg ha ⁻¹		t ha ⁻¹			g pot ⁻¹		cm		No
Non-saline irrigation water									
0	0	2.6	17.5	8.7	3.8	9.3	10.0	59.7	2.1
	150	2.8	18.9	9.4	4.6	9.9	10.3	63.6	2.3
120	0	2.9	21.1	11.6	4.8	10.9	10.8	61.7	2.7
	150	3.0	20.7	10.5	5.1	11.1	10.9	64.0	2.6
Saline irrigation water									
0	0	2.4	16.1	8.73	3.5	8.34	9.2	56.0	1.8
	150	2.7	17.5	8.38	4.4	9.41	9.6	57.9	2.1
120	0	2.6	17.9	9.33	4.5	9.25	10.0	59.3	2.1
	150	2.7	18.5	9.71	4.9	9.27	9.9	60.0	2.3
LSD (0.05)		0.11	0.23	0.30	0.12	0.21	0.22	0.45	0.11

3. Results and Discussion

3.1. Yield and yield components of wheat

The summary of ANOVA suggested that EC of irrigation waters significantly (p<0.05) affected the grain and dry matter yield and all the other components except root mass (Table 2-3). The P application significantly affected dry matter yield, stem, root and spike weight, spike length and number of tillers plant⁻¹.

The effects were non-significant (p>0.05) on grain yield and plant height. The EC_{iw} x P interaction was non-significant (p>0.05) for all the parameters except dry matter yield. Potassium application significantly (p<0.05) increased the dry matter yield and root biomass; while other parameters remained non-significant. The EC_{iw}, K, P interactions produced non-significant (p>0.05) effect on all the parameters except dry matter yield and stem mass which were significantly (p<0.05) affected by P x K and EC_{iw} x P x K interactions, respectively (Tables 2-3).

Table 3. Summary of analysis of variance (ANOVA) for yield and yield components of wheat as affected by the application of K and P with and without saline irrigation in saline-sodic soil

Source of variation	Grain yield	Dry matter yield	Shoot	Roots	Spike	Spike length	Plant height	Tillers plant ⁻¹
-----F ratio-----								
EC _{sw}	9.81**	52.3***	13.6**	1.58 ^{NS}	51.5***	15.9***	12.9**	6.21*
P	1.68 ^{NS}	52.5***	30.0***	15.6***	13.4**	8.87**	3.22 ^{NS}	6.73*
EC _{sw} x P	1.47 ^{NS}	5.56*	3.53 ^{NS}	0.003 ^{NS}	2.84 ^{NS}	0.20 ^{NS}	0.49 ^{NS}	0.75 ^{NS}
K	3.97 ^{NS}	6.87*	0.14 ^{NS}	11.4**	2.95 ^{NS}	0.99 ^{NS}	4.05 ^{NS}	1.62 ^{NS}
EC _{sw} x K	0.003 ^{NS}	0.74 ^{NS}	0.18 ^{NS}	0.05 ^{NS}	1.17 ^{NS}	0.01 ^{NS}	0.72 ^{NS}	0.75 ^{NS}
P x K	2.50 ^{NS}	5.15*	0.99 ^{NS}	1.68 ^{NS}	1.48 ^{NS}	0.58 ^{NS}	0.38 ^{NS}	0.31 ^{NS}
EC _{sw} x P x K	0.05 ^{NS}	0.66 ^{NS}	5.59*	0.02 ^{NS}	2.19 ^{NS}	0.21 ^{NS}	0.01 ^{NS}	0.21 ^{NS}

*, **, *** = Significant at P<0.05, 0.01 and 0.001, respectively and NS= Not-significant

The growth of the plants was adversely affected by saline irrigation (EC_{sw} = 5.7 dS m⁻¹) as compared to non-saline tap water (EC_{tw} = 0.6 dS m⁻¹) (Table 2-3). The grain and dry matter (DM) yield of wheat decreased to 2.4 and 16.1 t ha⁻¹, respectively with saline irrigation when compared to 2.6 and 17.5 t ha⁻¹ in pots treated with non-saline irrigation water without K and P treatments (Table 2-3). The K addition significantly (p<0.05) increased DM yield with saline- and non-saline irrigation at P₀ but at P₁, the effect of K was non-significant. Higher grain yield (2.97 t ha⁻¹) was obtained at P₁, K₁ and EC_{tw} and a lower yield of 2.4 t ha⁻¹ was recorded at P₀, K₀ and EC_{sw} (Table 2-3). Addition of P significantly (p<0.05) promoted the grain yield at EC_{tw}.

Respective wheat grain yield increase was 14 and 7% at 150 kg K₂O ha⁻¹ and 120 kg P₂O₅ ha⁻¹ as compared to yield (2.4 t ha⁻¹) without K and P with saline irrigation and increased grain yield by 21 and 22%, respectively, with non-saline irrigation. The improvement in the grain yield due to the K and P additions could be attributed to the ameliorative effects of plant nutrition (K and P) on plant growth under salt stress conditions.

The highest yield was 2.97 t ha⁻¹ employing combined P and K treatments under non-saline irrigation. The grain yield enhanced by 24% than control under saline irrigation (Table 2-3). Dry matter yield of wheat significantly (p<0.05) increased with the P (P<0.001) and K (P<0.05) applications. K₁ and P₁ treatments increased DM yield by 8 and 21% under non-saline irrigation as compared to control. The combined P and K application promoted DM yield under both types of irrigations while the lower yield of 16.1 t ha⁻¹ was recorded with saline irrigation after P and K treatment. A significant positive role of P in alleviating the adverse effects of salinity through increased nutrient uptake has been reported (Shibli *et al.*, 2001). The enhancement of shoot yield due to P application proved to be useful in saline-sodic soils (Cruz *et al.*, 1990).

Saline irrigation water significantly (P<0.001) decreased the biomasses of stems (P<0.01) and wheat spikes (Tables 2-3). The stem, root and spike biomass increased with the separate P₁ and K₁ application. Combined P and K applications produced the higher biomass of stem, roots and spikes under non-saline water as compared to saline irrigation water (Tables 2-3).

Saline irrigation significantly ($P < 0.001$) decreased spike length, plant height ($P < 0.01$) and tillers plant⁻¹ ($P < 0.05$) as compared to control. The P and K addition improved almost all the parameters, when averaged across ($n=9$) K, P and EC_{iw}, respectively. The combined P₁ K₁ treatments with non-saline irrigation produced the higher spike length (10.9 cm) and plant height (64.0 cm), while these values decreased to 9.3 and 56 cm, respectively with saline irrigation. A similar trend was observed regarding number of tillers plant⁻¹ but the maximum numbers were obtained with P1 (Tables 2-3).

It has been previously reported that increased soil salinity resulted in reduction of plant growth, yield and, in severe case, total crop failure (Qadir *et al.*, 2000). Rameeh (2012) reported significant interaction effects of salinity levels and genotypes for all the traits indicated that the variation trends of these traits among the genotypes were different at the salinity levels. In saline soils, water uptake by roots was limited because of higher osmotic potential which increased Na and Cl toxicity and thus plant production was affected in salt-affected soils (Flowers and Yeo, 1981). Also, the higher salinity caused P deficiency in wheat plants (Gibson, 1988). Evidence indicated that salinity may increase the P requirements of certain plants (Sharpley *et al.*, 1992). The saline irrigation increased soil salinity which resulted in reduced wheat DM yield due to decreased growth of wheat leaves (Iqbal, 2003). The addition of P and K improved plant growth which could be associated with the improvement of plant nutrition and/ or with the mitigation of salt stress.

3.2. Chemical composition of plant tissues

The summary of ANOVA revealed that saline irrigation water significantly affected root tissue [Ca] and K:Na ratio while all other ionic concentrations and K:Na ratio in shoot tissue were non-significantly affected by saline irrigation water (Tables 4-5).

The P addition significantly affected shoot and root [P] and that of [Na], [K] and [Mg] in shoot tissue while the ratio of K:Na was non-significantly affected under both irrigation. The EC_{iw} x P interaction had significant ($p < 0.05$) effect on [Na] and K:Na ratio in root tissues while [P], [Na], [K], [Ca], [Mg] and K:Na ratios were not affected in shoot tissue. The K addition significantly affected [Na], [K] and K:Na ratio in shoot except [P] and [Mg]. All other parameters were significantly affected by the addition of K in root. The EC_{iw} x K interaction could not affect other parameters of shoot and root tissue. The P x K interactions significantly affected [Ca] and [Mg] in root tissue. Except [Mg] in shoot and [Ca] and [Mg] in root tissue, all other parameters were not affected by EC_{iw} x P x K interaction (Table 4).

Shoot chemical analysis revealed that applied saline irrigation water affected ionic concentrations. The Na and Mg concentrations in the shoot increased with saline irrigation water whereas K concentration in plant shoot reduced in the unfertilized treatment. The Ca uptake by roots increased with saline irrigation irrespective of the P and K fertilization. The increasing P₂O₅ level from 0 to 120 kg ha⁻¹ with no K, significantly increased [P] from 78.8 to 93.1 and 82.3 to 98.3 in shoot ($P < 0.05$) and from 28.5 to 32.6 and 28.6 to 38.2 mmol kg⁻¹ in root tissue ($P < 0.001$) under non-saline and saline irrigation, respectively (Tables 4-5). [P] in shoot and root tissues was not affected by the addition of 150 kg K₂O, however, an increasing trend in the combined treatment was observed with 120 kg P₂O₅ ha⁻¹. When averaged across EC_{iw} and K treatments ($n=16$), the P addition increased [P] in both shoot and root tissue (Table 4). Root hairs are specialized plant cells and are responsible for greatly increasing root surface area making them important for water and ion uptake, such as for P (Bates and Lynch, 2000). The enhancement of P absorption under saline irrigation suggested an improvement in the P nutrition for P addition.

Table 4. Chemical composition of wheat shoot and root as affected by the application of K and P under saline irrigation water

P ₂ O ₅	K ₂ O	Shoot						Root					
		P	Na	K	Ca	Mg	K:Na	P	Na	K	Ca	Mg	K:Na
		mmol kg ⁻¹						mmol kg ⁻¹					
Non-saline irrigation water													
0	0	78.8	372.7	393.0	39.0	25.6	1.06	28.5	254.0	131.1	448.9	98.3	0.53
	150	76.7	349.6	468.7	18.3	32.1	1.35	29.3	224.9	177.6	331.0	82.4	0.79
120	0	93.1	347.5	388.1	25.5	41.4	1.12	32.6	312.3	150.3	403.2	90.4	0.49
	150	88.2	330.0	433.1	00.6	37.3	1.33	32.9	259.7	180.6	260.7	71.9	0.71
Saline irrigation water													
0	0	82.3	450.8	372.2	27.7	36.7	0.85	28.6	281.5	159.4	434.4	67.7	0.57
	150	83.9	351.3	512.3	10.5	26.3	1.47	29.1	250.8	182.7	564.6	120.0	0.75
120	0	98.3	357.8	362.6	23.7	38.2	1.02	38.2	225.2	154.9	670.7	127.9	0.70
	150	90.8	309.5	426.1	12.8	41.2	1.39	35.7	217.1	192.7	447.5	63.0	0.93
LSD (0.05)		1.23	6.45	6.56	0.12	1.45	0.10	0.26	6.56	3.45	6.78	4.55	0.07

Table 5. Chemical composition of leachate of saline-sodic soil as affected by P and K under saline and non-saline irrigation

P ₂ O ₅	K ₂ O	EC	pH	SAR	P	Na	K	Ca	Mg	Cl	SO ₄	CO ₃	HCO ₃
kg ha ⁻¹		dS m ⁻¹			mg L ⁻¹	mmol (±) L ⁻¹							
Non-saline irrigation water													
0	0	9.40	8.02	14.6	0.15	34.7	0.22	8.81	8.05	31.3	18.7	0.24	1.41
	150	11.8	8.04	18.3	0.14	48.4	0.26	10.3	9.70	41.0	25.5	0.20	1.53
120	0	10.7	7.97	13.9	0.35	38.4	0.23	10.3	10.1	39.6	17.4	0.26	1.60
	150	11.7	7.97	16.8	0.36	47.6	0.25	10.5	9.95	42.5	23.2	0.32	1.70
Saline irrigation water													
0	0	12.2	8.05	16.6	0.13	43.7	0.24	10.4	10.5	41.6	21.7	0.21	1.25
	150	12.9	7.97	20.5	0.11	54.9	0.28	11.1	10.5	49.9	25.0	0.22	1.49
120	0	11.7	7.97	16.4	0.31	42.0	0.24	10.8	10.9	45.1	16.8	0.30	1.52
	150	13.4	7.99	20.1	0.31	52.0	0.28	11.1	10.8	48.7	23.2	0.31	1.56
LSD (0.05)		1.23	1.34	1.45	0.02	1.56	0.02	0.34	0.03	0.34	0.12	0.04	0.05

The [Na] in shoot and root tissue was affected by the applied saline water (Table 4). The Na uptake by root tissue and its translocation to shoot tissue was significantly depressed with the addition of P and K fertilizers. The K and P addition tended to decrease [Na] in shoot with saline waters. The lower Na concentration measured in the wheat plants on the P addition as DAP could be as a result of lower Na uptake in response to NH_4 uptake. The differences in Na concentration in plant tissues in response to P application under saline conditions might be related to its accompanying cation (NH_4). The higher [Na] of 450 mmol kg^{-1} shoot was noticed at K_0 and P_0 in saline treatments which substantially decreased with K and reaching to a lower value of 309 mmol kg^{-1} at P_2K_2 . Roots maintained lower [Na] than shoot and exhibited similarity between P and K effect on [Na] under saline irrigation.

The increasing K levels enhanced ($P < 0.001$) [K] in both root and shoot tissue (Table 4). The K concentration of 512 and 192 mmol kg^{-1} was recorded in shoot and root, respectively with K_1 when irrigated with saline water. It was observed that the addition of P_2O_5 as DAP significantly ($P < 0.05$) reduced [K], which may be due to the dilution effect associated with increases in yield as the total K accumulation increased with P (Jarrell and Beverly, 1981). A consistent decreases in leaf tissue [Na] and increases in [K] with addition of 50 and 100 kg K ha^{-1} under saline conditions have been reported (Hussain *et al.*, 2013).

The higher K uptake significantly ($P < 0.001$) increased K:Na ratio in both shoot and root tissue. The addition of K_1 alone raised K:Na ratios of the leaf tissues to 1.4 and 1.5 as compared to 1.0 and 0.9 in control under non-saline and saline irrigation, respectively (Table 4). A similar trend was observed in root tissues. When averaged across EC_{iw} and P, the higher values of K:Na ratio were obtained with K_1 treatment in both shoot and root tissue. The K:Na ratio in shoot was positively related to shoot [K]. Data of

yield, [P], [K] and their total accumulation suggested that yield slightly increased with increasing P levels, [K] decreased while total K accumulation increased. Thus the observed changes in [K] could be associated with the classical dilution effect as reported by Jarrell and Beverly (1981). Total Na accumulation decreased hence the K:Na in total biomass of wheat increased with increasing total K accumulation at P_0 under both non-saline and saline irrigations.

The tolerance of wheat to salts was associated with the preferential accumulation of K against higher [Na] (Zaman *et al.*, 2005) that might have depressed Na uptake. Addition of K alone or in combination with P in saline medium significantly increased [K] and decreased [Na] thus increasing K:Na in wheat leaves (Shirazi *et al.*, 2005). The enhanced K uptake could be associated with direct competition between K and Na at root plasmalemma; an effect of K on Na transport into xylem and/or K induced net Na extrusion from roots (Munns *et al.*, 1983). Salt tolerance of *Triticeae* was associated with enhanced ability to discriminate between Na and K in the soil solution and to preferentially accumulate K and exclude Na (Ali *et al.*, 2004). It was reported that the K:Na discrimination character enhances a process already operating in cereal roots and to a greater or lesser extent in the roots of all plants (Ashraf and Sarwar, 2002). The selective uptake of K over Na by roots and the effects of K on reduced Na translocation to shoot resulting an overall increase in K:Na in the present study corroborated the importance of K in minimizing Na hazard and improving crop growth.

The concentrations and total Ca accumulation in shoot and root decreased non-significantly with increasing K levels at both P and waters levels (Table 4). The [Mg] significantly ($P < 0.001$) increased in shoot tissue at P_1 alone with non-saline irrigation. However, the treatments had no effect on [Mg] concentrations in root tissue. The [Mg] were found very low when compared with [Ca] in both shoot and root (Table 4).

The overall [Ca] were higher in shoot and root tissue. The decrease [Ca] could be associated with P and especially K treatments in this study. This could be due to the interactions of Na, K or Ca at the sites of uptake in roots (Gronwald *et al.*, 1990). Lynch and Lauchli (1985) reported that [Na] in root medium might induce Ca deficiency in plants grown with lower Ca. Since Ca plays a vital nutritional and physiological role in plant metabolism, Na induced Ca deficiencies have growth-distorting effects on developing leaves (Maas and Grieve, 1987). The presence of Ca might have mitigated the adverse effects of Na as suggested by the results of current study which also improved K:Na ratio in shoot and root (Minhas, 1996). Kinraide (1999) reported the interactions among Ca, Na and K in saline medium and their multiple toxic and ameliorative effects on root and shoot of wheat and observed that higher [Na] in the rooting medium and the tissues were not toxic unless [Ca] was also deficient. Higher [Na] and lower [Ca] inhibited shoot growth of rice cultivars and triticale lines (Grieve and Fujiyama, 1987). In saline soils, [Ca] increase as the total salt concentration increases. The Ca accumulation by plants from the soil solution can decrease because of ionic competition for absorption sites and with processes of precipitation and solubilization in the soil solution. The Ca activity is decreased by increasing the ionic strength of the solution which substantially affects its uptake. These combined effects together in a complex soil-plant system eventually reduce plant growth and yield under saline or saline-sodic conditions.

The growth of shoot increased and the Ca disorder was alleviated and the [Na] was lowered. The findings of the present study involving the effects of P and K treatments and their interactions resulted in higher [P], [K] and [Ca] and depressed uptake of Na by plant and this gave higher yields. This study suggested that the addition of P and K under saline conditions may be beneficial to crop growth due to high selectivity of roots for K

over Na and its translocation to shoots thus minimizing the adverse effects of Na in plant growth.

3.3. Chemical composition of soil leachate

Electrical conductivity (EC), SAR and [P], [Na], [Ca], [Mg], [Cl] and ratios of Na:K, Ca:P, Cl:P and SO_4 :P in leachates significantly increased with saline irrigation while pH values and [K], $[\text{SO}_4]$, $[\text{CO}_3]$ and $[\text{HCO}_3]$ did not change with saline irrigation waters. The addition of P to soils had significant effect on pH, SAR, [P], $[\text{SO}_4]$, $[\text{CO}_3]$ and $[\text{HCO}_3]$ and Ca:P, Cl:P and SO_4 :P ratios in leachates, while EC, [Na], [K], [Ca], [Mg], [Cl] and Na:K ratio were not affected with P levels. The $\text{EC}_{\text{iw}} \times \text{P}$ interaction had no effect on all the ionic concentrations except ratios of Ca:P, Cl:P and SO_4 :P (Table 5). The addition of K significantly affected values of EC, SAR and [Na], [K], [Cl], $[\text{SO}_4]$ and $[\text{HCO}_3]$ and Ca:P, Cl:P and SO_4 :P ratios while other parameters remained unchanged.

A total of 32 pots receiving treatments [$2\text{EC}_{\text{iw}} \times 2\text{P} \times 2\text{K} \times 4\text{R}$] were arranged in open air and each pot received total irrigation water of 3.5 L. The chemical analysis of leachates gave an insight to understand the complex soil-plant-leachate system under the P and K treatments and saline irrigation waters. Mean EC values of all leachates showed substantial leaching of salts with significant increase (13.8 dS m^{-1}) by the addition of combined $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ and $150 \text{ kg K}_2\text{O ha}^{-1}$ with saline irrigation ($\text{EC}_{\text{sw}} = 5.7 \text{ dS m}^{-1}$) as compared to 9.40 dS m^{-1} in control with non-saline irrigation (Table 5). Mean values showed that the leachates with saline irrigation had slightly higher EC than in those with non-saline irrigation. The high EC and SAR values of leachate (Table 5) due to applied treatments and irrigation were indicative of the reduction in soil salinity-sodicity as evident from EC_c and SAR of post-harvest soil. Significant reduction in soil EC_c (Table 7) proved the effect of irrigation on leaching of salts.

Table 6. Salts concentrations in leachates collected from saline-sodic soil after application of P and K under saline and non saline irrigation

P ₂ O ₅	K ₂ O	Volume	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	SO ₄ :P	Cl:SO ₄
kg ha ⁻¹		ml							
Non-saline irrigation water									
0	0	2481	158.7	3.93	40.5	60.3	213.0	127.5	1.67
	150	2429	186.5	4.72	39.6	73.5	293.6	183.8	1.62
120	0	2344	171.0	3.74	45.8	29.9	115.4	50.9	2.30
	150	2469	188.4	4.53	41.5	29.4	119.4	65.3	1.84
Saline irrigation water									
0	0	2340	181.0	4.19	43.2	87.2	346.4	179.3	1.93
	150	2586	198.9	4.94	40.2	99.1	444.9	221.5	2.01
120	0	2399	175.9	3.92	45.1	35.4	148.2	55.3	2.72
	150	2475	189.5	4.70	40.4	36.9	162.7	77.2	2.10
LSD (0.05)		3.26	5.36	0.44	1.62	3.58	5.77	4.26	0.02

Table 7. Chemical composition of post-harvest soil as affected by the application of P and K under saline irrigation water

P ₂ O ₅	K ₂ O	EC _e	pH _(1:5)	ABDTPA P	Na	K	Ca	Mg	CO ₃	HCO ₃	Cl	SO ₄	SAR
kg ha ⁻¹		dS m ⁻¹		mg kg ⁻¹	mmol (±) L ⁻¹								
Non-saline irrigation water													
0	0	1.81	8.80	8.0	12.5	0.17	3.56	4.88	0.60	4.40	3.50	8.93	6.12
	150	1.83	8.81	8.8	11.0	0.28	4.06	4.94	1.05	4.53	2.69	12.6	5.21
120	0	1.83	8.86	14.1	13.5	0.15	3.55	5.38	1.03	4.85	3.81	9.20	6.40
	150	1.78	8.98	13.7	12.0	0.27	3.06	4.81	1.00	4.40	3.38	12.0	6.04
Saline irrigation water													
0	0	2.70	8.82	10.1	17.4	0.28	5.00	7.38	0.93	4.18	11.0	10.9	7.00
	150	2.48	8.78	10.1	14.2	0.34	4.06	6.63	0.78	4.00	9.45	12.2	6.13
120	0	2.60	8.89	13.7	17.2	0.26	5.19	6.31	0.78	4.35	10.2	8.75	7.17
	150	2.63	8.81	13.3	13.1	0.35	4.88	7.51	0.55	4.20	10.7	11.8	5.26
LSD (0.05)		0.33	0.82	0.34	0.45	0.05	0.23	0.21	0.07	0.12	0.14	0.17	0.56

However, saline irrigation contributed to higher EC values of leachates.

Efficiency of treatments for removing Na from soil was evaluated as mmol of total Na kg⁻¹ leached. Irrigation with saline water significantly increased [Na] in all leachates while [K] was not affected with saline irrigation water (Table 5-6). The addition of K significantly increased [Na], Na:K ratio and SAR of the leachates. The values showed that [Na] were significantly increased with 150 kg K₂O ha⁻¹ alone (48 and 55 mmol kg⁻¹) or in combination with 120 kg P₂O₅ ha⁻¹ (47 and 52 mmol kg⁻¹) with non-saline or saline irrigation, respectively. However, [Na] were slightly higher with saline irrigation (Table 6-8). The K addition treatments played significant role in leaching of Na thus increasing Na:K ratios in nearly all the leachates, especially to 198.9 at K₁ as compared to 181.0 in control with specifically saline irrigation (Table 5). The [K] remained inconsistent with EC of irrigation water. Robbins (1984) concluded that higher [K] were held in soil while Na leached down that reduced SAR and ESP. Potassium competes with other cations such as Ca and Mg for retention on soil exchange sites and high K levels may lead to increased leaching of Na and associated anions such as SO₄ and Cl (Morton *et al.*, 2004).

The [Ca] and [Mg] significantly ($P < 0.05$) increased with saline irrigation but were not affected with K or P treatments (Table 5-6). A slight increase in [Ca] was observed with K under both irrigations. Hence, Ca:K ratio slightly decreased with K and increased with P. The leaching of Mg increased with P and K treatments alone or in combination and/or with saline irrigation. The Ca and Mg in leachates suggested that K application resulted in more Ca than Mg leaching (Morton *et al.*, 2004). The [Na], [Ca] and [Mg] were responsible for the variations in SAR of the leachates. Also, saline water in a saline-sodic soil increased soil SAR as a result of leaching of Na from surface layers (Akhtar *et al.*, 2003).

As compared to other ions, [P] seemed to be lower in the leachates ranging from 0.11 to 0.35 mg kg⁻¹.

The total P values of leachates, however, increased significantly with application of P alone or in combination with K. When averaged across K and irrigation waters, P leached was 0.13 and 0.33 mg kg⁻¹ at P₀ and P₁, respectively (Table 5-6). The EC of irrigation water affected [P], Ca:P, Cl:P and SO₄:P ratios. These ratios in leachates increased with K and decreased with P under both irrigation water. The overall low levels of P in leachates suggested the ion mobility of P in soil-leachate system. Curtin *et al.* (1992) reported that [P] leachate were usually lower (0.1 mg L⁻¹) when EC was higher. With increased sodicity, the water extractability of P increased substantially. This trend was not observed in this study as the values of SAR and P leached showed no consistency.

The [SO₄] and [Cl] significantly increased in all the leachates with the addition of 150 kg K₂O ha⁻¹ producing higher values with saline irrigation. The P addition significantly decreased [SO₄]. The significant interactive effect of P x K on Cl:P and SO₄:P ratios described the importance of K₂SO₄ and (NH₄)₂HPO₄ in saline-sodic soil (Table 6-8). Timpson *et al.* (1984) reported the dominance of SO₄ over Cl in the ground water which may be associated with gypsiferous parent material.

According to Suh *et al.* (2003), Na and Cl were weakly adsorbed on saline soil and Ca, K and Mg were easily leached down. Morton *et al.* (2004) also found the increasing rates of Cl leaching with application of K as compared to control.

The addition of 150 kg K₂O ha⁻¹ as K₂SO₄ alone or in combination with 120 kg P₂O₅ ha⁻¹ as DAP increased [SO₄] in the leachates. It was noticed that [SO₄] was increased with saline water compared to non-saline water.

The increased ratios of Cl:SO₄ with DAP and decreased with K₂SO₄ in leachate from the soil could play a vital role in the chemistry of soil.

Table 8. Ionic ratios in saturated extracts of post-harvest soil as affected by the levels of P and K under saline irrigation

P ₂ O ₅	K ₂ O	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	SO ₄ :P	SO ₄ :Cl
-----kg ha ⁻¹ -----								
Non-saline irrigation water								
0	0	83.7	3.55	23.0	13.9	13.8	35.2	2.6
	150	40.3	2.85	15.1	14.2	9.5	45.1	4.8
120	0	96.6	3.85	25.1	7.9	8.3	20.4	2.6
	150	45.5	3.93	11.7	7.0	7.6	27.3	3.7
Saline irrigation water								
0	0	64.5	3.49	18.5	15.4	33.7	33.5	1.0
	150	42.5	3.53	12.2	12.5	29.1	37.7	1.3
120	0	69.9	3.35	21.2	11.8	23.3	20.0	0.9
	150	38.2	2.72	14.1	11.4	24.9	27.5	1.1
LSD (0.05)		3.45	0.11	0.45	0.23	2.44	1.56	0.02

The [CO₃] and [HCO₃], in contrast to other cations and anions, were not affected with EC of irrigation waters (Table 6-8). The addition of 120 kg P₂O₅ ha⁻¹ and 150 kg K₂O ha⁻¹ increased [CO₃] and [HCO₃] in nearly all the leachates irrespective of the quality of irrigation water. The higher pH of soils might be associated with higher CO₃ and HCO₃.

Excessive irrigation with saline and non-saline water increased the leaching of salts from the soil profile. Qadir *et al.* (2000) reported that soils with excessive salt concentrations could be ameliorated by continuous ponding. Cropping in conjunction with leaching was found to be sustainable way to ameliorate saline soils. Viegas *et al.* (2001) reported that increasing levels of Na and Cl were toxic to plants that might cause disturbances in metabolic and physiological functions leading to poor crop production. To minimize adverse effects, Na and Cl could be leached down from the root zone through excessive irrigation (Qadir *et al.*, 2006). Continuous cropping with sodic water and inorganic fertilizer use slightly decreased the soil pH and SAR (Yaduvanshi and Swarup, 2007). These results supported the findings of the present study

suggesting that K and P fertilizers must be used to sustain the productivity of wheat in salt affected areas having saline ground water for irrigation.

3.4. Chemical composition of post-harvest soil

Results showed that the saline irrigation significantly increased EC_e, [Na], [K], [Ca], [Mg], [Cl], [CO₃], SAR and ratios of Ca:P, Cl:P and SO₄:Cl in saturated extracts of post-harvest soils, while AB-DTPA extractable [P] and [SO₄], Na:K, Na:Ca, Ca:K, and SO₄:P ratios in saturated extracts were not affected (Table 7-8). The effect of P treatment was significant on AB-DTPA extractable [P] and ratios of Ca:P, Cl:P, SO₄:P and SO₄:Cl in soils while other parameters were not affected by P addition. The interaction of EC_{iw} x P had significant effect on AB-DTPA extractable [P], [Ca], [CO₃], SAR, Na:Ca and Ca:P ratios. The application of K significantly affected [Na], [K], [SO₄], SAR and ratios of Na:K, Ca:K, SO₄:P and SO₄:Cl while other parameters were not affected. The interaction of EC_{iw} x K could not affect all the parameters except [Na], [CO₃], SAR and SO₄:Cl ratio. All the parameters were not affected by P x K interactions except [CO₃] and SO₄:Cl ratio. The interactions

of $EC_{iw} \times P \times K$ significantly affected [Mg] and SAR in soil saturation extracts while all other parameters were not affected (Tables 7-8).

The addition of P and K fertilizers under both saline and non-saline irrigation significantly influenced the salts and nutrients dynamics in the soils. A significant decrease in the values of EC_e , Na, Ca, K, SAR, and increase in pH was observed (Table 7) as compared to initial values. The overall higher values of pH in the post-harvest soil might attribute the release of HCO_3^- and CO_3^{2-} in the soil. The values of post harvest soil EC_e were significantly ($P < 0.001$) decreased by both saline and non-saline water. The significant decrease in EC_e values were obviously related to leaching of salts as evident from the decreases in concentrations of cations and anions. The values of post-harvest soils irrigated increased with saline water compared to those irrigated with non-saline waters (Tables 7-8). The decrease in EC of saline soils in pots irrigated with non-saline waters might be associated with consecutive irrigations and seasonal rainfalls. The [K] in soil solution significantly ($P < 0.001$) increased with the addition of K fertilizers (Tables 7-8). Addition of $150 \text{ kg K}_2\text{O ha}^{-1}$ increased [K] in soil to 0.28 and 0.26 at P_0 and 0.27 and 0.35 $\text{mmol}(+)\text{L}^{-1}$ at P_1 with non-saline and saline irrigation, respectively. Increases in the soluble [K] in soil promoted K uptake which could interfere the uptake of other cations (Na, Ca and Mg). These phenomena can reduce adverse effects of the salinity (Abd El-Hadi *et al.*, 2001).

The saline irrigation water had significant ($P < 0.001$) effect on the [Na] which increased with saline irrigation and decreased with K treatment (Tables 7-8). Reduced [Na] might be due to leaching due to irrigation, irrespective of saline or non-saline water. The effect of the addition of $150 \text{ kg K}_2\text{O ha}^{-1}$ alone ($P < 0.001$) or in combination with $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ was significantly decreased [Na] in soil solution (Tables 7-8). Correspondingly, the ratios of Na:K, Ca:K and SAR of soil

solution also decreased significantly ($P < 0.001$) with K treatments. Despite the plant's showed affinity for K over Na, the K uptake by plants is related to the Na:K ratio in the soil.

The values of SAR of the soil saturation extracts were decreased and the decrease in SAR might be associated with leaching down of Na with excess irrigation. Thus addition of K alone or in combination with P with excess saline or non-saline irrigation decreased Na producing as low as 5.21 and 5.26 SAR values. The soils with $SAR > 13$ are considered as sodic or saline-sodic soils (Richards, 1954). Initial higher values of SAR substantially decreased with irrigation and rainfall in pots. This suggested the successful reclamation of salt affected soils and improvements in soil nutrients could be achieved with the addition of P and K fertilizers.

The saline irrigation water had non-significant effect on AB-DTPA extractable [P] but increased significantly ($P < 0.001$) with the addition of P alone or in combination with K treatments. However, application of K alone inconsistently affected [P] in the soils. Addition of P_1 alone or in combination with K_1 treatments increased [P] to 11 mg kg^{-1} soil which is considered sufficient for plant growth (Soultanpour and Schwab, 1977). The values ranged from 9.26 to 13.7 mg kg^{-1} when averaged across EC_{iw} and K treatments (Table 7-8). The [Ca] and Ca:P ratios were significantly decreased by the addition of combined P and K with non-saline irrigation. A similar trend in [Mg] was observed. There was a slight increase in [Ca] and [Mg] with saline irrigation which may be associated with additions through saline irrigation to the soil solution.

Phosphorus solubility in saline soil with higher Ca activity is controlled by P sorption processes on the solid phase of Ca-minerals. The rate of P removal from solution due to sorption and/or precipitation was relatively slow and the initial calcium phosphate formed was thermodynamically unstable (Grattan and Grieve, 1992). Bauder and Brock (2001) reported that addi-

tion of phospho-gypsum (P-CaSO₄) to soil was needed to replace the Na. Therefore, the application of P fertilizer is suggested to improve the P status of soils. In saline soils, [Ca] usually increase as the total salt concentrations increase. The higher values of Ca and Mg may be beneficial in terms of reclamation of sodic soils by lowering SAR values. Zaman *et al.* (2002) reported that NaSO₄ was less toxic than NaCl for the growth of wheat provided K and Ca are available in the growth medium. Morton *et al.* (2004) reported that there was no effect of K on [Ca] and [Mg] despite leaching of both cations which could be attributed to their higher concentrations on the soil exchange sites. Therefore the availability of macronutrients in saline or saline-sodic soils is beneficial for the yield of crops. The excess of Ca in the medium causes retardation in the growth of shoot whereas in the saline-sodic medium when Na is more available, the abundance of Ca ion is required to check the toxic activities of Na ion (Zaman *et al.*, 2005).

The [Cl] and Cl:P ratio significantly (P<0.001) increased with saline irrigation, while [Cl] decreased slightly with K treatments. The [SO₄] and ratios of SO₄:P and SO₄:Cl increased with K1 treatments (Tables 7-8). The increased [SO₄] and its ratios might be due to addition of K as K₂SO₄ fertilizer. However, saline irrigation water did not produce much difference in SO₄ levels. The overall low soil [Cl] might be due to leaching of Cl from the soil profile. The high [Cl] with saline irrigation produced higher Cl:SO₄ ratios than with non-saline irrigations, but the ratios decreased at K1. The inputs of SO₄ as K₂SO₄ to soils tended to decrease Cl:SO₄ ratios.

The [HCO₃] was not affected by the application of P and K treatments as well as by the saline irrigation water. The [CO₃] were significantly (P<0.05) affected by all the treatments, with lowest values of 0.6 in control under non-saline treatment and 0.55 mmol L⁻¹ in saline treatments with P₂ and K₂ (Tables 7-8). The

behavior of soil to addition of treatments as K and P and their interactions with other ions may be variable due to the complex soil-water-plant system which is regulated by processes such as sorption, desorption, precipitation and complexation (Sposito, 1989). The chemical analysis of soil in the present study indicated the beneficial effect of K and P addition to soil in minimizing salt hazard and improvement in soil properties even under saline irrigation.

4. Conclusions

It is concluded that the application of K and P had significant effects on the dry matter yield. The growth of the plants was adversely affected by the saline irrigation. The grain and dry matter yield of wheat decreased with saline irrigation as compared to non-saline water. The P addition significantly affected shoot and root [P] and that of [Na], [K] and [Mg] in shoot tissue while the K:Na ratio was non-significantly affected under both irrigation systems. The EC_{iw} x P interaction had significant effect on [Na] and K:Na ratio in root tissue while [P], [Na], [K], [Ca], [Mg] and K:Na ratio were not affected in shoot tissue. The K addition significantly affected [Na], [K] and K:Na ratio in shoot. All the parameters were significantly affected by the addition of K in root. The Ca uptake by roots increased with saline irrigation. The increasing P₂O₅ level significantly increased [P] in shoot and root tissue under both irrigation waters. The addition of P increased [P] in both shoot and root tissue. The Na uptake by root and shoot tissues was depressed with the addition of P and K fertilizers. The higher K uptake increased K:Na ratio in both wheat tissues. The decrease [Ca] could be associated with P and K treatments. The values of EC, SAR and [P], [Na], [Ca], [Mg], [Cl] and ratios of Na:K, Ca:P, Cl:P and SO₄:P in the soil leachates significantly increased with saline irrigation while pH values and [K], [SO₄], [CO₃] and

[HCO₃] did not change with saline irrigation waters. Except other soil parameters, the addition of P had significant effect on soil pH, SAR, [P], [SO₄], [CO₃] and [HCO₃] and Ca:P, Cl:P and SO₄:P ratios in leachates. Saline irrigation significantly increased EC_e, [Na], [K], [Ca], [Mg], [Cl], [CO₃], SAR and ratios of Ca:P, Cl:P and SO₄:Cl in saturated extracts of post-harvest soils. This study could suggest that the addition of P and K under saline conditions may be beneficial to crop productivity and minimize the adverse effects of Na in plant growth.

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