PHOSPHORUS AND ZINC APPLICATION IMPROVES RICE PRODUCTIVITY

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ABSTRACT: Rice is an important cash crop and is one of the main export items of Pakistan. The yield of rice per hectare is very low in Pakistan as compared to other rice growing countries. This could be due to the fact that the soil of Pakistan is low in organic matter, nitrogen (N), phosphorus (P) and also some micronutrients particularly zinc (Zn) in rice growing areas. For this purpose, a field trial was conducted to check the effects of P and Zn application on rice yield. Rice cultivar Super Basmati was used as test crop which was sown under four levels of P viz. 0, 40, 80 and 120 kg ha^{-1} and four levels of Zn viz. 0, 8, 12 and 16 kg ha^{-1}. Results of the study elucidated that P application @ 80 kg ha^{-1} and Zn application of 12 kg ha^{-1} was highly beneficial to improve the rice productivity. Moreover, P application at higher level significantly lowered the Zn uptake and thus caused Zn deficiency which could be overcome by the higher level of Zn application. Therefore in order to get higher paddy yield, it should be fertilized @ 80 and 12 kg ha^{-1} of P and Zn, respectively.

Key words: Zn application, paddy yield, 1000-grain weight, P uptake.

INTRODUCTION

Rice (*Oryza sativa* L.) is an essential cash crop and one of the main export items of Pakistan but the average per hectare yield of rice is very low in Pakistan compared with other rice growing countries of the world (Economic Survey of Pakistan, 2011). This could be due to the fact that the soil of Pakistan is low in organic matter, nitrogen (N), phosphorus (P) and also some micronutrients particularly zinc (Zn) in rice growing areas.

All essential elements must be present in the soils in optimum amount and in forms usable by rice plants. Although the farmers commonly apply N, P and Zn to the rice fields (De Datta, 1981) but most of the applied P becomes unavailable to growing plants due to alkaline and calcareous nature of Pakistani soil (Iqbal *et al*., 2003; Sharif *et al*., 2000). Therefore P fertilization seemed highly crucial to perk up the productivity of several arable crops including rice (Ahmed *et al.*, 1992; Niamatullah *et al*., 2011, Khan *et al*., 2012; Rehim *et al*., 2012a, b). The low availability of P is caused by its fixation on exchange sites or formation of insoluble compounds (Leytem and Mikkelsen, 2005) as carbonate, appetite, hydroxyappetite and flour appetite. Therefore, the efficient use of P fertilizers depends upon the crop requirements, rate and time of application and placement methods (Rehim *et al*., 2012a).

Zinc deficiency is related to soil pH and its value is very low in calcareous soil having high pH (Alloway, 2008; Alam *et al*., 2010). Zinc mobility and uptake in soil is dependent on many factors such as soil acidity, Zn contents in soil, organic matter level and soil type. Widespread occurrence of Zn deficiency in lowland rice has been reported from various countries including India (Giordano and Mortvedt, 1982; IRRI, 2000). The Zn present in water soluble, exchangeable, and adsorbed fractions is readily available to plants, while the Zn associated with primary and secondary minerals is relatively unavailable to plants. Zinc is essential for several biochemical processes in the rice plant, such as cytochrome and nucleotide synthesis, auxin metabolism, chlorophyll production, enzyme activation, and membrane integrity (IRRI, 2000).

High-P levels can affect soil properties which in turn may influence the Zn availability to plants. Changes in chemical properties due to phosphate additions can alter the equilibrium of Zn in the soil, leading to a redistribution of Zn in different soil fractions. Numerous studies on P and Zn interactions have been conducted but have shown conflicting results. It has been reported that high P concentration in soil reduces Zn availability to plants (Mandal and Mandal, 1990). Application of phosphatic fertilizers at high doses increases the severity of such deficiency in soil which is low or marginal in available Zn (Norvell *et al.*, 1987; Salimpour *et al*., 2010).

Zinc is an active element in biochemical process and has a chemical and biological interaction with some other elements. Phosphorus is the most important element which interferes on zinc uptake by plants. To explore the interaction of Zn and P, numerous studies have been conducted earlier which reported that excessive accrual of P causes Zn deficiency (Marschner *et al*., 1990; Stukenholts *et al*., 1996; Das *et al*., 2005; Khorgamy and Farnis, 2009; Salimpour *et al*., 2010).

In the absence or low Zn concentrations; P uptake and transport increase in the shoot and leaves and thus causes toxicity to the plant. This increase only occurs with Zn deficiency and is not noted in other micronutrient shortages; means that Zn deficiency increases the permeability of plasma membrane in root as compared to P (Webb and Loneagan, 1988; Marschner, 1995; Hu *et al*., 1996; Bukvić1 *et al*., 2003). Various hypotheses have been suggested to explain this phenomenon like interaction of P with Zn in soil (Mandal and Haldar, 1980) and interference of P at the level of plant metabolism involving uptake, translocation and utilization of Zn etc. (Haldar and Mandal, 1981).

In view of aforesaid discussion, this field study was designed to assess the effects of different levels of P application on rice yield and Zn uptake in rice; and the efficiency of Zn fertilization in neutralizing the negative impact of P fertilization on Zn uptake and in improving rice productivity.

MATERIALS AND METHODS

This field experiment was conducted at Research Area, Department of Soil Science, Bahauddin Zakariya University, Multan to evaluate the effect of different levels of P and Zn application on the productivity of rice. Before sowing of the crop, composite soil sample from 0-15 cm and 15-30 cm depths were collected and analyzed for physico-chemical soil characteristics by following standard methods of analysis, which is presented in Table 1.

Rice cultivar of Super Basmati was used as a test crop. Phosphorus was applied at the rate of 0, 40, 80 and 120 kg ha^{-1} and Zn at the rate of 0, 8, 12 and 16 kg ha^{-1}. Each treatment was 3 m × 4 m in area and experiment was carried out in triplicates. The plots were arranged in randomized complete block design.

Rice nursery was raised by using wet method and twenty eight days old rice seedlings were transplanted in already puddled field. Recommended dose of nitrogen (N) and potash (K) respectively at the rate of 120 and 60 kg ha^{-1} was applied as basal dose by using urea sulphate of potash as a source. Moreover triple super phosphate (TSP) and zinc sulphate were used as sources of P and Zn. Half N and full dose of P and K were applied at sowing time and other half nitrogen was applied after three weeks of transplanting while Zn was applied twelve days after transplanting of rice seedlings. The crop was harvested at maturity and the data regarding plant height (cm), number of tillers per plant, 1000-grain weight (g), paddy yield (Mg ha^{-1}), phosphorus content in paddy (%), Zn content in paddy (ppm), phosphorus uptake by paddy (kg ha^{-1}) and Zn uptake by paddy (g ha^{-1}) was recorded during crop growth and at maturity to assess the effect of treatments on plant. The plant material was washed with distilled water and oven dried at 70°C to a constant weight. The oven dried plant material was cut into small pieces, ground and passed through 1 mm sieve (Yoshida *et al*., 1976). One gram of ground material was digested in HNO_3:$HClO_4$ mixture prepared in 2:1 ratio. The digested material was analyzed for total P by metavanadate yellow color method as described by Jackson (1962). Wet digestion procedure ascribed by Jones and Case (1990) was used for the determination of Zn from plant samples by using Atomic Absorption Spectrophotometer, Model SP 2900. Phosphorus and Zn uptake by paddy was calculated by multiplying paddy yield with phosphorus and Zn concentration (%) in paddy.

$$P\ uptake(kg\ ha^{-1}) = \frac{P\ contents\,(\%)\ in\ plant\ part\ (dry\ matter) \times Yield\ (kg\ ha^{-1})}{100}$$

P uptake (Kg ha^{-1}) = P contents (% in plant part (dry matter) x Yield (Mg ha^{-1}) x1000/100

P uptake by paddy (Kg ha^{-1}) = P concentration in paddy (%) x paddy yield (Mg ha^{-1}) x 1000/100

Zn uptake by paddy (Kg ha^{-1}) = Zn concentration in straw (%) x straw yield (Mg ha^{-1}) x 1000/100

The data regarding all the parameters was statistically analyzed using software “Statistix 8.1” version. A general linear model was used to compare results of the study and analysis of variance technique (ANOVA) was used to analyze data gathered from the experiment. Treatment differences were assessed by LSD test to separate significantly different treatment means (Steel *et al*., 1997).

RESULTS AND DISCUSSION

Plant height (cm): The P and Zn application had significant and non-significant effect on plant height of rice, respectively (Table 2). The highest plant height was noted at application of P @ 80 kg P_2O_5 ha^{-1} and further increase in P could not increase the plant height (Table 2). Regarding interactive effect, P application @ 80 and 120 kg P_2O_5 ha^{-1} observed maximum plant height with Zn application at the rate of 8 and 12 kg ha^{-1} compared with all other combinations (Table 2). More plant height at higher P and Zn levels might be due to more nutrient supply.

Number of productive tillers per plant: Interactive effect of P and Zn fertilization was significant on number of productive tillers of rice while the individual effect of

P and Zn application was non-significant (Table 2). Maximum productive tillers per plant (20) were noted with the application of P and Zn at the rate of 80 and 12 kg ha^{-1}, respectively compared with all other possible combinations. However, minimum number of productive tillers per plant were noted where both P and Zn were absent (Table 2). It might be due to the more nutrients supply and lack of Zn deficiency which is a common feature of paddy fields. Similar results were earlier recorded by Ahmad *et al*. (1992) and Rehim *et al*. (2012a) in rice and wheat, respectively. They concluded a significant increase in the tillering of rice and wheat crops with the application of P.

1000-grain weight (g): Both P and Zn application improved the 1000-grain weight of rice and the highest 1000-grain weight was obtained with the application of P of 80 kg P_2O_5 ha^{-1} and Zn application of 8 kg P_2O_5 ha^{-1} (Table 2). Results also indicated that the addition of either P or Zn was effective in increasing 1000-grain weight but combined effect of these two nutrients was higher than the effect of P or Zn alone. The interaction of P at the rate of 80 kg P_2O_5 ha^{-1} and Zn at the rate of 8 and 12 kg ha^{-1} showed significant increase in 1000-grain weight as compared to all other interaction (Table 2). Similar results were found by Ahmed *et al.* (1992).

Paddy yield (Mg ha^{-1}): Both P and Zn application improved the paddy yield and the highest paddy yield was obtained with the application of P of 80 kg P_2O_5 ha^{-1} (2.61 Mg ha^{-1}) and Zn application of 8 kg P_2O_5 ha^{-1} (2.30 Mg ha^{-1}) (Table 2). Results also indicated that the addition of either P or Zn was effective in increasing paddy yield but combined effect of these two nutrients was higher than the effect of P or Zn alone. The interaction of P @ 80 kg P_2O_5 ha^{-1} and Zn @ 8 kg ha^{-1} showed significant increase in paddy yield as compared to all other interaction (Table 2). Higher productive tillers and 1000-grain weight might be the cause of higher yield (Table 2). Similar results were found by Ahmed *et al.* (1992). They observed that combination of 80 kg P ha^{-1} and 10 kg Zn ha^{-1} gave a higher yield of rice than that of 80 kg P ha^{-1} alone, and that the interaction between P and Zn on grain yield was antagonistic. These results showed that the application of high rate of P decreased the availability of Zn while decreasing the grain yield, indicating an antagonistic effect. Results of field experiment showed that application of high rate of P decreased the grain yield. This can be overcome by adding sufficient amounts of Zn fertilizer to the soil. When Zn was applied along with low P the growth of barley was increased (Gene *et al.,* 2000).

Straw yield (Mg ha^{-1}): Phosphorous application had significant influence on the straw yield of rice and the highest straw yield was obtained (4.59 Mg ha^{-1}) with P @ 80 kg P_2O_5 ha^{-1} but it was statistically at par with P application of 120 kg P_2O_5 ha^{-1}, while application of Zn had non-significant effect on straw yield (Table 2). Interaction of P and Zn was found to be significant. Minimum straw yield was recorded with no or low level of Zn application at all levels of P applied (Table 2). These results showed that application of high rate of P decreased the availability of Zn and decreased the straw yield at low Zn levels, indicating an antagonistic effect. This can be overcome by adding sufficient amounts of Zn fertilizer to the soil. When Zn was applied along with low P the growth of barley was increased (Gene *et al.*, 2000).

Paddy P contents (%): Both P and Zn application had significant effect on paddy P **c**ontents which was increased with increase in P and Zn. The highest P **c**oncentration in Paddy was obtained by application of P @ 120 kg ha^{-1} and Zn @ 12 kg ha^{-1} (Table 3). Regarding interaction, paddy P concentration was the maximum at higher levels of P and Zn application (Table 3). Similar kind of results were found by Tiwari *et al.* (1975). They observed the increased concentration of P in plants with each increment of P.

Paddy Zn contents (ppm): The P application showed significant effect on Zn contents in paddy. It was observed that Zn contents in Paddy decreased with the increase in P rate (Table 3). The maximum Zn contents (29.28 mg kg^{-1}) were found in plots where no P was applied (Table 3) while Zn application had non-significant effect on paddy Zn contents (Table 3). Addition of P fertilizer to soil dramatically decreased the tissue Zn contents at all levels of P applied, but decreased amounts with increased level of P. Therefore addition of P fertilizer at higher level decreased the availability of Zn in plant tissue hampering the growth of rice. Similarly, Zhu *et al*. (2001) reported that plant Zn concentration decreased with increasing level of P. It is already reported that excessive P fertilization leads to Zn deficiency in plants. Much research revealed that excessive P fertilization leads to Zn deficiency in plant (Norvell *et al.,* 1987; Salimpour *et al*., 2010). Mandal and Mandal (1990) further reported that in greenhouse experiments, P application caused a progressive decrease in the Zn concentration in shoots and roots. This was attributed at least partly to the decrease in the water soluble plus exchangeable and organic complexes forms of Zn.

P uptake by paddy (kg ha^{-1}): Both P and Zn application had significant effect on P uptake in the study. P uptake in paddy was increased with the increase in P and Zn levels (Table 3). Interaction was found to be highly significant and maximum P uptake was recorded at higher levels of P and Zn applications (Table 3). Similar effects in crops like wheat, corn and maize have been reported by other workers (Reddy *et al.,* 1973; Hulagur *et al.,* 1975). The changes in concentration of the elements in the plant parts might be due to the changes in their absorption from the soil resulting from changes in availability and/or to dilution effect due to increased growth of plants and/or to the changes in the translocation of the elements from roots to tops.

Zn uptake by paddy (g ha^{-1}): The P application showed significant effect on Zn uptake in paddy. It was obtained that Zn uptake in paddy increased with the increased P rate. The maximum Zn uptake 71 g ha^{-1} was found in plots where P was applied @ 80 kg P_2O_5 ha^{-1} (Table 3). Zn application showed non-significant effect on Zn uptake in paddy. Thus the results clearly indicated that increased rate of P fertilizer up to a certain optimum level increased the dry matter yield and Zn uptake by plants, thereafter, a high P level in the soil reduced the availability of Zn. At high levels of P, the retention of more Zn in the roots was probably due to inactivation of Zn in roots, as reported by Dwivedi and Randhawa (1974), or may be due to the increased binding of Zn in the root cell walls, resulting in less Zn transportation to the upper portion of the plant (Youngdahl *et al.*, 1977). According to Safaya (1976), Zn deficiency symptoms became evident on corn plants when fertilized with 75 mg P kg^{-1} of soil. The application of P appeared to lower the translocation of Zn from roots to tops thereby reducing the Zn concentration in shoots which revealed the antagonistic interaction between P and Zn in roots with increased application of P. Much research revealed that excessive P fertilization leads to Zn deficiency in plant (Norvell *et al.*, 1987; Salimpour *et al*., 2010).

Table 1. Physico-chemical properties of experimental soil before sowing

Determinants	Units	Values	
		0-15 cm	15-30 cm
Sand	%	29	30
Silt	%	54	52
Clay	%	17	18
Textural class		Silty clay loam	
Saturation percentage		35	36
Organic matter	%	0.78	0.45
Total N	%	0.04	0.03
Available P	ppm	6.10	5.20
Extractable K	ppm	190.00	110.00
Ca CO_3	%	8.90	9.10
pH_s		7.80	8.00
EC_e	dS m^{-1}	3.12	2.47
AB-DTPA extractable Zn	mgkg^{-1}	0.53	0.69

Table 2. Effect of phosphorus and zinc application on yield and related traits of rice.

Treatments	Plant height (cm)	Productive tillers per plant	1000-grain weight (g)	Paddy yield (Mg ha^{-1})	Straw Yield (Mg ha^{-1})
Phosphorus (P) levels (kg ha^{-1})					
P_0 = 0	77.39c	14.68	19.94b	1.75c	2.23b
P_1 = 40	81.25bc	15.58	20.62b	1.98bc	2.73b
P_2 = 80	87.25a	17.75	23.88a	2.61a	4.59a
P_3 = 120	83.58ab	16.83	21.73b	2.21b	4.29a
Zinc (Zn) levels (kg ha^{-1})					
Zn_0 = 0	80.76	14.68	20.04b	2.04b	3.46
Zn_1 = 8	80.58	15.58	20.72b	2.03b	3.29
Zn_2 = 12	85.07	17.75	23.38a	2.30a	3.62
Zn_3 = 16	83.06	16.83	22.03ab	2.18a	3.47
Interaction between P × Zn					
P_0Zn_0	74.72d	13.03b	18.73d	1.61e	2.33ef
P_0Zn_1	78.33bcd	13.67b	19.95d	1.87cde	2.58def
P_0Zn_2	85.33abc	16.67ab	21.57bcd	2.34abcd	4.83a
P_0Zn_3	84.67abc	15.33ab	19.90d	2.34abcd	4.08abcd
P_1Zn_0	77cd	13.67b	19.28d	1.62de	1.75f
P_1Zn_1	77.33cd	15.67ab	21.03bcd	2.04bcde	2.92cdef
P_1Zn_2	87.67ab	17.33ab	22.33bcd	2.62ab	4.58ab
P_1Zn_3	80.33bcd	15.67ab	20.23cd	1.86cde	3.9abcde
P_2Zn_0	79.27bcd	15ab	21.05bcd	1.91bcde	2.25ef
P_2Zn_1	83.33abcd	17.33ab	21.13bcd	1.86cde	2.33ef
P_2Zn_2	90.67a	20a	26.83a	3.01a	4.53abc
P_2Zn_3	87ab	18.67ab	24.03abc	2.42abc	5.33a
P_3Zn_0	78.56bcd	14.33ab	20.23cd	1.85cde	2.57def
P_3Zn_1	86abc	16.67ab	20.37cd	2.16bcde	3.08bcdef
P_3Zn_2	85.33abc	18.33ab	24.80ab	2.46abc	4.42abc
P_3Zn_3	82.33abcd	18ab	22.73bcd	2.24bcde	3.83abcde

Means not sharing the same letter within a column differ significantly from each other at 5% level of probability

Table 3. Effect of phosphorus and zinc application on P and Zn contents and uptake of rice.

Treatments	Paddy P contents (%)	Paddy Zn contents (ppm)	P uptake by paddy (kg ha^{-1})	Zn uptake by paddy (g ha^{-1})
Phosphorus (P) levels (kg ha^{-1})				
$P_0 = 0$	0.24c	29.28a	4.29b	51b
$P_1 = 40$	0.27c	28.27ab	5.42b	56b
$P_2 = 80$	0.32b	27.05ab	8.22a	71a
$P_3 = 120$	0.35a	26.41c	7.69a	59ab
Zinc (Zn) levels (kg ha^{-1})				
$Zn_0 = 0$	0.27b	27.08	5.71b	56
$Zn_1 = 8$	0.28b	28.23	5.73b	57
$Zn_2 = 12$	0.31a	27.97	7.27a	64
$Zn_3 = 16$	0.32a	27.73	6.91ab	60
Interaction between P × Zn				
P_0Zn_0	0.23f	26.77b	3.74h	43c
P_0Zn_1	0.25ef	26.93b	4.82fgh	51bc
P_0Zn_2	0.32bcd	27.6ab	7.42abcde	65abc
P_0Zn_3	0.29bcde	27.03b	6.87bcdef	63abc
P_1Zn_0	0.24ef	28.93ab	4.04gh	47c
P_1Zn_1	0.27cdef	29.17ab	5.36efgh	60abc
P_1Zn_2	0.29bcdef	27.67ab	7.56abcde	72ab
P_1Zn_3	0.32bc	27.13b	5.96defgh	51bc
P_2Zn_0	0.24ef	29.3ab	4.63fgh	56bc
P_2Zn_1	0.28bcdef	28.87ab	5.17efgh	54bc
P_2Zn_2	0.33ab	27.4b	9.90a	83a
P_2Zn_3	0.38a	26.3b	9.36ab	64abc
P_3Zn_0	0.26def	32.13a	4.76fgh	59abc
P_3Zn_1	0.29bcdef	28.10ab	6.33cdefg	61abc
P_3Zn_2	0.32bc	25.53b	8.00abcd	63abc
P_3Zn_3	0.39a	25.17b	8.57abc	57bc

Means not sharing the same letter within a column differ significantly from each other at 5% level of probability.

Conclusion: P application significantly lowered the Zn uptake and thus caused Zn deficiency which could be overcome by higher levels of Zn applications. Therefore in order to get higher paddy yield, it should be fertilized @ 80 and 12 kg ha^{-1} of P and Zn, respectively.

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