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RESEARCH ARTICLE

Assessment of P-Zn Interactive Effects on Growth, P and Zn Uptake by Wheat in Salt-Affected Soil

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ABSTRACT

Soils of Pakistan have high pH, free lime ($CaCO_3$) contents and squat organic matter. Subsequently, nutrient maladies are the most serious threat to crop plants predominantly in salt-affected soils. A controlled investigation was performed to assess P-Zn interactive effects on growth, P and Zn uptake by wheat in natural salt-affected soil. Soil was collected from 0-15 cm layer of a salt-affected field around Faisalabad. The treatments comprised of different combinations of four rates of P (i.e. 0, 300, 600 and 900 mg P per pot) and three rates of Zn (i.e. 0, 60 and 120 mg Zn per pot) including salt-affected control. Thus, there were a total of eight treatments settled in completely randomized design replicated thrice. With applied treatments, a significant ($P \leq 0.05$) differences for number of fertile tillers of wheat, spike length, height of infertile tillers, number of grains per spike, P and Zn uptake by wheat straw and grains were noted. The maximum number of fertile tillers, grains per spike, maximum height of infertile tillers and P uptake in wheat straw was recorded with control closely followed by T_5 i.e. 900 mg P + 60 mg Zn per pot. Maximum P uptake by wheat grains, Zn uptake by wheat straw and grains was recorded with T_5. Therefore, regarding P-Zn interactive effects, application of 900 mg P + 60 mg Zn per pot gave the appropriate combination of P and Zn for wheat in salt-affected soil.

INTRODUCTION

Salinity is a serious problem of soil degradation that limits crops productivity in many regions of the world (Rengasamy, 2006). Crop plants performance, usually articulated as yield of crop, vegetative and reproductive biological yield of plant or quality of crop, might be undesirably influenced by soil/water salinity persuaded nutritional maladies. These maladies might be owing to the influence of soil/water salinity on nutrient phyto-availability, comparative uptake, translocation or apportioning within the plant parts (Ali et al., 2006; Nasim et al., 2008). In this regard, the development of salt-tolerant crop species/ genotypes having high nutritive value and productivity are mandatory to ensure global food security and needs of an increasing world population (Zafar et al., 2015). The proper combination of essential nutrients helps the crop plants to grow better and cope with salinity.

Phosphorus (P) is a major essential element that is required by plants for their growth and reproduction.

The P is utilized by plant for the storage of energy and its transfer, conservation and transmission of genetic code, and is the basic organizational constituent of cells and various biochemical molecules (Mishra, 2012). When P fertilizer is added, calcareous and alkaline soils can rapidly and firmly adsorb its large amount. Soil solution P is the instantaneous source of plant available P and critical concentration may vary from soil to soil and even for the same crop. So, it is necessary to maintain a critical concentration of P in soil solution to attain maximum yields of crops (Iqbal et al., 2012).

Among essential micronutrients, the Zinc (Zn) plays a vital role in growth of plant and regulates numerous metabolic reactions under saline conditions (Tahir et al., 2010). Plants take up Zn as the Zn^{2+} ion and diffusion is believed to be the dominant tool for Zn^{2+} transport to different plant parts. Due to continuous removal of Zn from soils, deficiency in a variety of crops is widespread; resulting in severe reduction in yields (Graham and Rengel, 1993). Moreover, in calcareous salt-affected soils, the bioavailability of Zn is predominantly low and plants growing on such soils frequently bare Zn deficiencies (Khoshgoftarmanesh et al., 2004).

The effects of salinity on the uptake of P and Zn in plants are relatively complex. Salinity could increase P uptake by plants, as plants in saline media were found more sensitive to P toxicity and consequently Zn deficiency (Gunes et al., 1999). Salinity can alter the micro nutrients absorption in plants, conditioned to the kind of crop and rates of salinity (Hu and Schmidhalter. 2001). According to Helmy and Ramadan (2009), application of Zn is useful for increasing plant growth and yield under saline conditions. In sodic soils, prevalent deficit of Zn and significant responses to applied Zn are also reported on production of diverse crops (Qadar, 2002). In high salinity, the use of Zn improved the growth of wheat (Khoshgoftarmanesh et al., 2006).

Moreover, in salt-affected soils, P-Zn interactive effects in crops fall in two sets, i.e. whether increasing P application decreases, or does not decrease Zn uptake in plants. Application of excessive P may also be an intention for reduction in the availability of Zn in different tissues of plants including grains (Iqbal et al., 2010). Earlier research has indicated that a low Zn with a high P application noticeably increased P uptake in plants, which might results in toxicity of P and give rise to symptoms approximating deficiency of Zn (Iqbal et al., 2012).

Wheat is grown throughout the world to fulfill ever increasing population and it is the staple food of people of Pakistan (Zafar et al., 2015). Of the total (79.61 mha) geographical area of Pakistan, 31.23 mha is cultivated, of which 11.5 mha is salt-affected (FAO, 2005). Wheat is grown on an area of 9.18mha in Pakistan with a total production of 25.4 million tons and an average of 2423 kg ha^{-1} (GOP, 2015). Wheat has been categorized as moderately salt-tolerant crop (Naz et al., 2015) but increasing concentration of salts in growth medium results in less height and tillering capacity compared to non-saline control (Shafqat et al., 1998).

Moreover, to-date much research work is done on the combined assessment of P-Zn interactive effects on different crops, however, there is lack of information about P-Zn effect on growth, P and Zn uptake by wheat in naturally salt-affected soil. Therefore, this study was conducted to investigate the P and Zn uptake responses of wheat under saline conditions, which could help to recognize the role of P and Zn interaction regarding nutritional quality of crops plant under salt stress.

MATERIALS AND METHODS

The present pot study was aimed with an objective to investigate the P and Zn uptake responses of wheat under saline conditions at Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Salt-affected soil was collected from saline area at Chak No. 220/G.B., Cheenewala, 15 km from Jhung road, Faisalabad. Before initiation of the pot study, soil was air–dried, passed through 2 mm sieve, thoroughly mixed and analyzed for physic-chemical properties following the methods prescribed by Iqbal et al. (2015).

The soil was found sandy clay loam (63.3% sand, 15% silt and 21.7% clay) having pH_s 8.02, electrical conductivity of saturated paste extract (ECe) 6.04 dS m^{-1}, sodium adsorption ratio (SAR) 20.07, saturation percentage (SP) 29.43%, CEC 9.31 $cmol_c$ kg^{-1}, $CaCO_3$ 6.21% and organic matter (OM) 0.86%. The AB-DTPA extractable P and Zn were 120.39 and 1.96 mg kg^{-1} soil, respectively.

There were eight different treatments arranged in completely randomized design (CRD) replicated thrice. In each pot, 12 kg soil was filled. The treatments were as follows: T_1 = Control (salt-affected soil, SAS), T_2 = SAS + 300 mg P per pot, T_3 = SAS + 300 mg P + 60 mg Zn per pot, T_4 = SAS + 600 mg P + 60 mg Zn per pot, T_5 = SAS + 900 mg P + 60 mg Zn per pot, T_6 = SAS + 300 mg P + 120 mg Zn per pot, T_7 = SAS + 600 mg P + 120 mg Zn per pot and T_8 = SAS + 900 mg P + 120 mg Zn per pot.

Single superphosphate was used as a source of P while $ZnSO_4.7H_2O$ was used for Zn. The N and K fertilizers were applied at 600 and 150mg per pot as urea and potassium sulfate, respectively. The half of the N and whole P, K, Zn (by making solution), were applied at sowing while the remaining nitrogen was applied at 30 and 45 days after sowing in two equal splits. In each pot, fifteen seeds of wheat cultivar Inqlab-91 were sown. After one week of germination, plants were thinned to five. The thinned plants were crushed into respective pots. The pumped ground water was used to irrigate the wheat.

The wheat growth data regarding number of fertile tillers, spike length, height of infertile tillers and number of grains per spike were recorded. Wheat straw and grain samples were analyzed for P and Zn uptake. Plant samples were digested in di-acid digestion mixture (HNO_3 + $HClO_4$), from which P was determined with the help of UV-vis spectrophotometer and Zn via flame atomic absorption spectrometry as described by Chapman and Pratt (1962).

Phosphorus or Zn uptake by wheat straw or grains was calculated by the following formula (Gill et al., 2004).

P or Zn uptake (mg per pot) by wheat straw = straw dry matter (g per pot) × P or Zn concentration in straw (mg g^{-1})

P or Zn uptake (mg per pot) by wheat grains = wheat grains (g per pot) × P or Zn concentration in grains (mg g^{-1})

Statistical analysis

All the obtained data were statistically analyzed using M-STATC Version 1.10 computer software package. When there was a significant difference ($P \leq 0.05$) among treatments for an attribute, Least Significant Difference (LSD) was calculated for comparisons of their means (Steel et al., 1997).

RESULTS

Growth and yield components of wheat

The data regarding the impact of applied treatments on the number of fertile tillers, spike length, height of infertile tillers and number of grains per spike of wheat variety Inqalab-91 in salt-affected soil is described in Table 1. The data indicated that the treatments had a significant ($P \leq 0.05$) effect on these growth and yield indices of wheat. The maximum number of fertile tillers of wheat, spike length, height of infertile tillers and number of grains per spike was recorded with control treatment. The minimum number of fertile tillers was recorded with T_7 and the decrease in the number of fertile tillers over that of the control was 52.21%. With T_6 the lowest spike length and height of infertile tillers were observed and decrease over that of the control was 39.51% and 20%, respectively. The least number of grains per spike was recorded with T_3 and decrease was 75.46 % over that of control (Table 1).

Phosphorus and Zn uptake by wheat

In present study, treatments significantly affected P uptake by wheat straw (Table 2), being maximum (5.59 mg per pot) for the control treatment and the decrease was 22.61% with T_2 compared to that of the control. However, the uptake of P by wheat grain was maximum (123 mg per pot) with T_5 and increase was higher by 27.92 % over that of control plants (Table 2). Whereas, minimum P uptake by wheat straw and grains was recorded with T_3, 300 mg P + 60 mg Zn per pot was applied (Table 2). Likewise, applied treatments significantly affected Zn uptake by wheat straw and grains (Table 2), being maximum with T_5. Minimum Zn uptake (0.11 g per pot) by wheat straw was recorded with T_3 and decrease was 46.54% over that of the control (Table 2). However, minimum Zn uptake (0.33 mg per pot) by wheat grains was recorded with T_4 receiving 600 mg P + 60 mg Zn per pot and decreased by 78.16 % over that of the control (Table 2).

DISCUSSION

The mechanisms of salinity-fertility interaction are not clear yet in earlier reports. According to Yermiyahu et al. (2008), there may be three types of interaction between two factors: antagonistic, additive or synergistic. However, relationships between salinity and P-Zn interaction are relatively multifarious and difficult to apprehend due to numerous factors being convoluted in P or Zn uptake response of plants, which might vary owing to soil or water salinity and their varying levels. In present study, P-Zn interactive effects on growth and yield components of wheat as well as P and Zn uptake responses of wheat under saline conditions were investigated.

Table 1: P-Zn interactive effects on no. of fertile tillers, spike length (cm), height of infertile tillers (cm) and no. of grains per spike of wheat in salt-affected soil

Treatment	No. of fertile tillers	Spike length (cm)	Height of infertile tillers (cm)	No. of grains per spike
T_1 = Control (salt-affected soil, SAS)	7.66^{a}	9.34^{a}	20.95^{ab}	29.79^{a}
T_2 = SAS + 300 mg P per pot	6.33 abc (-17.36)	8.01 bc (-14.24)	21.27 ab (1.53)	24.99 a (-16.11)
T_3 = SAS + 300 mg P + 60 mg Zn per pot	4.33 d (-43.47)	6.35 de (-32.01)	24.31 a (16.04)	7.31 d (-75.46)
T_4 = SAS + 600 mg P + 60 mg Zn per pot	5.00 cd (-34.72)	7.37 cd (-21.09)	24.28 a (15.89)	7.57 d (-74.58)
T_5 = SAS + 900 mg P + 60 mg Zn per pot	6.66 ab (-13.05)	8.80 ab (-5.78)	23.30 ab (11.22)	29.41 a (-1.27)
T_6 = SAS + 300 mg P + 120 mg Zn per pot	5.33 bcd (-30.41)	5.65 e (-39.51)	16.76 c (-20.00)	11.20 cd (-62.40)
T_7 = SAS + 600 mg P + 120 mg Zn per pot	3.66 d (-52.21)	7.04 cd (-24.63)	20.51 b (-2.10)	19.88 b (-33.26)
T_8 = SAS + 900 mg P + 120 mg Zn per pot	4.33 d (-43.47)	6.53 de (-30.09)	22.02 ab (5.11)	14.05 c (-52.83)
$LSD_{0.05}$	1.54	1.20	3.15	5.37

Values in parenthesis are percent increase (+) or decrease (-) over that control treatment. Means sharing dissimilar letter in a column are statistically significant ($P \leq 0.05$, n = 3).

Table 2: P-Zn interactive effects on P and Zn uptake (mg per pot) by wheat straw and grains in salt-affected soil

Treatment	P uptake (mg per pot) by wheat straw	P uptake (mg per pot) by wheat grains	Zn uptake (mg per pot) by wheat straw	Zn uptake (mg per pot) by wheat grains
T_1 = Control (salt-affected soil, SAS)	5.59^{a}	96.15^{b}	0.21^{b}	1.53^{bc}
T_2 = SAS + 300 mg P per pot	4.32 ab (-22.61)	119.9 a (24.70)	0.12 bc (-38.55)	1.18 c (-22.35)
T_3 = SAS + 300 mg P + 60 mg Zn per pot	2.28 c (-59.10)	21.83 d (-77.29)	0.11 c (-46.54)	0.39 d (-74.28)
T_4 = SAS + 600 mg P + 60 mg Zn per pot	3.04 bc (-45.57)	24.79 d (-74.21)	0.18 bc (-11.58)	0.33 d (-78.16)
T_5 = SAS + 900 mg P + 60 mg Zn per pot	3.09 bc (-44.73)	123.00 a (27.92)	0.46 a (119.34)	2.01 a (31.69)
T_6 = SAS + 300 mg P + 120 mg Zn per pot	2.67 c (-52.22)	88.64 bc (-7.81)	0.16 bc (-19.96)	1.66 ab (8.88)
T_7 = SAS + 600 mg P + 120 mg Zn per pot	2.58 c (-53.72)	71.29 c (-25.85)	0.12 bc (-39.02)	1.16 c (-23.98)
T_8 = SAS + 900 mg P + 120 mg Zn per pot	2.58 c (-53.83)	79.24 bc (-17.58)	0.11 c (-44.74)	1.41 bc (-7.64)
$LSD_{0.05}$	1.38	21.06	0.077	0.431

Values in parenthesis are percent increase (+) or decrease (-) over that control treatment. Means sharing dissimilar letter in a column are statistically significant ($P \leq 0.05$, n = 3).

In control, maximum wheat growth seems associated with soil used in present pot experiment had sufficient soil P to support normal plant growth and ultimately yield. El-Mahi and Mustafa (1980) also reported that saline soils generally contain more P than non-saline soils. Iqbal et al. (2012) also reported that sodic and saline-sodic soils usually contain higher available P than the normal soils because high concentration of $NaCO_3$ results in the formation of $NaPO_4$, which is more soluble (Ghafoor et al., 2004).In comparison with T_1, number of fertile tillers of wheat, spike length, number of grains per spike decreased with $T_2$where 300 mg P per pot was applied to the salt-affected soil. This might be due to the reason that phosphates and chlorides are absorbed by essentially the same mechanism; excess concentration of Cl^-, as found in highly saline soils, may adversely affect the absorption of phosphates because of competitive inhibition (Chabra et al., 1976). As a result, wheat growth is decreased by soil salinity. According to Steppuhn and Wall (1997) root zone salinity could affect the growth of wheat and may decrease number of fertile tillers per plant and hence the yield. Nieman and Clark (1976) reported that in the presence of higher concentration of orthophosphate salinity damaged the plant mechanisms in maize and results in accumulation of P. However, with 60 mg Zn per pot at increasing rates of P (300, 600 and 900 P per pot) significantly increased fertile tillers, spike length and height of infertile tillers of wheat. It has been reported that moderate soil salinity may even interact positively with the plant nutrients and could enhance the metabolism resulting in normal plant growth (Yermiyahu et al. 2008; Iqbal et al., 2012). Addition of 60 mg Zn per pot at increasing rates of P (300, 600 and 900 P per pot) non-significantly (except in T_5) affected the number of grains per spike of wheat. There might be grain loss, empty spikelets per spike and less number of grains per spike due to salinity and **toxicity**. With T_5, yield of wheat increased due to the reason that moderate soil salinity may even interact positively with the plant nutrients and could enhance the metabolism resulting in normal plant growth (Dregne and Mojallali, 1969; Hassan et al., 1970). Murtaza et al. (2009) reported that wheat grain yield was significantly affected by different P application rates. With 120 mg Zn per pot at increasing rates of P (300, 600 and 900 P per pot), there a decreasing trend was observed in number of fertile tillers, spike length and height of infertile tillers. Application of 60 mg Zn per pot at increasing rates of P (300, 600 and 900 P per pot), number of grains per spike of wheat was affected in-consistently. These might be due to an antagonistic effect between P and Zn at their higher rates in the presence of salinity. Higher concentration of P in plants could interrupt different metabolic processes like photosynthesis, respiration and N assimilation, ultimately resulting in poor growth leading to low biomass and yield. Bernstein et al. (1974) reported that salinity effect is greater at higher fertility states of soil, indicating that salts used to increase fertility may themselves have an additive effect to adverse response of salinity.

The maximum P uptake by wheat straw and grains was recorded for pots where only salt-affected soil (ECe 6.04 dS m^{-1}, SAR 20.07, pHs 8.02) was used and noP or Zn treatment was applied. However, maximum P uptake by wheat grains was recorded with T_5 which might be attributed to the reason that soil used in present study had already sufficient P (Table 2) to support normal plant growth. El-Mahi and Mustafa (1980) reported that saline soils contain more P than non-saline soils. It was observed that P uptake by wheat straw decreased in pots where 300 mg P per 12 kg^{-1}soilwas applied to the salt-affected soil. This might be due to the reason that phosphates and chlorides are absorbed by essentially the same mechanism, excess concentration of Cl^-as found in highly saline soils may adversely affect the uptake of phosphates because of competitive inhibition (Chabra et al., 1976). As a result, percent P concentration and P uptake by plants are generally decreased by soil salinity. Decrease in P uptake by wheat grains in salt-affected soil might also be due to decreased P uptake by wheat grains from the native pool. Increasing soil salinity generally reduce root growth, which in turn could decrease surface area of the roots in contact with P in soil and thus may result in less uptake of P (Khalil et al., 1967; Hassan et al., 1970). Fine and Carson (1954) concluded that Ca^{2+} and Na^{+} decreased the yield of barley and oat, P uptake and P concentration in plant material under saline soil conditions. Addition of 60 mg Zn per pot with increasing rates of P (300, 600 and 900 P per pot) slightly increased P uptake by wheat straw and grains. It seems that P concentration was depressed by salinity as well as by Zn application. Mousavi (2011) demonstrated that Zn application at low rates of P would decrease P uptake by plant parts. Although at a given level of Zn, when high rates of P were applied to soil, there was a slight increase in P uptake by wheat straw and grains. Application of 120 mg Zn per pot with increasing rates of P (300, 600 and 900 P per pot) considerably decreased P uptake by wheat straw and grains. It might be due to antagonistic effect between P and Zn at their higher application rates in the presence of salinity. Bernstein et al. (1974) reported that the salinity effect is greater at higher fertility status, indicating that salts used to increase fertility may themselves have an additive effect to adverse response of salinity. Gunes et al.(1999) reported that P uptake decreased with salinity but differences were statistically similar in saline conditions.

Maximum Zn uptake by wheat straw and grains were recorded from pots receiving 900 mg P + 60 mg Zn per pot might be due to the reason that at a certain level of salinity and Zn, the higher amount of applied P responded positively, resultantly, wheat plants would become more efficient to withstand salinity (Mass and Hoffman, 1977). Wheat plants attained better growth by responding to high P. As metabolism increased, Zn uptake increased due to catalytic effects. Imtiaz et al. (2006) reported that applied P had a inconstant influence on Zn uptake by wheat because the uptake of Zn was increased by exogenously applied 25 µg P g^{-1} soil (moderate), owing to better growth at this level of applied P. Hu and Schmidhalter (2001) reported that changes in Zn, Mn, Fe and B concentration in plants in salinity as influenced by the status of macronutrients, salinity and the organ of plants. Nazar et al. (2012) concluded that an increase in P and Ca concentration in the growth medium decreased concentrations of Zn, Mn and B under normal soils. Our results are in contrast with their work because salt-affected soil was used in present experiment. The uptake of Zn, Fe, Mnand Cu generally increases in crop plants insaline conditions (Martinez-Ballesta et al., 2010). Hassan et al. (1970) also reported that Zn and Mn concentration in corn and barley increased with an increase in salinity. Addition of 60 mg Zn per pot with increasing rates of P (300, 600 and 900 P per pot) significantly increased Zn uptake by wheat straw and grains. It has been reported that moderate soil salinity may even interact positively with the plant nutrients and could enhance metabolism resulting in high dry matter production and nutrient uptake (Dregne and Mojallali, 1969; Hassan et al., 1970). Application of 120 mg Zn per pot with increasing rates of P (300, 600 and 900 P per pot) considerably decreased Zn uptake by wheat straw and grains. It might be due to antagonistic effect between P and Zn at their higher rates in the presence of salinity. Burleson and Page (1967) and Warnock (1970) suggested that P interact with Zn at their higher rates and reduced its mobility within plant. The salinity effect is greater at the higher fertility status, indicating that salts used to increase fertility may themselves have an additive effect to adverse response of salinity (Yermiyahu et al. 2008; Iqbal et al., 2012).

Conclusion

During reclamation of saline soils, application of phosphatic fertilizers needs much care, especially P-Zn interactions should be considered. From results of present study it was observed that addition of 900 mg P + 60 mg Zn per pot seems an optimum dose for maximum growth and yield of wheat under moderately salt-affected soil conditions. Nevertheless, adverse effect of salinity can be decreased by increasing the P-Zn ratio of the salt-affected soil. However, the results need to be confirmed under field conditions and economic feasibility should be worked out.

Authors' contributions

All authors have equally contributed in the research and manuscript preparation.

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