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Interaction of Phosphorus and Potassium on Maize (*Zea mays* L.) in Saline-Sodic Soil

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Abstract

Salinity and nutrient deficiencies are the main constraints for high crop productivity. Interaction of diammonium phosphate and potassium sulphate in saline-sodic soil for maize (*Zea mays* L.) crop was investigated. The results demonstrated that maize responded well to K and P fertilization in saline-sodic soils. The effects of salinity and sodicity were ameliorated by the application of K and P fertilizers resulting in higher yield. K had greater influence on grain yield than P level. K application increased yield related parameters. The addition of P significant affected leaf [P] and [Na] content, Na:K and Ca:Na ratios. Potassium levels had significant effects on [Na], [K], [Mg] and Na:K ratio. Phosphorus and K interactions did not affect leaf chemical composition except Mg content. The P application resulted in an increase of [P] in maize leaf tissue as compared to control. A decrease in [Na] and Na:K ratio was observed with the addition of K. There was positive relationship between grain yield ($R^2 = 0.67$), dry matter yield ($R^2 = 0.76$) and leaf [P], respectively in soils treated with P. The tissue [Ca], ratios of Ca:K and Ca:P were non-significantly affected by the K and P treatments. Extractable [P] increased after P treatments in the soil. The application of K significantly decreased Na:K ratios in the soil. The decreasing trends of [Na] and Na:K ratios depicted a negative ($R^2 = 0.91$) correlation between Na:K and soil [K]. Such interaction of K and P could mitigate the adverse effects of salinity and sodicity.

Keywords: saline-sodic soil, maize, plant growth, phosphorus, potassium, nutrient concentration

1. Introduction

Global estimates on the soil salinity greatly vary for various regions (Flowers et al., 1986). About one-third of total global 160 million ha irrigated land (equivalent to 53 million ha), is salt-affected, which is a major constraint for sustainable agricultural activities and crop yields (Greenland, 1984). Poor management practices along increased use of saline water for irrigation have aggravated the problem (Framji, 1976). The accumulation of excessive soluble salts and/or exchangeable sodium is confined to arid and semi-arid lands. In the Indian subcontinent, highly salt-affected soils occur in India and Pakistan (Rashid, 2006). In addition to other soil physic-chemical stresses which decrease crop yields; salinity and sodicity also adversely affect soil fertility (Rashid, 2006). Intensive cropping and severe climatic conditions affect the land use due to poor fertility status of the soils. The production demands are increasing due to the growing human population. The immense potential of salt affected soils for much needed food production, fibre, fuel and forage crops is now more desirable than ever. The researchers and scientists continue their efforts to find out the proper management of degraded and salt affected lands for better crop production. Understanding the salt and nutrient interaction are important to evaluate the impacts on crop productivity under such soil conditions.

The salt tolerance of a crop depends upon whether salinity or nutrition is limiting the growth of plant (Maas & Hoffman, 1977). Studies related to salinity and nutrient interaction are commonly performed either in nutrient culture or soil culture both in the laboratory and glasshouse and sometimes in the field depending upon the objectives and questions to be answered (Grattan & Grieve, 1993). In the field, the solubility and bioavailability of nutrients in the soil solution, including P and K is controlled by their solid phase in equilibrium with solution phase. Spatially and temporally variability of the nutrients in the given soil solution further confound the understanding of such interactions. The rate and amount of nutrient uptake and their ratios obtained under field conditions are very different from those found in soil solutions because of variability in root development and plant growth.

There is an urgent need to increase productivity of soils, especially the salt affected soils and help innumerable low-income small farmers to improve their socio-economic conditions. Potassium plays an important role in plants to tolerate/mitigate ill effects of high salt contents in soils. Some varieties of a crop are more tolerant of salinity than others and their tolerance appears to be related to the ease with which the plant can take up K while not accumulating too much sodium: Salt tolerant varieties show a lower Na:K ratio throughout a wide range of saline conditions (Schachtman & Liu, 1999). Potassium also helps plants 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 application of K fertilizer increased the movement of K from soil to root-surface and improved the availability of K to wheat roots (Cao et al., 1991; Ali et al., 1999).

High Na concentrations in soils increase soil dispersion and compaction that reduce soil air space which consequently result in poor K uptake by plants. Several studies have indicated that the [K] in plant tissue is depressed with the increases in Na levels or the ratio of Na to Ca in the root media (Okusanya & Ungar, 1984; Nakamura et al., 1991; Subbarao et al., 1990; Cramer et al., 1985). The K uptake in plants by Na is reduced because of competitive process which depends upon whether the solution is dominated by NaCl or $NaSO_4$. Barley exposed to Na_2SO_4 salinity maintained only one-third shoot [K] compared to those grown in non-salinized solutions (Janzen & Chang, 1987). Application of K fertilizers to increase the concentration of K in soils helped overcome the depressive influence of poor aeration on K absorption by plants (Tisdale et al., 1985). Application of K nutrition also helped to correct the adverse effects of salinity on growth and yield of various crop plants (Awad et al., 1990; Martinez & Lauchile, 1994; Marschner, 1995; Kaya et al., 2003).

Phosphorus, like K and N, is an important macronutrient that is involved in many essential functions in plant life especially in energy storage and transfer. The salinity x P interaction in plant nutrition is highly complexed and some time confusing to understand. It depends upon the plant species, growth stage, and salt types and degree of salinity and level of P in growth media (Zhukovskaya, 1973). Although the soil nutrient status is the primary growth limiting factor both in normal and low-salinity conditions but in soils with high salinity, high salt concentration becomes more crucial than nutrient deficiency (Champagnol, 1979). Most of the data pertaining to salinity x P response functions needs to be revisited for critical analysis regarding the interactions under low, moderate, and high salinity levels.

The problem of salinity-sodicity is a major threat to agricultural stability in Pakistan. Salt affected soils cover an area of 5.73 (Rashid, 2006) or 6.67 M ha (Khan, 1998; Qureshi & Barrett-Lennard, 1998; Ali et al., 2004). A fairly large area of District Kohat in southern Khyberpukhtunkhaw province is affected by saline and saline-sodic soils. Most of the farmers of the area have abandoned farming. The major constraints include inadequate resource development in the region with scarcity of water, accompanied with saline ground water, drought and stress problems for field crops, aggravated by uncertain, untimely and inadequate rainfall. Because of high evpotranspiration and low rainfall, the accumulation of salts in the soil profile has further aggravated the situation. The extent of salinity and sodicity in the Lachi area of District Kohat was evaluated (Khattak & Khan, 2004).

Since most of the research work have been performed on salinity and nutrients interactions in soils and plants based on information obtained from experiments conducted in solution or sand culture, which is much simpler as compared to the complex soil-plant system that do not reconciled with each others (Adams & Doerge, 1987). With this hypothesis in mind, a research study was conducted to evaluate the performance of maize in saline-sodic soil irrigated with saline waters and treated with K and P.

2. Materials and Methods

A comprehensive study was conducted to investigate the role of K and P fertilizers in saline agricultural area of Lachi, district Kohat, Pakistan. District Kohat is situated in the southern part of the Khyberpukhtunkhaw province, almost 70 km away from Peshawar. Kohat is surrounded by Peshawar, Afridi and Orakzai hills in the north, Bannu district and Waziristan in the south-west, Mianwali district in the south, Indus river in the East. The area lies between longitude 32°47′ and 34°5′ North and latitude 69°53′ and 72°1′ East. It falls in the semiarid and sub-humid subtropical continental category of climate classification and the temperature increases from 11.6 °C (winter) to 33.9 °C (summer) with mean annual temperature of 16.7 °C (Soil Survey of Pakistan, 2007). In the central Kohat area, the mean annual rainfall is below 400 mm. Most of the rainfall is received in Jul-Aug and part of it in Febr. and Mar. Parent rock material of the district Kohat comprised of sandstone, limestone conglomerates and salt rocks. Extending towards district Karak in the south, level plains are converted to small hills and mountains with gentle sloping. The soils are reddish or yellowish brown, moderately calcareous ranging from fine sandy loam to silty clay and clay loams and weakly structured. The general direction of watershed in Kohat is northwest to southwest. The canals taking off from Tanda dam provide irrigation down of Kohat city to limited area. In addition, the lands of Kohat areas are mostly irrigated by some open wells and lift pumps. The water reservoirs underlying the area are deep and contain saline water which is used for the crop production but with adverse effect on yield. Vegetables, sugarcane, wheat, maize and fruit plants like guava and plum are grown in Kohat areas.

The experimental site, Lachi is located about 95 km from Peshawar and 30 km from Kohat city on the left side of Indus highway. The chemical analysis of the soil and water samples revealed that the western region is free of the problem of salinity and the ground water is also of good quality. The soils of the eastern part along the Indus highway are salt affected with poor quality ground waters. A vast plain area, several thousand hectares, stretched between the eastern part of Indus high way and Khushalgarh, Punjab border, is affected by salinity-sodicity to varying degree. On the southern side are series of mountains with saline-sodic parent material, mainly causing the development of salt-affected soils and contributing salts into the ground waters. The particular sites selected for experimental activities include Jalalabad, Manduri and Naseemabad located on the right of Khadar Khel road. The adjacent villages include Khadar Khel, Momandi, Shadi Khel Banda and Gul Shah Khel Banda. These are mainly alluvial flood plains with level topography having poor drainage system. The farming community is aware of the gravity of the situation but have no choice for proper management.

Site was selected for experimental activities at Lachi. The site was located 33°23′43″ N. The soil was fine loamy, mixed hyperthermic Typic Haplustepts (Soil Survey of Pakistan, 2007). It is silty clay loam saline-sodic (EC_e = 5.0–9.0 dS m^{-1}) soil and located at Nasimabad on the right of Khadar Khel road 3 km towards East from Lachi bazar. Soils were irrigated with ground water having EC_{iw} between 2.2–3.0 dS m^{-1}.

2.1 Experimentations

The following experiments were designed and conducted to study the effect of different levels of K and P on maize (*Zea mays* L.) grown on saline-sodic soil in selected site of Lachi, district Kohat Pakistan. Soils were irrigated with saline ground water. The experiment was conducted to evaluate the impact of K and P fertilizers in combinations and alone in minimizing the salt hazard and to enhance crop productivity at Lachi. Three levels of K_2O (0, 75 and 150 kg ha^{-1}) as K_2SO_4 and three levels of P_2O_5 (0, 60 and 120 kg ha^{-1}) in the form of diammonium phosphate (DAP) were applied in three replications. The area of each plot was kept 5 × 5 m^2 with total of 27 plots. The basal dose of urea at the rate of 120 kg N ha^{-1} was applied to the soil. Local maize variety Hamesh was sown on ridges. The experiment was laid out in two factorial split plot randomized complete block (RCB) design.

2.2 Soil and Plant Analysis

Composite sample representing 6 to 8 sub-samples, at 0-30 cm depth from experimental field was collected before sowing at each site and after harvesting of crops. Soil samples were mixed thoroughly to be representative of the respective site. Similarly, 6-8 fully mature, young leaves were collected from maize plants. These soil and plant samples were transferred to clearly labeled plastic bags and brought to the laboratory of Soil and Environmental Sciences, Agricultural University Peshawar for further processing. After air drying the soil samples were gently crushed and sieved (2 mm) and properly stored for analysis. Soil texture was determined by hydrometric method (Bouyoucos, 1962; Gee & Bauder, 1986). Similarly, plant leaves collected were washed with distilled water and oven-dried at 70 °C for 48 h, ground in Wiley-Mill. The samples were then analyzed for cations and anions using the procedures of Yoshida et al. (1976) and Benton et al. (1991). Sample of soils, waters and plants were analyzed using the following methodology. AB-DTPA-extractable P in the soil was determined colorimetrically (Soultanpour & Schwab, 1977). The pH of soil suspension with soil:water ratio of 1:5 and water samples was determined using a 105 ion analyzer pH meter (McLean, 1982; Thomas, 1996). Electrical conductivity (EC) was measured using a digital EC meter, Wiss. Techn. Werkstatten (WTW) D12 Weilheim (Rhoades, 1982). Potassium and sodium in the soil extract, plant and water samples were analyzed by Perken-Elmer flame photometer (Richards, 1954). Calcium and magnesium were determined in soil, plant and water samples by titration with EDTA (Richards, 1954). Carbonates and bicarbonates were determined by titration with acid (Richards, 1954). Chloride was determined by titration with silver nitrate (Richards, 1954).

Sulfate was determined using a turbidity method (Bardsley & Lancaster, 1960). Lime ($CaCO_3$) content of the soil was measured by the procedure of 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 (Richards, 1954). SAR of the soils and waters was calculated using the formula.

$$SAR = \frac{[Na]}{\sqrt{\frac{[Ca+Mg]}{2}}} \tag{1}$$

The data were analysed using Microsoft Excel 2007 spread sheets to calculate averages, standard deviation (SD) or percentages. The factorial analysis was conducted using statistical package of MSTATC program (Steel & Torrie, 1980).

3. Results and Discussion

3.1 Pre-Sowing Soil Chemical Composition

Chemical analysis of the soils revealed that EC values of soil saturation extracts ranged from 4.78 to 7.54 dS m^{-1} with an average of 6.37 ± 0.84 dSm^{-1}. pH of the soil suspension (1:5) ranged from 8.2 to 8.9 with the mean value of 8.6 (Table 1). The average P value was 2 mg kg^{-1} and ranged from 0.9 to 5.2 mg P kg^{-1}. The AB-DTPA-extractable [P] in soil lied either as deficient (< 3 mg kg^{-1}) or medium (< 7 mg kg^{-1}) (Soultanpour & Schwab, 1977). The [Na] was found above the normal level ranging from 33.4 to 61.3 with a mean value of 46.9 mmol(+) L^{-1} (Table 1). On the basis of higher [Na], higher SAR (> 10) and elevated pH and EC_e (> 4.0 dSm^{-1}) values, the soil was classified as saline-sodic (Richards, 1954; Sposito, 1989).

Table 1. Pre-cultivation chemical composition of saline-sodic soil

Soil properties	Units	Range	Mean±SD
EC_e	dS m^{-1}	4.78-7.54	6.37±0.84
pH	----	8.17-8.85	8.64±0.26
P	mg kg^{-1}	0.90-5.20	2.00±0.99
Na	mmol(+) kg^{-1}	33.4-61.3	46.9±8.49
K	mmol(+) kg^{-1}	0.15-0.41	0.25±0.06
Ca+Mg	mmol(+) kg^{-1}	13.9-25.7	18.4±2.63
Cl	mmol (-) kg^{-1}	20.5-34.8	26.1±3.83
SO_4	mmol (-) kg^{-1}	18.2-48.6	34.7±9.11
CO_3	mmol (-) kg^{-1}	0	0
HCO_3	mmol (-) kg^{-1}	3.30-6.90	5.16±0.96
SAR	----	9.44-21.5	15.6±3.25

3.2 Maize Dry Matter and Grain Yield

The application of K fertilizers significantly affected grain yield ($P < 0.001$), dry matter yield and plant height ($P < 0.01$), while the effect of P and P × K interactions on maize was not significant for these parameters (Table 2). Summary analysis of variation (ANOVA) on the effect of P and K on maize growth and yield in saline-sodic soils is given in Table 3. As compared to control increases (%) in maize grain yield obtained with the application of K_1 and K_2 were 53 and 55 at P_0, 72 and 76 at P_1 and 60 and 71 at P_2, respectively. The difference of grain yield at K_1 and K_2 were non-significant across all P levels. The addition of 60 and 120 kg P_2O_5 ha^{-1} increased grain yield by 22% and 30% as compared to control (Table 2). Grain yield was affected by K level more than P level. However, addition of 60 kg P_2O_5 ha^{-1} produced highest grain yields of 2.06 t ha^{-1} at K_2 which was statistically similar to P_2K_2 treatment.

Table 2. Maize yield components as affected by the application of P and K in saline-sodic soil

P_2O_5	K_2O	Grain yield	% increase	Dry matter yield	% increase	Plant height
-------kg ha^{-1}-------		t ha^{-1}		t ha^{-1}		cm
0	0	1.17	control	2.91	control	109.7
	75	1.77	53	4.75	63	123.9
	150	1.81	55	4.76	64	117.8
60	0	1.42	22	3.92	34	104.2
	75	2.01	72	5.00	72	121.3
	150	2.06	76	5.21	79	116.9
120	0	1.52	30	4.14	42	107.4
	75	1.87	60	4.58	57	109.3
	150	2.00	71	5.29	82	115.3

Table 3. Summary analysis of variation (ANOVA) on the effect of P and K on maize growth and yield in saline-sodic soils

Source of variation	Grain yield	Dry matter yield	Plant height
	------------F-value------------		
P	3.21 ^{NS}	0.89 ^{NS}	2.14 ^{NS}
K	17.6***	5.75*	9.80**
P × K	0.30 ^{NS}	0.41 ^{NS}	1.53 ^{NS}

Note. *, **, *** indicate significance level at $P < 0.05$, < 0.01 and < 0.001, respectively; NS = not-significant.

The increases in dry matter yield were 34 and 42% with P_1 and P_2 at K_0, while the yield was substantially increased to 79 and 82% at K_2 as compared to control (P_0K_0). The results suggested that increases in dry matter yield were more discernable with increasing K as compared to P alone which caused increases of 34 and 42% over K_0P_0. Irrespective of K treatment, grain yield increased non-significantly over control with P_1 and P_2 which were similar to each other (Tables 2-3), while dry matter and plant height were similar. Similarly, the level of K showed consistent increases in these parameters but the difference between P_1 and P_2 were non-significant but greater than control. Maize yield as a whole was low as compared with the yield commonly produced in the non-saline fertile soil due to the low initial germination percentage (> 50%). The re-sowing of seeds slightly increased germination with no significant effect on overall maize yield which might be due to the susceptibility of maize crop to high salt concentrations.

Maize is classified as salt sensitive crop (Mass & Hoffman, 1977). Most studies revealed that salt stress is mainly due to NaCl and resistance of plant against salts is more affected in germination stage (Mengal & Kirkby, 1987; Lauter et al., 1981; Shannon, 1984). Several researchers reported that the response of maize to salinity was varied depending on the stage of development (Maas et al., 1983). Munns (1993) reported that growth reduction at early phase was due to the effect of salt concentration in the soil solution and genotypes respond identically at early phase. Alberico and Cramer (1993) concluded that maize growth in early stages was affected primarily by osmotic effect. The intensity of sodicity and salinity in soil can reduce the effective rooting depth of cereal crops (Dang et al., 2006). During this study maize seed showed sensitivity to the salinity/sodicity and thus produced less number of plants per plot thus resulting in low yield.

The addition of K and P treatments minimized the adverse effect of salts as evidenced by the improvement of yield despite an initial low germination. The salinity and phosphate interaction in the plant have been variedly reported (Ravikovitch & Yoles, 1971; Champagnol, 1979). An increase in tomato yield was reported due to P application at different salinity levels (Cerda & Bingham, 1978; Kafkafi, 1984). The interactions of salinity and fertility could be based on the variability in the experimental conditions. Most of the earlier studies were conducted in the solution culture (Bernstein et al., 1974; Adams & Doerge, 1987) which were less complex as compared multiple interactions of cations and anions in soil-plant-saline irrigation system.

Welch and Flannery (1985) also concluded that adding K to soils increased dry matter yield of maize by increasing plant water use efficiency. On the other hand, increased salts uptake resulted in the decrease in the dry matter yield of maize (Taban et al., 1999). The findings of Bar-Tal et al. (1991) showed that applied K significantly increased maize yield but did not eliminate the deleterious effects of high Na and Na:Ca ratios on maize yield despite the beneficial effect of increasing K content and reducing the Na:K ratios in plant tissues. These observations may be valid under the given level of applied K and degree of sodicity.

3.3 Leaf Tissue Chemical Composition

The ANOVA for chemical analyses of maize leaf tissue (Table 5) revealed that addition of P treatments showed significant ($P < 0.01$) effect on leaf [P] and [Na] and on ratios of Na:K and Ca:Na, and non-significant effect on [K], [Ca], [Mg], Ca:K and Ca:P ratios. The K levels had significant effect on [Na], [K], [Mg] and Na:K ratio ($P < 0.001$) and non-significant effect was recorded on [P], [Ca] and Ca ratio to K, Na and P. Phosphorus and K interactions non-significantly affected leaf chemical composition except Mg ($P < 0.001$) (Tables 4-5).

The [P] in maize leaf tissue increased with P_1 and P_2 as compared to control (P_0K_0). The [Na] was noticed lowest at P_1K_1 and highest at P_2K_0. As compared to P_0K_0, tissue [Na] decreased by 17 to 21% with K_1P_0 and K_2P_0 while increases of 10 to 36% were observed with K_1P_2 and K_2P_2 when compared to K_0P_2 whereas the effect of K1 and K2 at P1 was inconsistent (Tables 4-5). A decrease in [Na] and Na:K ratio was observed with the addition of K_1 and K_2, respectively. There was positive relationship between grain yield ($R^2 = 0.67$) and dry matter yield ($R^2 = 0.76$) (Figure 1) and leaf [P], respectively in soils treated with P_2O_5 levels at K_0 (n = 9). A moderate negative relationship ($R^2 = 0.51$) was observed between Na:K ratio and leaf [K] (Figure 2). The reduction in tissue [Na] with added K at P_1 can be associated with the magnitude of increases in plant yield, compared to P_0 and P_2. The increases in biomass were maximum in plots treated with K_1 and K_2 at P_1, which showed marked decrease in [Na]. This has supported the dilution effect (Jarrell & Baverly, 1981). Close perusal of yield data and tissue nutrient concentrations and respective ratios suggested that as yield increases with increasing K, the [Na] decreased and vice versa. The leaf [K] consistently increased with K_1 and K_2 and were not affected by P levels. A positive correlation was observed between leaf [K] and grain ($R^2 = 0.52$) and dry matter yield ($R^2 = 0.56$) of maize, respectively in K treated soil at P_0 (Figure 1).

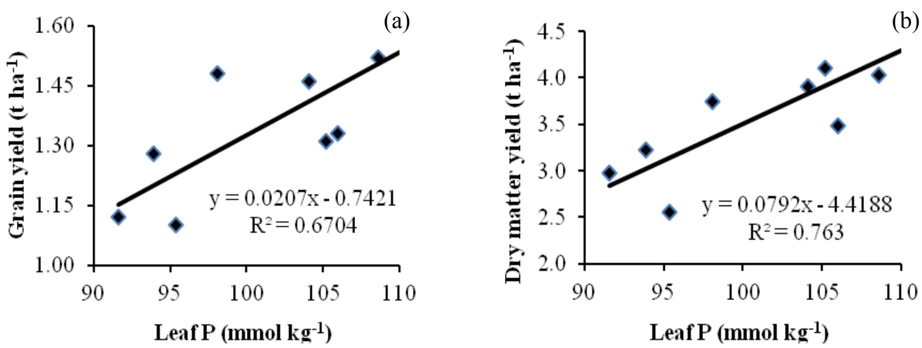

Figure 1. Relationship of grain yield (a) and dry matter yield (b) to leaf [P] in P_2O_5 treated (n = 9) saline-sodic soil

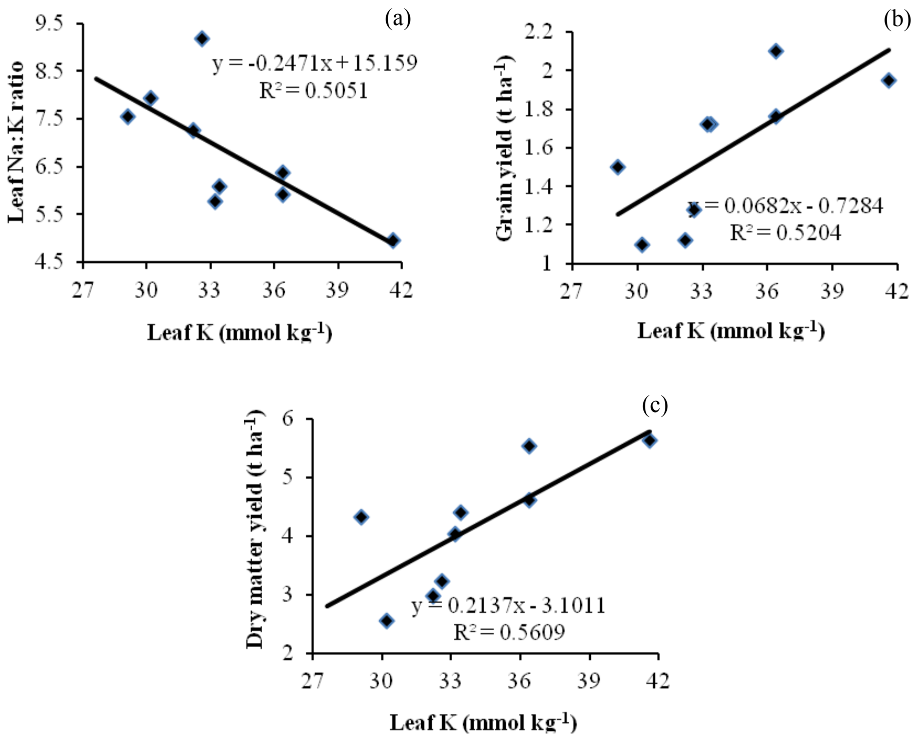

Figure 2. Relation of leaf K:Ca ratio (a), grain yield (b) and dry matter yield (c) of maize to leaf [K] in K_2O treated (n = 9) saline-sodic soil

The tissue [Ca] and ratios of Ca:K and Ca:P were non-significantly affected by the K and P treatments whereas the [Mg] was non-significant under P application but it was increased with increasing K dose at P_0 and P_1 and decreased at P_2. This shows a significant interactive effect of P and K (Table 4). It appeared that at higher P (120 kg P_2O_5 ha^{-1}), [Mg] decreased due to enhanced plant size while at P_1 (60 kg P_2O_5 ha^{-1}) this trend was reversed. Since the dry matter yield increased from 3.92 to 5.21 t ha^{-1}, and the [Mg] also increased from 78.7 to 115.3 mmol kg^{-1}, this phenomenon could be attributed to synergetic effect of K on Mg uptake at lower P fertility level.

Table 4. Ionic concentrations in maize leaf tissue as affected by P and K in saline-sodic soils

P_2O_5	K_2O	P	Na	K	Ca	Mg	Na:K	Ca:K	Ca:Na	Ca:P
-------kg ha^{-1}-------		------------------------mmol (±) kg^{-1}---------------------								
0	0	93.6	257.7	31.7	240.8	92.6	8.23	7.59	0.92	2.57
	75	92.7	218.3	33.0	236.9	83.2	6.67	7.20	1.09	2.56
	150	91.7	204.2	37.1	247.4	110.0	5.54	6.86	1.22	2.72
60	0	102.5	186.9	29.5	240.2	78.7	6.34	8.15	1.28	2.34
	75	100.7	156.5	34.6	233.2	80.7	4.51	6.86	1.52	2.34
	150	102.4	177.7	34.5	238.7	115.3	5.17	6.97	1.33	2.32
120	0	109.8	298.9	33.5	241.5	99.3	8.94	7.14	0.80	2.21
	75	103.4	262.3	35.0	230.1	97.6	7.48	6.58	0.88	2.20
	150	107.3	235.5	37.1	237.2	71.2	6.34	6.38	1.02	2.22

Table 5. Summary analysis of variance (ANOVA) on the effect of P and K on chemical composition of leaves of maize grown in saline-sodic soils

	Variables Analyzed					
SOV	P	Na	K	Ca	Mg	Na:K
		----------------------------F-values--------------------------				
P	22.3**	43.2**	2.43 ^{NS}	2.45^{NS}	0.88 ^{NS}	57.8**
K	1.41 ^{NS}	9.50**	7.46**	3.78^{NS}	10.6**	22.5***
P × K	0.38 ^{NS}	1.64 ^{NS}	0.78 ^{NS}	2.67^{NS}	24.1***	2.22 ^{NS}

Note. *, **, ***= Significant at $P < 0.05$, 0.01 and 0.001, respectively and NS = Not significant.

Increasing P and K levels significantly affected the ratio of Na:K but Ca:Na was non-significantly affected by P and K treatments. Increasing K_1 to K_2 depressed [Na] and enhanced [K], resultantly Na:K ratio was decreased with K_1 and K_2 and with the levels of P. The addition of P alone showed higher but statistically similar values of 8.23 and 8.94 of Na:K ratio at P_0K_0 and P_2K_0 than 6.43 at P_1K_0 which were related to the [Na], [K] and dry matter yield at these treatments. It has been reported elsewhere that at higher [Na], Ca transport to the leaves was impaired and plant yield was also reduced (Fortmeier & Schubert, 1995; Hajibagheri et al., 1987). During in the present study, the ratio of Ca:Na tended to enhance with the K addition. Although [Na] in tissue was depressed by K, but [Ca] showed variable response to K, so the ratio of Ca:Na varied non-significantly. Preferential uptake of Ca over Na has been known to alleviate the adverse effect of Na on crop (Suarez & Grieve, 1988; Mass & Grieve, 1987; Cramer, 1992). However, the complexity of soil solution and composition of saline irrigation waters in an open field system might have confounding effects.

3.4 Ionic Concentrations of Post Harvest Soil

Table 7 shows the summary of ANOVA on the ionic concentrations of soil saturation extracts as affected by K and P treatments [3P × 3K × 3R] and the interaction of P × K in saline-sodic soil after maize crop harvesting. The values of soil AB-DTPA extractable P, saturation extracts SAR, [K], Ca:P Cl:P and SO_4:P were significantly affected by P treatments, while addition of K significantly influenced pH (1:5), EC_e, SAR, [Na], [K], [Mg], [Cl], Na:K, Na:Ca, Ca:K, Cl:P and $Cl:SO_4$ ratios whereas the P × K interaction had significant effect on [Ca] and Cl:P and SO_4:P ratios (Tables 6-8).

Table 6. Chemical analyses of saturated extracts of post-harvest saline-sodic soil as affected by the application of P and K fertilizers

P_2O_5	K_2O	pH $_{(1:5)}$	ECe	AB-DTPA P	SAR	Na	K	Ca	Mg	Cl	SO_4	HCO_3
-------kg ha^{-1}-------			dS m^{-1}	mg kg $^{-1}$		--------------------------mmol (±) kg^{-1}---------------------						
0	0	9.64	9.59	3.06	15.7	74.0	0.27	24.6	20.9	60.3	55.8	6.70
	75	9.50	9.02	4.40	12.9	61.0	0.42	30.8	14.4	47.7	60.6	6.20
	150	9.42	8.79	3.89	11.9	52.5	0.54	25.9	13.3	34.8	64.3	5.93
60	0	9.55	8.68	5.20	16.4	79.3	0.41	26.4	20.7	59.5	57.4	5.90
	75	9.53	8.08	3.90	16.7	74.5	0.55	24.6	15.2	45.8	63.2	5.83
	150	9.54	8.99	3.10	14.0	60.8	0.71	25.1	12.8	28.0	64.0	5.67
120	0	9.62	10.2	7.47	15.4	75.9	0.40	29.6	19.9	57.8	63.1	6.13
	75	9.53	8.37	6.98	13.9	60.7	0.52	24.5	13.9	29.2	62.0	5.63
	150	9.61	9.15	7.72	12.1	57.2	0.59	30.0	14.8	30.8	65.2	5.67

Table 7. Summary analysis of variance (ANOVA) for the effect of P and K on chemical composition of saturation extracts of post-harvest saline-sodic soil

SOV	pH	EC_e	AB-DTPA P	SAR	Na	K	Ca	Mg
P	0.57 ^{NS}	1.22 ^{NS}	121.6***	12.6*	2.06 ^{NS}	12.5*	0.48 ^{NS}	0.00 ^{NS}
K	4.33*	7.92**	0.23 ^{NS}	14.9***	31.1***	82.0***	0.03 ^{NS}	14.3***
P × K	1.46 ^{NS}	1.56^{NS}	2.68 ^{NS}	1.28 ^{NS}	0.66 ^{NS}	1.01 ^{NS}	2.13 ^{NS}	2.79 ^{NS}

SOV	Cl	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	$Cl:SO_4$	$SO_4:P$
P	1.82 ^{NS}	6.15 ^{NS}	5.43 ^{NS}	4.05 ^{NS}	17.3*	11.8*	1.93 ^{NS}	17.9*
K	50.7***	42.9***	12.9***	18.5***	0.85 ^{NS}	24.9***	34.5***	4.04*
P × K	1.98 ^{NS}	2.07 ^{NS}	2.64 ^{NS}	1.02 ^{NS}	2.46 ^{NS}	3.55*	0.70 ^{NS}	5.30**

Note. *, **, *** = Significant at $P < 0.05$, 0.01 and 0.001, respectively and NS = Not significant.

Table 8. Ionic ratios in the saturation extracts of post-harvest saline-sodic soil as affected by the application of P and K fertilizers

P_2O_5	K_2O	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	$Cl:SO_4$	$SO_4:P$
--------kg ha^{-1}-------								
0	0	277.6	3.09	91.7	161.1	705.8	1.10	873.6
	75	148.5	1.98	74.5	143.1	405.4	0.80	677.0
	150	97.8	2.03	48.0	138.4	343.3	0.56	807.8
60	0	197.4	3.02	66.2	101.7	404.8	1.06	535.0
	75	136.9	3.06	45.8	127.5	419.7	0.72	780.2
	150	86.1	2.44	35.8	161.9	320.8	0.44	995.1
120	0	194.3	2.63	76.3	79.3	276.4	0.91	408.8
	75	117.0	2.51	47.0	74.9	161.4	0.47	448.8
	150	96.9	1.91	50.7	79.7	141.0	0.48	420.6

With the exception of AB-DTPA extractable P, all ions were determined in water saturated extracts in the post-harvest soil. Comparing the effect of P and K treatments on the ionic concentration of soil solution, the solution concentrations of an ion is determined by the degree and extent of removal by a crop, leaching, adsorption, precipitation, co-precipitation and addition through fertilizer treatments and through irrigation waters containing Na, Ca, Mg, K, SO_4, Cl and HCO_3. In such a complex system involving soil-plant leaching receiving saline irrigation waters, the role of formation of soluble and insoluble complexes will be an important factor affecting ion uptake, leaching and adsorption (Sposito, 1989; Spark, 1995).

The values of post harvest soil pH and ECe showed non-significant variation with the addition of P. These parameters significantly decreased with the K application (Table 6). An overall increase in the values of EC_e and pH (1:5) in the post harvest soil were observed when compared with the initial pre-harvest soil values (Table 1). The increase in salt concentrations of post harvest soil could be associated with the enhanced evapotranspirations coupled with limited rainfall under saline irrigation applied to the crop during the hot and dry summer months.

The AB-DTPA extractable [P] significantly ($P < 0.001$) increased with the addition of P treatments as compared to control (P_0), while K treatments and P × K interaction showed non-significant effects on P values (Table 6). In the absence of K, increasing AB-DTPA [P] increased linearly with increasing P but at K_1 and K_2, [P] decreased at P_1 and increased at P_2. Across all K levels, the P effect was more pronounced on soil [P]. As indicated by ANOVA (Table 7), SAR, [Na] and [K] were significantly affected by P and K levels, while [Ca], [Mg] and [Cl] were non-significantly affected by P treatments, while [Mg] and [Cl] showed a significant decrease with K at all levels of P. Since [Na] in saturation extracts decreased and [K] increased with the addition of K and [Ca] and [Mg] remained unchanged, therefore, SAR, Na:K, Na:Ca and Ca:K decreased with K_2SO_4 (Table 8).

The application of K significantly ($P < 0.001$) decreased Na:K ratios in soil (Table 6). The highest Na:K ratio (277.6) was noted under control (P_0K_0) and then decreased to 97.8 with the application of K_2 at P_0. The Na:K ratios of 86.1 and 96.9 were calculated at P_1 and P_2, respectively (Table 6). The decreasing trends of [Na] and Na:K ratios depicted a negative ($R^2 = 0.91$) correlation between Na:K and soil [K]. When compared to K_0, SAR values decreased with K_2 from 15.7 to 11.9 at P_0, 16.4 to 14.0 at P_1 and from 15.3 to 12.1 at P_2. The higher values of SAR and Na at 60 kg P_2O_5 ha^{-1} as compared to P_0 and P_2 could suggest that phosphate probably has exchanged Na into soil solution while at higher level of P_2, more soluble Ca-P and Mg-P or sparingly soluble complexes were formed (Lindsay, 1979) which enhanced [Ca+Mg] in the soil solution and decreased SAR. The soil [K] in saturation extract was increased to 0.54, 0.71 and 0.59 mmol(+) L^{-1} by the addition of 150 kg K_2O ha^{-1} at P_0, P_1 and P_2, respectively, as compared to K_0. These increases in water soluble [K] were also found in the leaf tissue [K].

In solution culture studies, Bernstein et al. (1974) found that increasing solution [K] did not affect leaf [K] or the yield of corn. Bar-Tal et al. (1991) found an increase in the yield of corn grown on sandy soil but they concluded that despite beneficial effects of decreasing Na:K, the K fertilization did not reduce the deleterious effects of salinity. Nguyen et al. (2001) reported that K application significantly increased soil extractable K values. Results obtained from studies conducted in solution culture or in sandy soil do not represent the complex open soil-plant leachate and saline irrigation system due to multiple interactions. In the present studies, however, the application of K not only increased soil K levels but also enhanced K uptake by plants which improved the yields of maize.

Although [Ca] responded non-significantly to P levels, however, 60 and 120 kg P_2O_5 ha^{-1} significantly ($P < 0.05$) decreased the ratios of Ca:P at K_0, while K application promoted Ca:P ratios in soil extract. The decreases in Ca:P ratio are associated with increasing soil [P] while increases in Ca:P with addition of K_2SO_4 may indicate competitions of SO_4 and HPO_4 and H_2PO_4 in soil solution-exchange phase and or replacement of Ca into solution by increasing [K] from exchange sites. Parent et al. (1994) reported an antagonism between soil P and Ca. This negative relationship may result from reduced activity of P in the soil solution due to the higher ionic strength of the media and low solubility of Ca-P minerals (Grattan & Grieve, 1999). The addition of P to P-deficient soils is beneficial for crops not experiencing severe salt stress (Champagnol, 1979). Zahoor et al. (2007) reported that phosphorus uptake in shoot and root was suppressed under both Cl and SO_4 salts as compared to normal soil. However Cl salt was observed to be more toxic for shoot P uptake compared to SO4.

The ratios of Na:Ca and Ca:K in soil saturation extracts were significantly ($P < 0.001$) affected by the application of K treatments (Table 6). When averaged across P levels, the application of K consistently decreased these ratios due to lowered [Na] in case of Na:K and higher [K] in case of Ca:K ratios. The values of Na:Ca ratios showed an increasing trend while Ca:K decreased with P application. The application of P and K tended to decrease [Mg] and [Cl] but the decrease was more significant ($P < 0.001$) with K application. The [Cl] drastically decreased and [SO_4] tended to increase with increasing levels of K_2SO_4. The increasing [Cl] reduced the Cl:P and Cl:SO_4 ratios. The addition of P_1 and P_2 lowered the SO_4:P ratio as compared to P_0.

Most important aspect of the Na-K concentrations in the soil solution is that [Na] were over 200 fold higher in K_0 plots but reduced to 100 with the treatment of 150 kg K_2O ha^{-1} as evident from Na:K ratios. The Na:Ca ratio closely varied from 1.91 to 3.09, Ca:K from 35.8 to 91.7 and Ca:P from 74.9 to 161.9 in the soil saturated extract. Generally, K_2SO_4 treated plots had much lower Na:K ratio, Na:K and Cl:SO_4 ratio while phosphate treated plots lowered Ca:P, Cl:P and SO_4:P. These trends were closely associated with the chemical composition maize plant, which may account for the positive effect of K_2SO_4 and $(NH_4)_2HPO_4$ on crop growth and nutrition.

In conclusion, the results demonstrated that addition of K_2SO_4 and phosphate-P did minimize adverse effect of Na, Cl and SO_4 in the saline soil receiving irrigation waters and promoted maize yield substantially.

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