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PRECEDING RICE GENOTYPES, RESIDUAL PHOSPHORUS AND ZINC INFLUENCE HARVEST INDEX AND BIOMASS YIELD OF SUBSEQUENT WHEAT CROP UNDER RICE-WHEAT SYSTEM

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Abstract

Continuous cropping of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) for several decades resulted in depletion of plant nutrients in soil and decline in yields of both crops. One strategy to increase crop productivity under rice-wheat system is balanced application of crop nutrients. Field experiment was conducted to assess the impact of phosphorus (0, 40, 80, 120 kg P ha^{-1}) and zinc levels (0, 5, 10, 15 kg Zn ha^{-1}) on the productivity of rice genotypes (fine and coarse) and their residual effects on tillers m^{-2}, straw and biomass yields, and harvest index of the succeeding wheat under rice-wheat cropping system in Northwest Pakistan during 2011-12 and 2012-13. Wheat variety (cv. Siran-2010) was grown on the same layout after rice harvest but no additional P and Zn was applied to wheat crop in both years. The results revealed that tillers m^{-2}, straw and biomass yields, and harvest index of wheat were significantly greater in treatments receiving the higher P level (120 > 80 > 40 > 0 kg P ha^{-1}) and Zn level (15 > 10 > 5 > 0 kg Zn ha^{-1}) during the preceding rice season. The results further showed that tillers m^{-2}, straw and biomass yields, and harvest index of wheat were significantly greater when grown after the low yielding fine rice genotype (Basmati-385) than grown after high yielding coarse genotypes (F-Malakand & Pukhraj). The residual of P and Zn concentration in soil were higher in the second than in first year of experiment. These results confirmed strong carry over effects of both P and Zn applied to the previous rice crop on the productivity of subsequent wheat under rice-wheat cropping system.

Key words: Wheat, Harvest index, Biomass, Residual P & Zn, Rice-wheat system

Introduction

Rice, wheat and maize are important cereal crops in Pakistan and the yield of these crops are lower as compared to other countries of the world. The important factors are tillage, plant population and mulches (Gul *et al.,* 2014). However rice-wheat cropping system is one of the most important cropping systems in Asia and also in Pakistan. In Pakistan, the rice-wheat system covers an area of 1.6 million hectares. However, the productivity of the rice-wheat cropping system in Pakistan is very low (Ahmad & Iram, 2013). Both, rice and wheat crops are highly nutrient exhaustive and therefore, their continuous cropping deplete the inherent soil fertility, causing deficiency of several nutrients (Zia *et al*., 1996; Shah *et al*., 2011). The phosphorus (P) and zinc (Zn) deficiency are the two most important nutritional constraints to rice growth all over the world (Ismail *et al*., 2007). The Zn and P imbalance in the plant results in excessive accumulation of P, causing Zn imposed deficiency (Cakmak, 2000; Das *et al*., 2005; Mirvat *et al*., 2006; Alloway, 2009; Khorgamy & Farnis, 2009; Salimpour *et al*., 2010). P has significant role in crop production and thus is required in sufficient quantity (Khan *et al.,* 2013; Wahid *et al.,* 2015). Recovery of the applied P by crops in the year of fertilizer application is very low (10 to 30 %) depending upon soil, crop and management factors (Karamanos *et al*., 2007). Malik *et al*., (1992) reported that P reserves of the Punjab soils in Pakistan and response of crops to P is declining with the passage of time. The current farmer's use of P fertilizer for rice-wheat cropping sequence is inadequate and continuation of these doses would worsen P deficiency (Saleque *et al*., 2006). According to Yadvinder *et al*., (2000), application 32 kg P to wheat crop and 15 kg P ha^{-1} to rice crop on P deficient and light textured soils is recommended in northern India. Dobermann *et al*., (1996) suggested that a rice crop depletes about 7-8 kg ha^{-1} when P fertilizer was not used. Kolar & Grewal (1989) applied 13 kg P ha^{-1} to wheat and rice crops individually to first crop and observed its residual effect on subsequent crop which was significantly inferior to its direct application. According to (Tandon, 1987), crops seldom absorb more and often less than 20 % of fertilize P during the first cropping season after application. Zinc deficient soils are widespread in subtropical areas such as India, Pakistan, Latin America and Turkey (Cakmak, 2008). Zinc deficiencies can cause yield losses up to 40% without the crop showing any symptoms (Ozkutlu *et al*., 2006). In Pakistan about 70% of the agricultural land area is Zn deficient (Hamid & Ahmed, 2001). Research on the effect of proper combinations of Zn and P levels on different rice genotypes and their residual effect on the productivity of succeeding wheat crop have not been conducted. For sustainable rice and wheat production, research on the interactive effects of Zn and P levels on rice genotypes and their residual effect on the succeeding wheat crop is very much important. This study was therefore conducted to investigate if the residual P and Zn applied to the current rice crop had any significant effects on the productivity of the subsequent wheat crop?

Materials and Methods

Site description: Field experiment was conducted to investigate the impact of zinc (Zn) and phosphorus (P) levels on three rice (*Oryza sativa* L.) genotypes and their residual effects on the biomass yield harvest index of subsequent wheat (*Triticum aestivum* L., cv. Siran) under rice-wheat cropping system. The experiment was carried out at Batkhela, Malakand Agency on farmer's field in Northwest Pakistan during 2011-12 and 2012-13. Batkhela is located at 34°37'0" N and 71°58'17" E in DMS (Degrees Minutes Seconds) or 34.6167 and 71.9714 (in decimal degrees). The soil of the experimental site is clay loam, slightly alkaline in reaction (pH = 7.3), non-saline (ECe = 1.02 dS m^{-1}), moderately calcareous in nature ($CaCO_3$ = 7.18 %), low in soil fertility containing less organic matter (0.71 %), extractable P (5.24 mg kg^{-1}) and Zn (0.93 mg kg^{-1}).

Experimentation: The experiment was conducted in RCB design with split-plot arrangement using three replications. Combination of four phosphorus (P) levels [0, 40, 80 and 120 kg P ha^{-1}] and three rice genotypes [Bamati-385 (fine), Fakhre-e-Malakand (coarse) and Pukhraj (coarse)] was used as main plots, while four zinc (Zn) levels [0, 5, 10 and 15 kg Zn ha^{-1})as sub plots. A sub-plot size of 12 m^2 (3 m x 4 m) consisting of 25 hills m^{-2} with hill to hill distance of 20 cm apart was used. A uniform dose of 120 kg N ha^{-1} as urea and 60 kg K_2O ha^{-1} (MOP) was applied to all treatments in case of rice crop. All K, P (triple super phosphate) and zinc (zinc sulphate) was applied at the time of transplanting, while nitrogen (N) as urea was applied in two equal splits i.e. 50 % each at transplanting and 30 days after transplanting. The amount of sulfur (S) was maintained constantly in the Zn applied plots by adding additional S using SOP. All subplots were separated by about 30 cm ridges to stop movement water/nutrient among different treatments. After harvesting of rice crop, wheat (cv. Siran) was planted on same layout in 30cm apart rows. No additional P and Zn were applied to wheat crop. However, nitrogen (N) at 140 kg N ha^{-1} was applied in three equal splits i.e. $1/3^{rd}$ each at sowing, 30 days after emergence and booting stage. All other agronomic practices were uniform for all treatments in case of wheat crop.

Data handling and recording: Data on various parameters (tillers m^{-2}, straw yield, biomass yield, and harvest index) of subsequent wheat crop was recorded. Number of tillers were counted in two central rows each 2m (meter) long at two different places in each sub-plot, and then converted into number tillers m^{-2}. The four central rows each three meter long in each treatment were harvested at maturity, the materials was dried, weighed and converted into biomass yield (kg ha^{-1}). The dried material was then threshed; grains were separated, cleaned, weighed and converted into grain yield (kg ha^{-1}). Straw yield was calculated by subtracting grain yield from yield, while harvest index (%) was calculated by dividing grain yield by yield and multiplied with 100 using the following formulae:

Straw yield = Yield – Grain yield

$$\text{Harvest Index (\% } = \frac{\text{Grain yield}}{\text{yield}} \times 100$$

Statistical analysis of data: Data were subjected to analysis of variance according to randomized complete block design with split plot arrangement (Steel *et al.*, 1996), and means between treatments were compared using LSD test (p≤0.05). A brief summary of ANOVA combined over the two years is given in Table 1.

Table 1. Analysis of variance for tillers m^{-2}, straw yield, biomass yield and harvest index of subsequent wheat crop as affected by preceding rice genotypes, residual phosphorus and zinc under rice-wheat cropping system.

SOV	D.F.	Level of significance combined over the two years ($p \leq 0.05$)			
		Tillers m^{-2}	**Straw yield**	**Biomass yield**	**Harvest index**
Years (Y)	1	ns	**	***	ns
Replications (Years)	4	ns	ns	ns	ns
Genotypes	2	***	*	***	***
Y x G	2	ns	ns	ns	**
Phosphorus (P)	3	***	***	***	**
Y x P	3	ns	ns	ns	ns
P x G	6	***	***	ns	***
Y x P x G	6	ns	ns	ns	ns
Pooled Error-I	**44**				
Zinc (Zn)	3	***	***	***	ns
Y x Zn	3	ns	ns	ns	ns
Zn x G	6	***	ns	ns	ns
Y x Zn x G	6	ns	ns	ns	ns
P x Zn	9	***	ns	ns	*
Y x P x Zn	9	ns	ns	*	ns
P x Zn x G	18	***	ns	ns	ns
Y x P x Zn x G	18	ns	ns	ns	ns
Pooled Error-II	**144**				
Total	**287**				
CV of main plots		4.8	8.9	5.4	7.1
CV of sub plots		3.2	10.6	5.8	7.9

ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

Results

Tillers m^{-2}: Number of tillers m^{-2} of wheat was significantly affected by residual P and Zn levels and preceding rice genotypes (Table 2). Interactions of P x Zn, P x G, Zn x G and P x Zn x G were also found significant. Year and all other interactions had no significant effect on tillers m^{-2}. Maximum tillers m^{-2} (296) were recorded for wheat when grown on the plots treated with 120 kg P ha^{-1} to the preceding rice crop and minimum tillers m^{-2} (232) were recorded when P was not applied to the previous rice crop. In case of Zn, maximum tillers m^{-2} (273) were produced when grown on plots that received 15 kg Zn ha^{-1}, while minimum tillers m^{-2} (260) were recorded when Zn was not applied to the previous rice crop. Wheat grown after fine genotype (B-385) had higher tillers m^{-2} (280) being at par with F-Malakand (277), while wheat grown after Pukhraj produced less number of tillers m^{-2} (247)as shown in Table 2.

Interaction of P x Zn indicated that increase in levels of both nutrients (P and Zn) to the previous rice crop increased tillers m^{-2} of subsequent wheat crop (Fig. 1). In interaction of P x G, revealed that increase in P level increased tillers m^{-2} of subsequent wheat crop. However, number of tillers m^{-2}reduced significantly when wheat was grown after Pukhraj as compared to other two genotypes (Fig. 2). Interaction of Zn x G revealed that increase in Zn level up to 5 kg ha^{-1} under fine rice genotype increased tillers m^{-2} of wheat crop (Fig. 3). In case of two coarse genotypes, the increase in Zn levels increased tillers m^{-2} but the increase was more when wheat was grown after F-Malakand as compared with Pukhraj. Interaction among P x Zn x G indicated that increase in levels of both nutrients (P and Zn) to the previous rice genotypes increased tillers m^{-2} in wheat but the increase was more when wheat was grown after B-385 (Fig. 4).

Straw yield: Straw yield of wheat was significantly affected by residual P and Zn levels, rice genotypes and year (Table 3). All interactions except P x G were found non-significant for straw yield of the subsequent wheat crop. Average of the two years data indicated that maximum straw yield (6392 kg ha^{-1}) was produced with application of 120 kg P ha^{-1} to the previous rice crop, while minimum straw yield (4692 kg ha^{-1}) wheat was recorded in P control plots. In case of residual Zn, maximum straw yield (5945 kg ha^{-1}) was produced with 15 kg Zn ha^{-1} applied to the previous rice crop being at par with 10 kg Zn ha^{-1} (5852 kg ha^{-1}). Minimum straw yield (5322 kg ha^{-1}) of wheat was recorded in Zn control plots. Wheat grown after B-385 increased its straw yield (5774 kg ha^{-1}) being at par with wheat grown after F-Malakand (5751 kg ha^{-1}), but wheat grown after the high yielding genotype Pukhraj reduced its straw yield (5570 kg ha^{-1}) significantly. Mean two years data indicated that year two had more straw yield (5870 kg ha^{-1}) for wheat than in year one (5527 kg ha^{-1}). The interaction between P x G indicated that increase in P level to the previous rice genotypes increased straw yield of subsequent wheat crop (Fig. 5). However, the straw yield decreased significantly when wheat was grown after Pukhraj while increasing P levels.

Table 2. Tillers m^{-2} of subsequent wheat crop as affected by preceding rice genotypes, residual phosphorus and zinc.

	Years		
Phosphorus (kg ha^{-1})	**2011-12**	**2012-13**	**Mean**
0	230	233	232 d
40	258	265	261 c
80	282	286	284 b
120	295	297	296 a
$LSD_{0.05}$	**7.6**	**4.8**	**4.4**
Zinc (kg ha^{-1})			
0	258	262	260 c
5	268	270	269 b
10	269	272	270 b
15	270	276	273 a
$LSD_{0.05}$	**4.9**	**3.1**	**2.9**
Genotypes			
B-385 (fine)	278	282	280 a
F-Malakand (coarse)	274	280	277 b
Pukhraj (coarse)	246	248	247 b
$LSD_{0.05}$	**6.6**	**4.2**	**3.8**
Years mean	**266**	**270**	
Interactions	**Level of significance**	**Figures**	
Y x P	ns		
Y x Zn	ns		
Y x G	ns		
P x Zn	***	1	
P x G	***	2	
Zn x G	***	3	
P x Zn x G	***	4	

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.
ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

Table 3. Straw yield (kg ha^{-1}) of subsequent wheat crop as affected by preceding rice genotypes, residual phosphorus and zinc.

	Years		
Phosphorus (kg ha^{-1})	**2011-12**	**2012-13**	**Mean**
0	4382	5002	4692 d
40	5541	5848	5695 c
80	5855	6175	6015 b
120	6327	6456	6392 a
$LSD_{0.05}$	**255.9**	**242.4**	**171.3**
Zinc (kg ha^{-1})			
0	5172	5473	5322 c
5	5625	5725	5675 b
10	5589	6114	5852 a
15	5720	6169	5945 a
$LSD_{0.05}$	**324.4**	**241.2**	**171.2**
Genotypes			
B-385 (fine)	5527	6021	5774 a
F-Malakand (coarse)	5656	5846	5751 a
Pukhraj (coarse)	5396	5744	5570 b
$LSD_{0.05}$	**ns**	**209.9**	**148.3**
Years mean	**5527 b**	**5870 a**	
Interactions	**Level of significance**	**Figures**	
Y x P	ns		
Y x Zn	ns		
Y x G	ns		
P x Zn	ns		
P x G	***	5	
Zn x G	ns		
P x Zn x G	ns		

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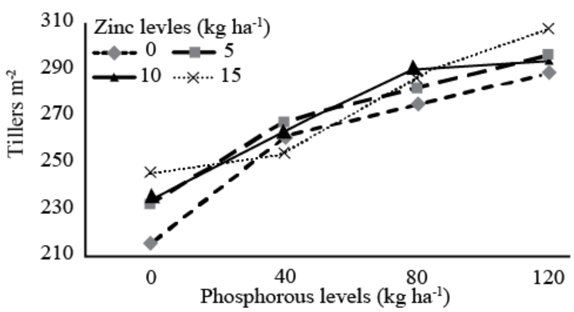

Fig. 1.Number of tillers m^{-2} of subsequent wheat crop as affected by residual phosphorus and zinc (P x Zn) interaction.

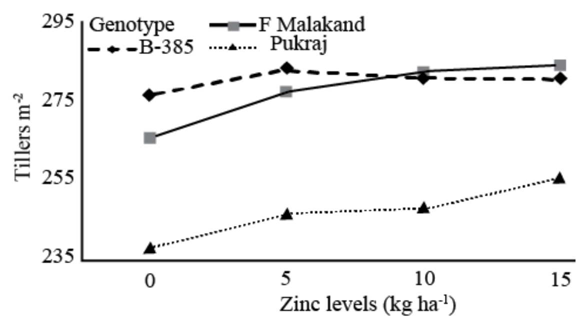

Fig. 3.Number of tillers m^{-2} of subsequent wheat crop as affected by residual zinc and preceding rice genotypes (Zn x G) interaction.

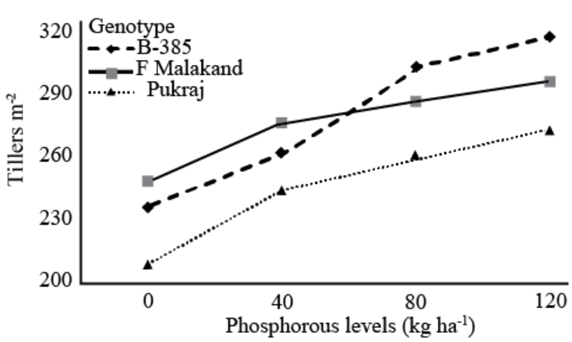

Fig. 2.Number of tillers m^{-2} of subsequent wheat crop as affected by phosphorus and preceding rice genotype (P x G) interaction.

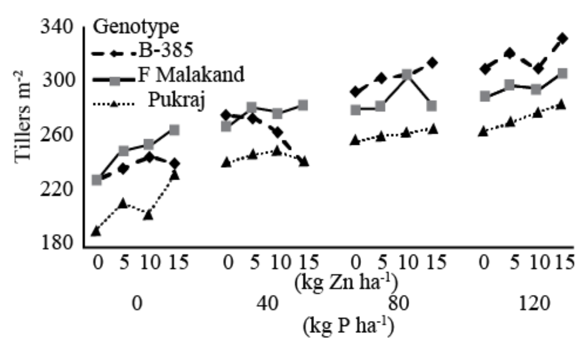

Fig. 4.Number of tillers m^{-2} of subsequent wheat crop as affected by residual phosphorus, zinc and preceding rice genotypes (P x Zn x G) interaction.

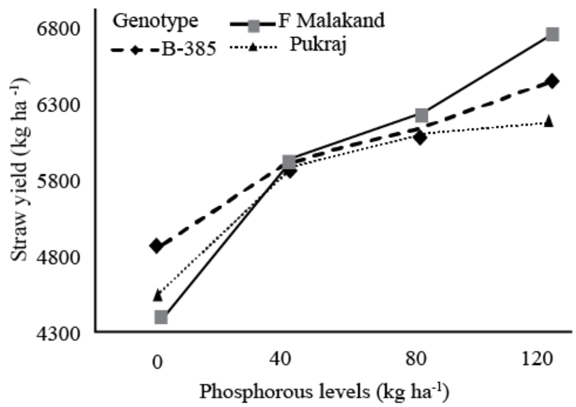

Fig. 5. Straw yield (kg ha^{-1}) of subsequent wheat crop as affected by residual phosphorous and preceding rice genotypes (P x G) interaction in rice-wheat cropping system.

Biomass yield: Biomass yield of wheat was significantly affected by residual P and Zn levels, rice genotypes and year (Table 4). All interactions were found non-significant for yield of the subsequent wheat crop. Maximum yield (10698 kg ha^{-1}) was produced by wheat when grown on the plots that received the highest of 120 kg P ha^{-1}in the previous rice crop, while minimum yield (8138 kg ha^{-1}) was recorded on the plots where P was not applied to the previous rice crop. In case of residual Zn, maximum yield (10071 kg ha^{-1}) was obtained in the plots that received the highest of 15 kg Zn ha^{-1}by the previous rice crop, while minimum yield (9143 kg ha^{-1} was recorded in Zn control plots. In case of preceding rice genotypes, wheat grown after B-385 had higher yield (10008 kg ha^{-1}), followed by wheat grown after F-Malakand (9837 kg ha^{-1}). Wheat grown after Pukhraj had less yield (9215 kg ha^{-1}). Year two had significantly more yield (9967 kg ha^{-1}) than year one (9406 kg ha^{-1}).

Table 4. yield (kg ha^{-1}) of subsequent wheat crop as affected by preceding rice genotypes, residual phosphorus and zinc.

	Years		
Phosphorus (kg ha^{-1})	**2011-12**	**2012-13**	**Mean**
0	7767	8509	8138 d
40	9322	10050	9686 c
80	9970	10478	10224 b
120	10565	10832	10698 a
$LSD_{0.05}$	**275.8**	**236.4**	**176.5**
Zinc (kg ha^{-1})			
0	8858	9428	9143 d
5	9508	9808	9658 c
10	9524	10224	9874 b
15	9733	10409	10071 a
$LSD_{0.05}$	**306.4**	**215.2**	**185.6**
Genotypes			
B-385 (fine)	9684	10332	10008 a
F-Malakand (coarse)	9527	10146	9837 b
Pukhraj (coarse)	9006	9424	9215 c
$LSD_{0.05}$	**238.8**	**204.7**	**152.8**
Years mean	**9406 b**	**9967 a**	
Interactions	**Level of significance**		
Y x P	ns		
Y x Zn	ns		
Y x G	ns		
P x Zn	ns		
P x G	ns		
Zn x G	ns		
P x Zn x G	ns		

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.
ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

Harvest index: Harvest index of the subsequent wheat crop was significantly affected by residual P levels and preceding rice genotypes (Table 5). However, residual Zn levels and year had no significant effect on harvest index of wheat. Among interactions, Y x G, P x Zn and P x G were found significant for harvest index. Lowest harvest index (41.23%) was recorded with the residual effect of 80 kg P ha^{-1}applied to the previous rice crop, however it was significantly not different from plots treated with 40 and 120 kg P ha^{-1}. The maximum harvest index (42.23%) was recorded in P control plots. Among preceding rice genotypes, wheat grown after B-385 increased harvest index (42.44%) being at par with wheat grown after F-Malakand (41.90%). Wheat grown after Pukhraj reduced harvest index to minimum (39.65%). The Y x G interaction indicated that wheat grown after B-385 had higher harvest index in year one, but in contrast wheat had higher harvest index when grown after F-Malakand in year two (Table 5).

The P x Zn interaction indicated that when P was not applied and Zn was applied at the rate of 5 and 10 kg Zn ha^{-1} to the previous rice crop resulted in higher harvest index in subsequent wheat crop (Fig. 6). When Zn was not applied and P was applied at the rate of 40 or 120 kg P ha^{-1} to the previous rice crop also had positive impact on the harvest index of wheat. Interaction between P x G indicated that increase in P levels up to 80 kg ha^{-1} under fine genotype (B-385) as preceding crop, increased harvest index of subsequent wheat crop. However, both coarse genotypes as preceding crops under P control plots increased the harvest index of wheat (Fig. 7).

Table 5. Harvest index (%) of subsequent wheat crop as affected by preceding rice genotypes, residual phosphorus and zinc.

	Years		
Phosphorus (kg ha^{-1})	**2011-12**	**2012-13**	**Mean**
0	43.68	41.18	42.43 a
40	40.63	41.85	41.24 b
80	41.35	41.11	41.23 b
120	40.35	40.49	40.42 b
$LSD_{0.05}$	**ns**	**ns**	**0.999**
Zinc (kg ha^{-1})			
0	41.74	41.97	41.85
5	41.22	41.59	41.41
10	41.70	40.31	41.00
15	41.37	40.76	41.06
$LSD_{0.05}$	**ns**	**ns**	**ns**
Genotypes			
B-385 (fine)	43.10	41.79	42.44 a
F-Malakand (coarse)	41.18	42.63	41.90 a
Pukhraj (coarse)	40.24	39.06	39.65 b
$LSD_{0.05}$	**1.435**	**1.054**	**0.865**
Years mean	**41.51**	**41.16**	
Interactions	**Level of significance**	**Figures**	
Y x P	ns		
Y x Zn	ns		
Y x G	**		
P x Zn	*	6	
P x G	***	7	
Zn x G	ns		
P x Zn x G	ns		

Means of the same category followed by different letters are significantly different at 5% level of probability using LSD test.
ns stands for non-significant, while *, ** and *** stands for significant at 5, 1 and 0.1 % level of probability, respectively.

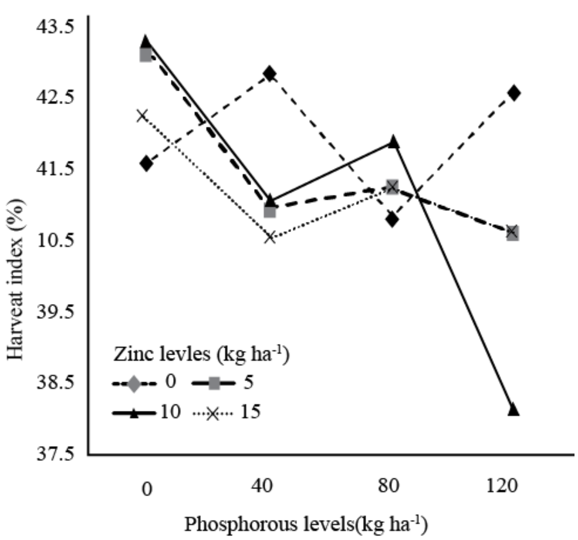

Fig. 6. Harvest index (%) of subsequent wheat crop as affected by residual phosphorous and zinc (P x Zn) interaction.

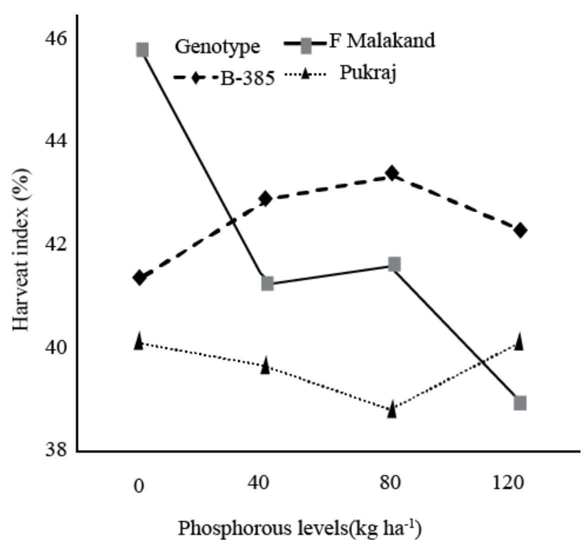

Fig. 7.Harvest index (%) of subsequent wheat crop as affected by residual phosphorous and preceding rice genotypes.

Discussion

Impact of residual P on subsequent wheat: Wheat biomass and harvest index increased when planted on plots having more residual soil P after rice harvest. Our results indicated that the highest rate of 120 kg P ha^{-1} applied to the previous rice crop increased its residual content to maximum level (11.3 mg kg^{-1}) in the soil after rice harvest that had positive impact on subsequent wheat biomass and harvest index. The residual P concentration in soil after rice harvest significantly increased with increase in P levels to the previous rice crop (11.3 > 9.8 > 8.1 > 4.1 mg P kg^{-1} soil obtained with application of 120, 80, 40 and 0 kg P ha^{-1}, respectively). Our results are in line with those of Lal *et al.*, (2000) that residual P in soil samples after harvest increased considerably with increasing rates of P. In their experiment, Rehman *et al.*, (2007) reported a maximum value of 10.95 mg P kg^{-1} residual P after sorghum harvest when P was applied at higher rate. In our experiment the increase in residual soil P increased tillers and spikes m^{-2}, 1000 grains weight and grain yield of wheat (data not shown) and showed positive relationship with biomass and harvest index of wheat. The increase in biomass and harvest index of wheat was attributed to the less uptake of P by the previous rice crop and more residual P was available for the subsequent wheat crop (Cooke, 1982; Wild, 1988; Tandon, 1992; Sahrawat *et al.*, 1992 and 1995; Karamanos *et al.*, 2007). These results confirmed that P-fertilizers can have long lasting residual effects on succeeding wheat crop and the level of residual soil P gradually increased contributing more to P pool available for the wheat plants (Harapiak & Beaton, 1986; Rehman *et al.*, 2006 and 2007). Earlier many researchers reported that the residual soil P had significantly increased the yield of subsequent wheat crop without P fertilizer application in the rice-wheat rotation (Kolar & Grewal, 1989; Khan & Makhdum, 1990; Saeed *et al.*, 1992).

Impact of residual Zn on subsequent wheat: The highest biomass yield and harvest index from the subsequent wheat crop were obtained due to the higher residual soil Zn concentration in the plots that received the higher Zn levels (15 & 10 kg Zn ha^{-1}) in the previous rice season. The residual Zn concentration in soil after rice harvest were significantly higher with higher Zn level applied to the previous rice crop (1.44 > 1.37 > 1.26 > 0.75 mg Zn kg^{-1} soil obtained with application of 15, 10, 5 and 0 kg Zn ha^{-1}, respectively). The increase in residual soil Zn increased tillers and spikes m^{-2}, 1000 grains weight and grain yield (data not shown) that had positive impact on the biomass and harvest index of subsequent wheat crop. The increased in wheat biomass and harvest index was attributed to less up take of Zn from the soil and left more residual soil Zn for the subsequent wheat crop (Tahir *et al.*,1991; Zia *et al.*,1996; Rashid, 2005; Khan *et al.*, 2009). Wheat biomass and harvest index decreased significantly with less residual soil Zn concentration in the plots that received no zinc in the previous rice season. Cakmak *et al*., (2001) reported that soil Zn deficiency is a widespread constraint for wheat production, particularly in arid and semiarid regions where soil pH value and $CaCO_3$ content are high and organic matter content is low. On Zn deficient soil higher Zn level must be applied to the current wheat crop or more Zn must be applied to the previous rice crop to increase residual soil Zn under rice-wheat system. The high residual Zn concentration in soil remained from previous crop increases grain yield of the next crop on Zn-deficient soil (Graham & Rengel, 1993).

Impact of preceding rice genotypes on subsequent wheat: Number of tillers m^{-2}, straw and biomass yields, and harvest index of subsequent wheat crop were significantly more with higher residual soil P and Zn concentration in plots under fine rice genotype as preceding crop. Because the low yielding fine genotype (B-385) took less P from the soil and so left more residual soil P (9.1 mg kg^{-1}) for the subsequent wheat. Similarly, the low yielding fine genotype (B-385) took less Zn from the soil and left more residual Zn in soil (1.34 mg kg^{-1}) after harvest that have positive impact on the biomass and harvest index of subsequent wheat. On the other hand, number of tillers m^{-2}, straw and biomass yields, and harvest index of subsequent wheat crop were significantly less with lower residual soil P and Zn in plots under coarse rice genotypes as preceding crop. The decrease in wheat biomass and harvest index was attributed to the uptake of more P by the two high yielding rice genotypes (F-Malakand and Pukhraj) and decreased their residual P in soil (8.1 and 7.8 mg kg^{-1}, respectively). Likewise, the two high yielding rice genotypes (F-Malakand and Pukhraj) took more Zn from the soil and decreased its residual soil Zn (1.19 and 1.08 mg kg^{-1}, respectively). The decrease in residual soil P and Zn decreased tillers and spikes m^{-2}, 1000 grains weight and grain yield (data not shown) of wheat that had negative impact on the biomass and harvest index of subsequent wheat crop. Hussain *et al.*, (2012) found that wheat yield after Super Basmati ranged from 3.08 to 3.98 t ha^{-1} with an average of 3.4 t ha^{-1} while after rice-386 it ranged from 2.2 to 4.5 t ha^{-1} with an average of 3.78 t ha^{-1}. Biomass yield and harvest index of subsequent wheat were significantly higher in year two than in year one. The difference in the biomass and harvest index of wheat in both years might be attributed to the fluctuation in rainfall and temperature data as well as change in soil fertility in the two years. The increase in biomass yield and harvest index of wheat in year two over year one might be due to the higher rainfall that might have positive impact on growth, yield and yield components of wheat.

Conclusions

Nutrient management is very important for improving wheat productivity grown after rice. Our results confirmed that wheat grown on plots having more residual P and Zn due to the higher rates of both nutrients applied to the preceding rice crop had positive impact on the number of tillers m^{-2}, straw and biomass yields, and harvest index of subsequent wheat crop. The highest rate of 120 kg P ha^{-1} applied to the previous rice crop increased its residual soil content (11.3 mg P kg^{-1}) after harvest and increased subsequent wheat biomass and harvest index. Similarly, the highest rate of 15 kg Zn ha^{-1} applied to the previous rice crop increased its residual content (1.44 mg Zn kg^{-1}) in the soil after harvest and had positive impact on wheat biomass and harvest index. The high yielding rice genotypes (F-Malakand and Pukhraj) took more P and Zn from the soil and decreased their residual content in the soil. On the other hand, the low yielding fine genotype (B-385) took less P and Zn from the soil and left more residual soil P and Zn contents for the subsequent wheat. Wheat biomass and harvest index was decreased tremendously when grown after the high yielding coarse rice genotypes than grown after fine genotype. Therefore, wheat grown after the high yielding genotype (Pukhraj) either needs an additional P and Zn application or higher rates of both P and Zn could be applied to the preceding high yielding rice genotypes for increasing productivity of the subsequent wheat crop. Biomass and harvest index of wheat was higher in the second year of experiment than the first year of experiment and showed positive relationship with increase in P and Zn contents in soil over the years. Differences in biomass yields and harvest index of wheat in the two years indicates that P and Zn recommendations for increasing the yield under rice-wheat system cannot be easily transferred among different climates. Therefore we recommend further research for different environments in the country.

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