WHEAT GROWTH AND NUTRIENT UPTAKE AFTER PHOSPHORUS AND POTASSIUM APPLICATIONS IN SALINE-SODIC FIELD OF SEMI-ARID REGION

CRESCIMENTO DO TRIGO E ABSORÇÃO DE NUTRIENTES APÓS APLICAÇÕES DE FÓSFORO E POTÁSSIO EM CAMPO SALINO-SÓDICO DO SEMI-ÁRIDO

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ABSTRACT: Nutrient deficiency is a limiting factor in saline-sodic soils resulting in low crop production. The study investigated wheat response to P and K added to soils. The K was applied at 0 (K0), 75 (K1), 150 (K2) kg K_2O ha^{-1} as K_2S0_4 and at (0 (P0), 60 (P1), 120 (P2) kg P_2O_5 ha^{-1} as $(NH_4)_2HPO_4$ in three replications under two-factorial randomized complete block (RCB) design. Both treatments significantly enhanced wheat grain (118%) and dry matter yield (60%) at P2K2 compared to control. The P treatments significantly affected leaf P, Mg, SO_4, Ca:P, SO_4:P ratios and soil P, Ca:P, Cl:P and SO_4:P ratios, while K on leaf K, Na, Ca, SO_4 concentration, K:Na, K:Ca, SO_4:P,Ca:P ratios and soil pH, Na, K, Ca, SO_4 concentrations, SAR, Na:K, Ca:K and Na:Ca ratios. Leaf Na was decreased to 85.3 mmol (+) kg^{-1} at K2 compared to 105.3 mmol (+) kg^{-1}at P2K0. Negative correlation (R^2=0.906) of leaf K:Na was found with leaf Na concentration. The correlation of dry matter was higher (R^2=0.851) with leaf K:Na ratio than grain yield (R^2=0.392). It is concluded that the addition of K and P addition shows beneficial effects in improving crop nutrition and wheat yield in the saline-sodic soil environment.

KEYWORDS: Arid region. P. K. Saline-sodic soil. Semi-arid region. Wheat growth.

INTRODUCTION

Reclamation of salt-affected soils through appropriate on-farm fertility management practices serves as a vital tool for the enhancement of crop production (JORDAN et al., 2004). Under salt stress, proper fertilizer applications to the soil can increase crop yields (HUSSAIN et al., 2014). Potassium (K) and phosphorus (P) can be important in minimizing the negative impacts of high salt stress in soils (GARG; GUPTA, 1998). The plants' tolerance against salt stress may be improved by optimized K nutrition (RÖMHELD; KIRKBY, 2010) as K plays important role in regulating the osmotic potential of crops and minimizing salt stress in saline environments. However, the P and salinity interactions in plant nutrition are complicated and vary with crop species, types of salts, levels of salinity, growth conditions, and the P concentrations of growing media (NISTE et al., 2014).

Salinity compromises the agricultural potential as well as imparts serious implications on the socio-economic conditions of the farming community (HAIDER; HOSSAIN, 2013). There is an agreement that higher concentrations of salts in the rhizosphere create the osmotic stress which disturbs the nutrient balance and develops specific ion toxicity in salt-affected soils.

A positive relationship between K uptake and the salinity tolerance in wheat and barley was reported (CUIN et al., 2008). The accumulation of compatible solutes by plant tissues is improved in the presence of K which helps to mitigate salinity induced damages. For example, the presence of proline minimizes the effects of high osmotic pressure by salts in soil and water and permits water uptake by plants, protects enzymes and proteins, and improves the cell wall structure (SUN et al., 2015). The application of K in the presence of Ca reversed the salinity induced stress in *Cichorium endivia* L., cv. Green Curled (TZORTZAKIS, 2010). The adverse effects of salinity on plants grown on P deficient soils and improved wheat growth in moderate and high soil salinity with P are reported. Also, P improved uptake of N, P, K, and Zn in sandy and calcareous soils (WAGDI et al., 2013). The physiology of the wheat plants was stabilized with P application which was due to supporting K transport in the plant (KHAN et al., 2013). Studying the interactive effects of K and P nutrition on wheat under natural field conditions of salinity is vital to understand the crop response and nutrient uptake.

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The impacts of P and K fertilizers on soil reclamation and growth of maize and sugar beet were studied in the same area (HUSSAIN et al., 2014; 2015). The present study aimed to further investigate the interactions of P and K and salinity on wheat growth and nutrient uptake in a saline-sodic environment.

MATERIALS AND METHODS

Background and description of the study location

Pakistan falls in arid and semi-arid climate region with salt-affected soils ranging from 5.73 m ha (RASHID, 2006) to 6.67 m ha (ALI et al., 2004). This poses a major threat to the sustainability of agriculture in Pakistan. District Kohat lies in southern Khyber Pakhtunkhwa province of Pakistan with a large area affected by salinity and sodicity (HUSSAIN et al., 2015). High evapotranspiration and low rainfall elevate salt accumulation in the soil profile. The use of saline groundwater for irrigation because of the unavailability of freshwater, low rainfall, and high salinity stress have aggravated the situation to the extent that most farmers have abandoned farming as their major livelihood resources.

The experimental field lies in Tehsil Lachi of District Kohat in the north-western province of Pakistan. The soils are mixed hyperthermic Typic Halusteps (Soil Survey of Pakistan, 2007). The region is semi-arid to sub-humid subtropical continental situated in longitude 32^0 47' and 34^0 5' North and latitude 69^0 53' and 72^0 1' East (Soil Survey of Pakistan, 2007). Soil is calcareous, yellowish to reddish-brown with fine sandy loam to silty clay and clay loam textured and is poorly structured. Groundwater used for irrigation is of poor quality with an EC_{iw} level of 2.2–3.0 dS m^{-1}. The soils of the area are classified as saline-sodic soils based on measured parameters (EC_e= 5.0-9.0 dS m^{-1}, SAR>15).

Experimentation

A farmer's field with characteristics of salinity and sodicity was selected for the experiment. The K_2S0_4 was applied at three doses of 0, 75, and 150 kg K_2O ha^{-1} while di-ammonium phosphate (DAP) at three doses of 0, 60, and 120 kg P_2O_5 ha^{-1} in 27 plots of 5x5 m^2 in three replications. The urea was applied as a basal dose to all the plots uniformly at 120 kg N ha^{-1}. Inqilab-91 was selected as the experimental wheat variety which is widely used as a major wheat crop in the study area, while seed rate was kept as 120 kg ha^{-1}. Two-factorial randomized complete block (RCB) design was applied to the experiment. The experiment was completed at crop maturity.

Analytical procedures

Before the sowing of the crop and the start of irrigation, composite soil samples, and groundwater samples were collected and analyzed. The plastic bottles were cleaned and rinsed for the collection of groundwater samples. The samples were filtered using Whatman filter paper No. 40 and saved for further analysis. At crop maturity, grain, and dry matter yield (Mg ha^{-1}) of wheat were determined. Fully matured and young leaves of wheat plants were collected prior to harvesting of the crop. The leaf samples were cleaned with purified water and dehydrated in an oven at 70 ^{0}C for 2 days. After drying, the leaves were milled and saved for further analyses. The leaf samples were wet-digested as follows: A 0.5 g of oven-dried leaf samples were weighed and transferred to flask. A 10 mL of concentrated HNO_3 was added to the samples and were left overnight. The next day, 4 mL of $HClO_4$ was added to the flask and gently heated in block heater for complete digestion. The digested material was cooled and filtered. Distilled water was added to make the desired volume. Chemical analysis for cations and anions in leaf samples was done.

Soil samples from each pot were collected at the depth of 0-30 cm after harvesting of crops. Samples were openly dried and then crushed and sieved through 2 mm sieve. The samples were then saved for further analyses. The texture of the soils was determined using the hydrometric method. A 250 g soil was weighed, and the distilled water was added carefully to make the saturated soil paste while continuously stirring with a spatula. After that, the shining paste was developed, it was kept for a night to completely dissolve the salts, as well as the equilibrium, was achieved (RICHARDS, 1954). The samples were extracted to obtain clear extract using an aspirator. The saturation extract was refrigerated.

The electrical conductivity (EC) of the saturation extracts and the groundwater samples was measured with digital Electrical conductivity meter, Wiss. Techn. Werkstatten (WTW) D12 Weilheim. The pH of groundwater samples as well as suspension of 1:5 soil: water was determined with 105 Ion analyzer pH meter (MCLEAN, 1982; THOMAS, 1996). The Na and K concentrations in mmol (+) L^{-1} were determined in **s**oil saturated extracts, groundwater, and plant samples using the Perkin-Elmer flame photometer model No. 2380. The [Ca] and [Mg] in saturation extract was determined by titration methods (Richards, 1954). The SAR of saturation extract and the groundwaters was calculated using mmol (+) L^{-1} concentrations of Na, Ca, and Mg by the following formula.

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

MSTATC statistical program was used for statistical analysis of the data. Regression analysis was performed for important variables such as yields of wheat and concentrations of ions and their ratios to understand important relationships.

RESULTS

Wheat yield

There was a significant effect of K and P treatments on grain ($P<0.01$ and $P<0.001$) and dry matter ($P<0.001$) yields of wheat. Grain yield was significantly ($P<0.05$) influenced by P-K interactions but non-significant for dry matter yield (Table 1). Grain yield enhanced by 28 and 4.0 at P1K1and P1K2 and 40% and 16% at P2K1 and P2K2, respectively, comparative toK1 and K2 at P0. The increase on the other hand was by 50 and 88% at K1 and K2 without P but elevated to 93 and 95% at P1 and to 110 and 118% at P2 ha^{-1}, respectively, when compared with P0K0 (Table 1). There seemed to be a progressive increase in yield at all K levels at P0. But with P1 and P2 addition at these K levels demonstrated a much higher effect of P on wheat grain yield.

The significant ($P<0.001$) increase in dry matter (DM) yield was observed with P and K treatments. The DM yield improved by 7 and 23 % at K1 and K2 with P0, 18 and 26 % at P1 and 28 and 61 % at P2, respectively, compared to P0K0 (Table 1). The dry matter yield was highest at P2K2 as compared to P0K0. The increasing rates of K_2O and P_2O_5 in saline-sodic soils consistently enhanced dry matter yield as shown by mean (n=9) data in Table 1. The analysis of variance (ANOVA) shows the influence of P, K treatments on yields of wheat grown under salt-affected conditions. The P treatments improved grain yields while K promoted dry matter yield under salt-affected conditions.

Chemical analysis of wheat leaf samples

The ANOVA for chemical analysis of leaf tissues of wheat showed that the application of P significantly influenced leaf concentrations of P ($P<0.001$), Mg ($P<0.01$), SO_4 ($P<0.001$) and ratios of Ca:P and SO_4:P ($P<0.001$) but with non-significant effect on Na, K, Ca and K:Na, K:Ca and Ca:Na ratios (Table 2). Similarly, the addition of K significantly affected concentrations of leaf K ($P<0.05$), Na, SO_4, Ca ($P<0.01$) and K:Ca, K:Na ($P<0.01$), SO_4:P ($P<0.001$) and Ca:P ratio ($P<0.05$) while the effect was non-significant for P and Mg concentrations and Ca:Na ratio. The interaction of P and K significantly affected Ca ($P<0.05$) and Mg ($P<0.01$) concentrations and Ca:P and SO_4:P ($P<0.01$) ratios while non-significant on.

Table 1. Wheat yield and the summary of ANOVA on the effect of K and P treatments in saline-sodic soils

P_2O_5	K_2O	Grain yield	% increase over control	Dry matter yield	% increase over control
----------kg ha^{-1}--------		Mg ha^{-1}		Mg ha^{-1}	
0	0	1.77	-	12.4	-
	75	2.66	50	13.3	7
	150	3.33	88	15.3	23
60	0	2.65	50	12.9	4
	75	3.41	93	14.6	18
	150	3.45	95	15.6	26
120	0	3.19	80	15.3	23
	75	3.72	110	15.9	28
	150	3.85	118	20.0	61
Summary Analysis of Variation					
	SOV[1]	------------------------F value----------------------			
	P	18.4**		108.0***	
	K	57.2***		17.2***	
	P x K	4.55*		NS	

*, **, ***= Significant at P<0.05, 0.01 and 0.001, respectively and NS= Not significant
[1] Source of Variation

The chemical composition of wheat leaves indicated that P concentration decreased from 35.2 to 25.6 mmol (+) kg^{-1} with K1 and K2, respectively at P0, but increased to 59.3 59.3 mmol P kg^{-1}at P2 when compared with P0 (Table 2). The correlation of K concentrations [K] in leaves was positive with soil [K], showing increased bioavailability. The [Na] in leaves reduced to 83.4, and 85.3 mmol (+) kg^{-1} at K2 compared with 90.8 and 105.3 mmol (+) kg^{-1} Na at $P0_0$ and P2 at K0. These results suggested that P enhanced Na concentrations without K, while K1 and K2 at lowered [Na] in leaves at all P levels (Table 2). The K:Na ratios in leaves showed a positive correlation (R^2=0.655) with leaf [K], while negative correlation (R^2=0.90) with leaf [Na] (Fig. 1). A higher correlation (R^2=0.851) of wheat dry matter yield was noted with leaf K:Na ratio as compared to wheat grain yield (R^2=0.392) (Fig. 2).

The addition of diammonium phosphate might have suppressed the K uptake and K:Na ratios in leaves possibly due to the suppressing effect of NH_4 on K (Table 2). However, the leaf P was more positively correlated with wheat gain yield (R^2=0.53) than dry matter yield (R^2=0.46) (Fig. 3).

The [SO4] in leaves increased with the application of K_2SO_4but P addition tended to suppress SO_4. The highest SO_4 concentration of 493.8 mmol (-) $kg^{-1}$was found at K2P0 (Table 4). That is why a negative correlation (R^2=0.57) was found between SO_4:P and the leaf P concentration (Fig. 4). On the other hand, SO_4:P ratios in the leaves were increased with K_2SO_4application. Table 5 represents the analysis of variance (ANOVA) showing the influence of P and K on the chemical properties of wheat leaves. The [Mg] was not affected but the [Ca] and the Ca:P ratios increased at K_2P0_4 but decreased at higher P levels (P2) in wheat leaves.

Chemical composition of the pre- and post-harvest soil

Prior to the sowing of seed and the applications of the treatments, the individual soil samples were taken randomly from the whole experimental field at the depth of 0-30 cm and were thoroughly mixed to produce composite soil samples and were analyzed for the chemical properties (Table 3). Based on high values of pH (>8), EC (>4 dS m^{-1}), and SAR (>13), the soils were categorized as saline-sodic. The [K] and [P] were found lower than the normal levels (<2 mmol K L^{-1} and <7 mg P kg^{-1}), while Ca and Mg were found in moderate quantities. The high Na concentrations produced high SAR values of soil.

The composite soil samples were taken from each experimental plot after the harvesting of the crop and were analyzed for ionic concentrations (Table 4). The soil pH was highest in control plots as compared to plots treated with P2 and K2, while EC_e remained unchanged in all plots. The P treatments significantly (P<0.001) enhanced AB-DTPA extractable [P] but remained non-significant with K treatments (Table 5).

Table 2. Ionic concentrations and ratios in wheat leaf tissue after P and K applications in saline-sodic soils

P_2O_5	K_2O	P	Na	K	Ca	Mg	SO_4	K:Na	K:Ca	Ca:P	SO_4:P
----kg ha^{-1}-----		-----------------------mmol (±) kg^{-1}----------------------									
0	0	35.2	93.1	832.7	726.7	536.7	292.7	9.04	1.15	21.0	8.56
	75	33.2	79.0	834.3	736.7	496.7	466.7	10.6	1.14	22.2	14.0
	150	25.6	77.3	890.3	780.0	536.7	493.8	11.7	1.16	30.5	19.3
60	0	33.6	90.8	787.7	1030.0	633.3	287.9	8.73	0.78	30.7	8.68
	75	35.0	88.0	789.0	705.0	600.0	331.7	9.10	1.13	20.4	9.51
	150	32.3	83.4	843.0	733.3	666.7	337.9	10.2	1.16	22.9	10.5
120	0	56.9	105.3	704.7	936.7	480.0	352.4	6.76	0.75	16.6	6.29
	75	51.4	104.4	741.0	740.0	876.7	354.1	7.12	1.01	14.3	6.90
	150	59.3	85.3	847.3	666.7	750.0	438.6	10.1	1.28	11.5	7.56
Summary Analysis of Variance (ANOVA)											
	SOV[1]	--F-ratio---									
	P	63.4***	2.5 NS	4.7 NS	1.0 NS	19.8**	13.0*	3.2 NS	2.4 NS	38.8**	37.5***
	K	1.1NS	8.0**	6.0*	10.1**	3.5 NS	7.0**	12.1**	8.8**	4.0*	15.9***
	P x K	2.8 NS	0.9 NS	0.6 NS	3.6*	6.1*	2.2 NS	0.6 NS	2.6 NS	9.0***	7.0**

*, **, ***= Significant at P<0.05, 0.01 and 0.001, respectively and NS= Not significant
[1] Source of Variation

Table 3. Chemical composition of saline-sodic soil before cultivation

Soil Properties	Units	Range	Mean ± SD
pH	-	8.2 – 8.8	8.6 ± 0.2
EC_e	dS m^{-1}	4.2 – 9.4	5.5 ± 1.5
P	mg kg^{-1}	5.9 –11.2	7.7 ± 1.5
Na	mmol (+) L^{-1}	32.6 – 64.1	39.4 ± 9.8
K	mmol (+) L^{-1}	0.2 – 0.6	0.3 ± 0.1
Ca + Mg	mmol (+) L^{-1}	14.0 – 35.7	20.6 ± 6.7
Cl	mmol (-) L^{-1}	23.6 – 58.5	31.3 ± 10.7
SO_4	mmol (+) L^{-1}	3.2 – 6.2	4.2 ± 1.1
SAR	-	10.4 – 15.2	12.4 ± 1.4
$CaCO_3$	%	15.3 – 19.4	17.5 ± 1.2

The addition of P increased AB-DTPA extractable P and also the ratios of Ca:P, Cl:P and SO_4:P, while the soil pH, concentrations of Na, K, Ca, SO_4, SAR and ratios of Na:K, Na:Ca, and Ca:K were influenced by K. The interaction of P x K non-significantly affected all parameters with the exception of Cl:P and SO_4:P ratios (Table 5).

The [K] remained inconsistent at P1 and P2 alone, when averaged across (n=9) P levels but increased with combined P and K treatments (Table 4).The [K] in soil enhanced from 0.41 to 0.57 at P0, 0.36 to 0.56 at P1, and 0.42 to 0.65 mmol (+) L^{-1} at P2 with K2, respectively. It demonstrated that P addition did not affect soil [K] but with the addition of K treatments. The [Na] was found relatively higher at P0K0, P2K0, and P0K2, but decreased significantly ($P<0.05$) at P1K1 and P2K2 as compared to control (Table 4 and 5). Similarly, Na:K ratios were significantly ($P<0.001$) decreased from 87.8 to 43.7 at higher P and K, as compared with control (Table 4). A negative correlation (R^2=0.637) was found between soil Na:K ratios and soil [K] (Fig. 5).

The sodium adsorption ratio (SAR) was significantly ($P<0.001$) influenced by K application (Table 4) and hence a negative correlation (R^2=0.631) was observed between SAR values and soil [K] in saturation extract (Fig. 5). The elevated [Ca] at P0K2 seemed to have decreased Na concentrations as well as the SAR to 9.6 as compared to control. The SAR values showed a decreasing tendency to 8.80 and 10.6 and to 9.42 and 8.15 with P levels at K1 and K2 respectively, P1K2 and P2K2 as compared to control SAR values (12.0). Such trends indicated that P treatments at higher K levels substantially decreased SAR of the soil.

The concentrations of Ca were not influenced by P, but the ratio of Ca:P in soil were significantly ($P<0.001$) reduced (Table 5). Similarly, SO_4:P also decreased significantly ($P<0.001$), but P treatments did not influence the concentrations of Cl, CO_3, and HCO_3 (Table 5). A negative correlation (R^2=0.89) was observed between soil SO_4:P and the P treatments (Fig. 6). Similarly, there was a negative correlation (R^2=0.73) between Cl:P and AB-DTPA extractable soil P (Fig. 6).

Table 4. Chemical composition of saturated extracts of post-harvest (wheat) silty clay loams saline-sodic soils after P and K application

P_2O_5	K_2O	pH	EC_e	P	SAR	Na	K	Ca	Mg	Cl	SO_4	CO_3	HCO_3	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	Cl:SO_4	SO_4:P
----kg -	ha^{-1}-		dS m^{-1}	mg kg^{-1}		----------------------------mmol (±) L^{-1}--------------------------														
0	0	8.6	5.4	4.6	12.0	36.5	0.4	10.0	8.4	42.0	7.3	1.5	2.6	87.8	3.66	24.1	69.1	284.4	5.6	50.4
	75	8.6	5.2	6.1	10.2	29.6	0.5	9.83	7.2	31.4	7.9	1.4	2.9	57.9	3.11	18.8	49.7	164.0	4.0	40.4
	150	8.4	5.8	6.2	9.6	32.3	0.6	12.2	11.0	50.2	9.1	1.6	3.2	57.2	2.71	21.3	60.4	247.9	5.4	45.3
60	0	8.6	5.0	8.3	12.1	31.8	0.3	8.8	5.2	41.9	7.6	2.0	2.8	89.5	3.62	24.7	32.8	154.1	5.5	28.4
	75	8.4	4.5	6.0	8.8	26.0	0.4	9.0	8.6	34.9	8.2	1.4	3.0	71.2	2.96	24.5	48.1	193.0	4.4	43.9
	150	8.4	5.1	7.5	9.4	29.5	0.6	11.2	8.5	41.4	8.4	1.5	2.7	53.5	2.71	19.9	47.3	172.5	4.8	35.8
120	0	8.6	5.4	9.6	11.5	35.2	0.4	10.9	7.8	37.1	8.0	1.7	3.3	84.6	3.27	26.1	35.2	121.7	4.5	26.1
	75	8.4	5.8	9.4	10.6	34.1	0.6	10.7	9.8	46.8	9.3	1.8	2.8	58.9	3.18	18.6	35.5	155.4	4.9	31.0
	150	8.2	5.5	11.7	8.1	28.3	0.7	15.1	9.9	34.7	9.4	1.4	3.1	43.7	2.00	23.0	40.2	92.1	3.6	25.1

Table 5. Summary analysis of variance (ANOVA) on the effect of P and K on the ionic concentrations and ratios of saturation extracts of silty clay loam saline-sodic soils

	Variables Analyzed												
SOV	pH	AB-DTPA P	Na	K	Ca	SO_4	SAR	Na:K	Na:Ca	Ca:K	Ca:P	Cl:P	SO_4:P
	-----F-ratio-----												
P	0.32^{NS}	92.4***	5.02^{NS}	3.85^{NS}	1.38^{NS}	1.09^{NS}	0.57^{NS}	3.47^{NS}	0.81^{NS}	0.52^{NS}	12.7*	10.9**	134.3***
K	7.12*	2.17^{NS}	7.43**	26.2***	4.62*	5.90*	33.2***	38.6***	12.8**	4.14*	0.49^{NS}	0.28^{NS}	0.81^{NS}
P x K	0.61^{NS}	2.51^{NS}	2.58^{NS}	1.45^{NS}	0.20^{NS}	0.33^{NS}	2.83^{NS}	1.01^{NS}	0.80^{NS}	1.60^{NS}	2.13^{NS}	3.03*	4.04*

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

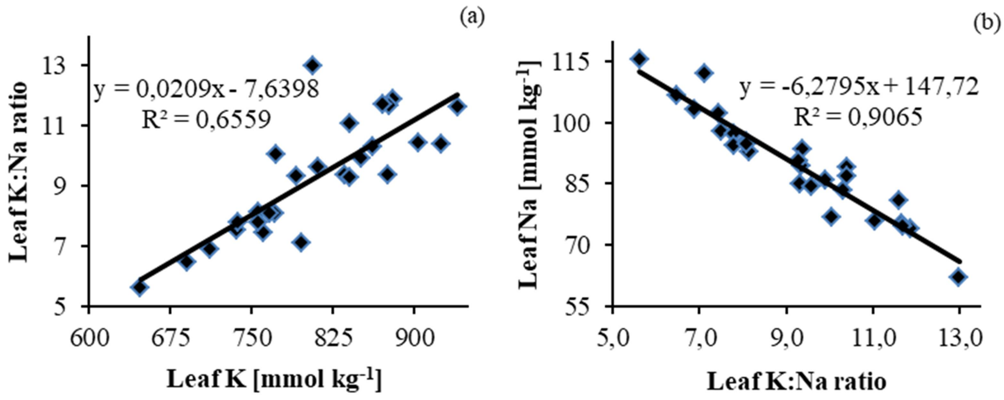

Figure 1. Leaf K:Na ratio in relation to leaf [K] (a) and leaf [Na] in relation to leaf K:Na ratio (b) in saline-sodic soil

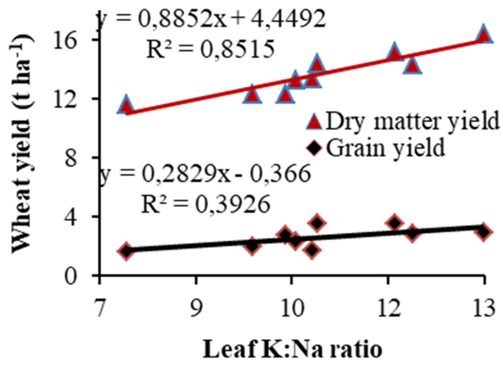

Figure 2. Grain and dry matter yield of wheat in relation to K:Na ratio in leaf tissue of wheat grown in K_2SO_4 treated (n=9) saline-sodic soil

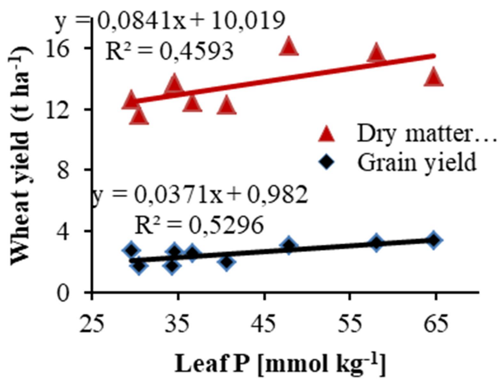

Figure 3. Grain and dry matter yield in relation to P concentrations in leaf tissue of wheat grown on P_2O_5 treated (n=9) saline-sodic soils

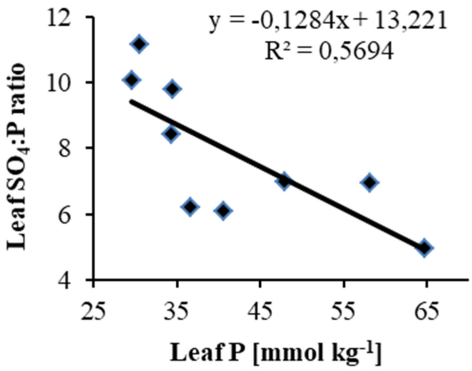

Figure 4. Leaf SO_4:P ratios in relation to [P] leaf tissue of wheat grown on P_2O_5 treated (n=9) saline-sodic soil

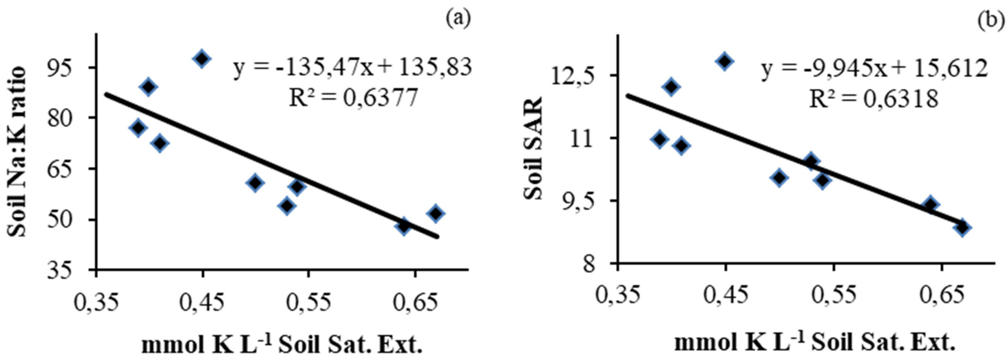

Figure 5. Soil Na:K ratio and SAR in relation to [K] in saturated extracts in K_2O treated (n=9) saline-sodic soil

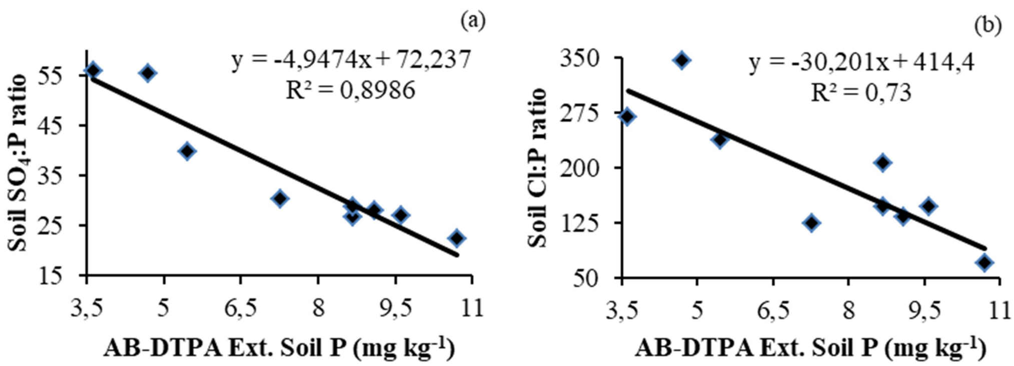

Figure 6. Soil SO_4:P (a) and Cl:P ratios (b) in relation to AB-DTPA ext. soil P in P_2O_5 treated (n=9) saline-

DISCUSSION

Wheat growth as influenced by P and K application

The findings of this study indicate a potential contribution of P and K to crop nutrition and growth. The salinity and sodicity are responsible to disturb the nutrient balance of the crops, resulting in stunted growth and poor yields. The deficiency of P and K nutrition and/or the competition of these nutrients with other ions restricts their uptake by plants under salt-affected soil conditions. The optimization of P and K fertilization can improve plant metabolism to tolerate salt stress resulting in higher yields of crops. In the present study, the grain yield of wheat increases consistently with increasing P and K levels in salt-affected soils. The combined P and K applications resulted in the highest grain and dry matter yields when compared with control. Phosphorus had a greater effect on grain yield as compared to the effect of K in saline-sodic soil. SINGH et al. (2006) confirmed the positive response of wheat to supplementary P in the presence of Na which resulted in higher grain yield at higher salt concentrations.

Relatively lower wheat yields at control treatments are caused by the effect of Na-salts, while increases in yield are associated with high K uptake by wheat (MEHDI et al., 2007). KRISHNASAMY et al. (2014) examined four wheat cultivars under varying K and Na levels and reported that high Na concentration reduced wheat growth of all cultivars at low K, but adequate K maintained a higher number of tillers in most cultivars.

Nutrient uptake and wheat yield

Analysis of leaf tissues is important to monitor nutrient deficiencies and uptake under applied treatments, in saline-sodic soil conditions. The application of P and K treatments influenced the chemical composition of the leaf. Plants P concentrations [P] were increased with P application. Similar results were reported by NIAZI et al. (1990). Also, the leaf K concentrations were significantly increased with the application of K_2SO_4 which helped to alleviate crop stress. There was a positive correlation between leaf K and soil K concentrations. The addition of K reduced leaf [Na] while increasing trend in [Na] was observed when P was applied alone. The depressing effect of K fertilizer on leaf [Na] in wheat, sugar beet, and maize crops is reported by HUSSAIN et al. (2015).

A positive correlation K:Na and leaf [K] and with the DM yield of wheat suggested a depressed Na uptake which promoted the yield of wheat in the present study. If the whole plant parts are compared, the leaves and stem contain much higher concentrations of K than roots or grains (NABIPOUR et al., 2007). Uptake and accumulation of K by plant roots are strongly inhibited by high Na concentrations (NETONDO et al., 2004). The K supply enhanced [K] and K:Na in leaves and shoot of all wheat cultivars, and high net photosynthesis rate in fully expanded leaves of wheat than at low K levels (KIRSHNASAMY et al., 2014).

A distinct relationship between wheat grain yield and the [P] in leaves was observed. The SO_4 uptake was depressed by P application but K treatments as K_2SO_4 enhanced concentrations of SO_4 ratios in leaf tissue. The Ca uptake was enhanced with K at P0 but inhibited at P1 and P2. There was no difference in Ca:P at P0K0 and K1, but increased at K2, substantially with increasing P levels. A complex interaction process may be involved among Ca, K, SO_4, and PO_4 in the soil which affected uptake and inhibition of ions by plants. Application of K_2SO_4 enhanced Ca concentrations without P, which might have favored the development of soluble complexes of $CaSO_4$ in saline soils supporting Ca uptake by plants (SPOSITO, 1989). Results suggest that interactions of applied P and K fertilizers with Na, Ca, Cl and SO_4 mitigate the influence of salts and promote crop growth in saline-sodic soils.

Influence on soil chemical composition

Phosphorus is rendered insoluble and immobilized in a saline soil solution because of the effect of high ionic strength (NISTE et al., 2014). In our study, the application of P had a significant effect on soil [P] as well as Ca:P, Cl:P, and SO_4:P ratios. Application of K had a significant influence on pH, and concentrations of Na, K, Ca, SO_4, SAR values and ratios of Na:K, Na:Ca, and Ca:K. Concentrations of K in soil remained unchanged with the addition of P alone but increased at K1 and K2. The soil P availability increased with P application which supported wheat yield, but it depressed other macronutrients like K and N, as reported in various studies (HAO et al., 2005). The P and K reduced Na:K ratios when compared with control. A negative correlation (R^2=0.63) was found between soil [K] and soil Na:K ratios. Adding higher levels of K and P significantly lowered Na:K ratios as compared to control. The salt-tolerant crops tend to retain high [K] while excluding Na from the shoots (FLOWERS; HAJIBAGHERI, 2001). Moderate native [K] sometimes even becomes unavailable to plants because of high competition with Na in soils. Therefore, K application to such soil may enhance its selectivity and bioavailability for the plants. Application of K to a highly saline soil promoted dry matter yield of barley, supported high accumulation of K and maintained lower Na:K ratio which also suggested positive role of K in mitigating salt stress (ENDRIS; MOHAMMAD, 2007).

The K treatment also promoted higher Ca concentrations in soil and reduced Na when compared with control. Similarly, the SAR values were decreased with P at higher K treatments. The application of K as K_2SO_4 increased SO_4 in soil but the application of P lowered SO_4:P ratios in soil. A negative correlation ($R^2 = 0.898$) was found between soil SO_4:P ratios and the P treatment. NISTE et al. (2014) reported that Cl inhibits more N than SO_4, therefore the application of S as K_2SO_4 to salt-affected soils improves concentrations of N, P, and K which supports higher wheat yield. Application of gypsum in combination with K fertilizers to saline-sodic soils irrigated with saline water amended soil chemical properties and facilitated wheat growth. The correlation between soil Cl:P ratios and soil P was found negative (R^2=0.73). The Cl toxicity of salt-affected soils was minimized with P treatment.

CONCLUSIONS

The study demonstrates that the addition of P and K fertilizers enhanced both grain and dry matter yields of wheat. Effect of P treatment on grain yield was more profound than K application but dry matter yield increased more with K when compared with control. Whereas the combined effect of high P and K dozes (120 kg P_2O_5 ha^{-1} and 150 kg K_2O ha^{-1}) was more pronounced in grain yield showing 118% increases when compared with P or K alone. The P and K improved leaf K, P, Ca, and SO_4 concentrations, increased K:Na and SO4:P ratios while reducing Na and Cl concentrations when compared with control values. The dry matter yield correlated more positively with K: Na ratios in leaf. The applied K amended soil K, Ca, SO_4 concentrations, and reduced Na levels, SAR, and Na:K in saline-sodic soils, while P application improved soil P while decreasing the Cl levels in the soil. This study suggested that applications of K and P fertilizers bring positive changes in soil-plant-nutrients dynamics and hence plant yield in a saline environment.

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RESUMO: A deficiência de nutrientes é um fator limitante em solos salino-sódicos, resultando em baixa produção agrícola. O estudo investigou a resposta do trigo ao P e K adicionados ao solo. O K foi aplicado em 0 (K0), 75 (K1), 150 (K2) kg K_2O ha^{-1} como K_2S0_4 e em (0 (P0), 60 (P1), 120 (P2) kg P_2O_5 ha^{-1} como $(NH_4)_2HPO_4$ em três repetições sob delineamento de blocos completos casualizados (RCB) de dois fatores. Ambos os tratamentos aumentaram significativamente o rendimento de grãos de trigo (118%) e de matéria seca (60%) em P2K2 em comparação com o controle. Os tratamentos com P afetaram significativamente o P foliar, Mg, SO_4, as razões Ca:P, SO_4:P e o P do solo, e as razões Ca:P, Cl:P e SO_4:P, enquanto K no K foliar, Na, Ca, concentração de SO_4, razões K:Na, K:Ca, SO4:P, Ca:P e pH do solo, Na, K, Ca, concentrações de SO_4, SAR, razões Na:K, Ca:K e Na:Ca. O Na da folha foi reduzido para 85,3 mmol (+) kg^{-1} em K2 em comparação com 105,3 mmol (+) kg^{-1} em P2K0. Correlação negativa (R^2 = 0,906) do K:Na na folha foi encontrada com a concentração de Na na folha. A correlação da matéria seca foi maior (R^2 = 0,851) com a relação K:Na da folha do que rendimento de grãos (R^2 = 0,392). Conclui-se que a adição de K e P apresenta efeitos benéficos na melhoria da nutrição da cultura e na produtividade do trigo em solo salino-sódico.

PALAVRAS-CHAVE: Crescimento do trigo. P. K. Região semiárida. Região árida. Solo salino-sódico.

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