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EFFECTS OF SOLE AND MIXED CULTURE OF WHEAT CROP AND PHOSPHORUS FERTILIZATION ON THE SOLUBILITY OF PHOSPHORUS IN THE SOIL

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Abstract

Farmers face a challenging task to harvest yield potential of crops as well as improving fertilizer use-efficiency under their limited farm resources. Among the macronutrients, the relative efficiency of phosphorus fertilizer is very low in alkaline-calcareous soils under arid and semi-arid environments. Therefore, a field study was undertaken to quantify the interactive effects of wheat varieties and phosphorous fertilization on grain yield and solubility of phosphorous nutrient in the rhizosphere. The treatments consisted of (a) two wheat varieties (Sehr-2006, Shafaq-2006, mixed culture) and (b) three phosphorus levels (0, 45, 85 kg P_2O_5 per hectare) were arranged in randomized complete block design and replicated four times. The results showed that biological grain yield and 1000-grain weight of wheat increased by 8.7%, 14.46% and 8.48% under mixed culture of varieties sehr-2006 and shafaq-2006, respectively over the solely grown varieties. The application of phosphorus @ 85 kg P_2O_5 ha^{-1} resulted in increased quantity of total biological yield, grain yield and 1000-grain weight compared to unfertilized crop. The uptake of nitrogen and phosphorus contents were substantially enhanced under mixed culture cropping pattern over sole wheat cultivars. The availability of phosphorus was increased by19.70% under mixed cropping over sole culture. It is inferred from the study that mixed cropping produced synergetic effects on the availability of nutrients in the rhizosphere, and thereby resulted in the higher production of wheat crop.

Key words: Facilitation mechanism, Phosphorus fertilization, Wheat varieties, Mixed culture, Rhizosphere, Nutrients concentration, Phosphorus availability.

Introduction

Wheat (*Triticum aestivum* L.) is a staple after rice food crop around the globe. It is consumed by 35% of the population, provides 55% carbohydrates and 20 % of total food calories. The demand is substantively high due to logarithm increase in population and increase in production arithmetically (Safa *et al.*, 2009).The wheat production is fluctuated greatly due to various biotic and abiotic stresses. Among the abiotic stresses, the mineral nutrition contributes about 20 to 30% towards yield production (Alam & Shah, 2003). In the realm of nutrients management, phosphorus fertilization holds a key position in sustaining the productivity of wheat crop as well as improving efficiency of added nitrogenous, potassic and micro-nutrient fertilizers.

In Pakistan, more than 80 percent soils are deficient in phosphorus and its quantity is being mined at the rate of -281(000 tons per year), (Anon., 2015). Furthermore, a significant proportion of phosphorus, is converted into calcium phosphate and becomes unavailable to plants, as soil are highly alkaline in reaction and calcareous in nature (Sharif *et al.*, 2000). The availability of phosphorus from labile pool is also very low (Hinsinger, 2001). Thereby, its demand out-strips the supply to crop plants during their critical periods of development under P-deficiency stress. Therefore, plants make certain adaptive measures, i.e., changes in root growth, morphology and induce exudation of certain metabolites and acids to solubilize phosphorus in the rhizosphere (Li *et al*., 2009) and/or the formation of root clusters (Lambors *et al*., 2008). Various investigators reported that desorption and availability of P is enhanced, when cereal crops are grown in mixed culture of white lupin (Cu *et al*., 2005) pigeonpea (Ae *et al.*, 1990), fababean (Li *et al*., 2007) and chickpea (Li *et al.*, 2004).

However, a greater variation exists among plant species with regard to accumulation, depletion and mobilization of P in the rhizosphere (Vu *et al*., 2008). Furthermore, Helal (1990) found that organic and in-organic P is greatly taken by the plants, because of their higher phosphatase activities in the rhizosphere. Various researchers (Krannitz and Caldwell, 1995; Huber-Sannwald *et al*., 1996) found that one's plant root morphology is altered in response to changes occurring in the root system of the neighbouring plants. There are evidences that some crop plants are proficient in exploring and utilizing the nutrient through enhanced development of dense and extensive root system (Jackson *et al.*, 1990; Caldwell *et al.*, 1991). Montgomery *et al*. (2010) and Brooker *et al.* (2008) found simultaneous interaction between competition and facilitation processes exist in response to relative effectiveness exerted by roots of different crop species. Moreover, other investigators (Prieto *et al*., 2011; Armas *et al*., 2011) found that facilitation phenomenon between crop species was accelerated by exploration of indigenous nutrients resources, direct exchange of nutrients, transportation of water and carbon through myccorrhizal networks and proliferation of rooting system under different eco-edaphic environments Starners *et al*. (2008) reported that desorption process and uptake of P by plants was also accelerated due to increase in microbial population and modulation of roots exudates on the chemical composition in the rhizosphere. Sun & He (2010) found that occurring of various signaling networks and chemical interactions produce direct or indirect effects on soil-plant continuum. Currently, a little information is available about the facilitation process for mutual interactions in sharing of phosphorous nutrients in the intra-plant species. Therefore, a field study was undertaken to evaluate the impact of wheat-wheat interaction in response to differential phosphorus levels on the relative distribution of P content in the soil, growth and yield potential of wheat crop.

Materials and Methods

The field investigations were carried out to determine the soil-plant interaction in response to sole and/or mixed culture of wheat varieties and differential P fertilizer application. The research was conducted at the experimental farm of Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, Pakistan (longitude: 71º 30' 79" E; latitude 31º 16' 4" N; altitude 124 m).The treatments consisted of two wheat varieties (Sehr-2006, Shafaq -2006 and mixture of both), and (b) phosphorus fertilizer levels (0, 45, 85 kg P_2O_5 ha^{-1}), were arranged in a factorial design replicated four times. At the time of sowing, the whole quantity of differential P-levels (triple superphosphate) and 50 kg N ha^{-1} (urea) was applied, followed by top dressing of 50 kg N ha^{-1} at the time of second irrigation. The weeds were controlled by foliar spray of herbicides and complemented with mechanical and manual measures. The cultural practices were carried out to maintain proper growth and development of crop. The soil samples were collected from the plough layer before imposition of fertilizer treatments and analyzed according to Ryan *et al*. (2001). The area was free from the any excess of salts (EC_e 1.45 dSm^{-1}) pH (8.2) DTPA-exchangeable-K (91.5 mg kg^{-1}), DTPA-extractable-P (3.8 mg kg^{-1}), organic matter content (0.75%), total nitrogen content (0.06%), and classified as silt loam textural class.

Data on fresh and dry weights of shoot and root organs and plant height were recorded at stem elongation stage. The material was oven dried at 70ºC for 24 hours to a constant weight. The plant material was collected by uprooting the whole plant along with root organs from each experimental plot at maturity. The plants were divided into stem, grain and roots. The shoot and root parts were oven dried at 70ºC for 24 hours. The soil samples from rhizosphere in the proximity of 1.0 mm and for bulk soil entity were gathered from the surface from each treatment according to Hinsinger (2001). The aggregates of soil adhered to roots were gently tapped, dipped in distilled water, blotted and incubated at 60ºC for five days. The soil samples were air-dried and analyzed for available –P according to method (Ryan *et al.,* 2001).The chemical analysis of plant material for nitrogen and phosphorus content was done according to method (Ryan *et al.*, 2001). Data were analyzed statistically according to Fisher's Analysis of Variance (ANOVA) technique and differences among treatment means were compared using the least significant difference (LSD) at 5 % level of probability (Steel and Torrie, 1997).

Results

Statistical analysis of data showed that shoot/root fresh weights and shoot/root dry weight were significantly affected by the varieties and P-levels, however, impacted non-significantly due to their interactive effects at stem elongation stage Averaged across P-levels, growing of mixed culture of wheat varieties was significantly affected compared to growing varieties 'Sehar-2006' and 'Shafaq-2006' as sole crops. Maximum quantity of shoot and root fresh weights was 36.25g and 5.12g; 38.68g and 5.56g, and 39.61g and 5.81g for varieties, 'Sehr-2006' 'Shafaq-2006' and mixed culture, respectively. Averaged across varieties quantities of shoot and root fresh weight increased linearly with each increment of P-dose. The application of 85 kg P_2O_5 ha^{-1} produced maximum quantity of root and shoot fresh weight by 44.74 g and 6.94 g, respectively. However, it did not differ significantly with crop treated with 45 kg P_2O_5 ha^{-1} (Table 1). Averaging data of shoot and root dry weights, across P-level, the individual variety 'Sahr-2006 and 'Shafaq-2006' did not differ significantly but differed significantly, by growing of varieties in mixed culture. Maximum quantities of shoot and root dry weights was 6.64g and 2.20g; 7.08g and 2.34g, and 7.51g, and 2.59g for 'Sehr-2006' and 'Shafaq-2006' and mixed culture varieties, respectively. The application of 85 kg P_2O_5 ha^{-1} fertilizer produced maximum quantity of 8.03g and 4.03g for shoot and root dry weights, however, it differed a little application of 45 kg P_2O_5 ha^{-1} dose of fertilizers (Table 1). Data for plant height recorded at stem elongation stage and maturity differed significantly in response to varieties, P-levels and their interactive effects. The maximum plant height of 90.95 cm was recorded in the mixed culture varieties compared to 80.81cm and 83.58cm attained by varieties 'Sehr-2006 and 'Shafaq-2006', respectively. Averaged across varieties, crop treated with 45 kg P_2O_5 and/or 85 kg P_2O_5 ha^{-1} attained significantly higher plant height by 87.83cm and 89.38cm compared to 78.13cm under unfertilized crop (Table 2).

Data for biological yield and grain yield and their components were significantly affected due to growing of sole varieties and/or mixture and differential P-levels, however non-significantly affected by their interactive effects. Averaged across P-levels, maximum quantity of grain yield of 4.74 Mg ha^{-1} was harvested from mixed culture of varieties compared to produce of 4.15 Mg ha^{-1} and 4.47 Mg ha^{-1} gathered from varieties 'Sehr-2006' and 'Shafaq-2006', respectively. Averaged across varieties, grain yield increased progressively with each increment of P-levels. Crop fertilized with 85 kg P_2O_5 ha^{-1} produced 5.35 Mg $ha^{-1,}$ yield compared to 3.05 Mg ha^{-1} by unfertilized crop, which translated into 42.99% over the untreated check. Moreover, mixed culture of varieties produced heavier 1000-grain weights by 47.5 g compared to 43.87 g and 45.63 g obtained from varieties 'Sehr-2006' and 'Shafaq-2006', respectively. Averaged across varieties, 1000- grain weight increased with increasing doses of phosphorus fertilizer. The crop fertilized with 85 kg P_2O_5 ha^{-1}produced maximum heavier 1000-grain weight by 53.98 g in comparison with 36.67 g produced by unfertilized crop, which amounted to 32.06% increase in proportion to weightage.

Table 1. Interactive effects of wheat varieties and phosphatic fertilizer levels on shoot/root fresh and shoot/root dry weights at stem elongation stage.

Variety	Phosphorous levels (kg P_2O_5 ha^{-1})			Mean
	0	45	85	
(a) Shoot fresh weight (g)				
Sehr-2006	26.06	39.13	43.56	36.25 b
Shafaq-2006	28.07	43.74	44.23	38.68 ab
Sehr + Shafaq	27.41	45.00	46.42	39.61a
Mean	27.18b	42.62 a	44.74a	
(b) Root fresh weight (g)				
Sehr-2006	2.42	6.35	6.60	5.12 b
Shafaq-2006	2.94	6.76	6.98	5.56 ab
Sehr + Shafaq	3.19	7.01	7.24	5.81 a
Mean	2.85 b	6.70a	6.94a	
(c) Shoot dry weight (g)				
Sehr-2006	4.86 b	7.40 a	7.66 a	6.64 a
Shafaq-2006	5.36 b	7.93 a	7.96 a	7.08 ab
Sehr + Shafaq	5.83 b	8.23 a	8.48 a	7.51 a
Mean	5.35 b	7.85 a	8.03 a	
(d) Root dry weight (g)				
Sehr-2006	1.01 c	2.80 b	2.79 b	2.20 b
Shafaq-2006	1.03 c	3.00 ab	3.01 ab	2.34 ab
Sehr + Shafaq	1.24 c	3.23 ab	3.31 ab	2.59 a
Mean	1.09 b	3.01 a	3.04 a	

Means sharing the same letter(s) do not differ significantly at ($p<0.05$) level

Table 2. Interactive effects of wheat varieties and phosphatic fertilizer levels on plant height (cm) at various stage of growth

Variety	Phosphorous levels (kg P_2O_5 ha^{-1})			Mean
	0	45	85	
(a) Stem elongation				
Sehr-2006	58.06	66.10	71.50	65.22 b
Shafaq-2006	61.33	65.63	66.40	64.45 b
Sehr + Shafaq	65.53	70.63	71.86	69.34 a
Mean	61.64 b	67.45 a	69.92 a	
Maturity				
(b) Sehr-2006	76.63 f	81.93 f	83.87 c	80.81 c
Shafaq-2006	78.06 f	85.13 c	87.57 b	83.58 b
Sehr + Shafaq	79.70 e	96.43 a	96.73 a	90.95 a
Mean	78.13 b	87.83 a	89. 38 a	

Means sharing the same letter(s) do not differ significantly at ($p<0.05$) level

The statistical analysis of data revealed that straw yield was affected significantly by various treatments. Averaged across P-levels, that varieties 'Sehr-2006 and 'Shafaq-2006' did not differ within themselves, but differed significantly due to the mixed culture. The growing of mixed culture wheat varieties produced 6.75 Mg ha^{-1} compared to 6.31 Mg ha^{-1} and 6.72 Mg ha^{-1} straw yield by Sehr-2006 and Shafaq-2006 varieties. Averaging straw yield of varieties, maximum quantity of 7.42 Mg ha^{-1} was produced by crop fertilized with 85 kg P_2O_5 ha^{-1} in comparison with 5.33 Mg ha^{-1} by unfertilized crop. The increase in straw yield was found to be 32.02 % and 27.76 % at P-fertilizer application at the rate of 85 and 45 kg P_2O_5 ha^{-1}, respectively over unfertilized crop (Table 3).

Data for nitrogen concentration in different parts of plant differed significantly in response to varietal and P-levels treatments at stem elongation stage. Averaged across P-levels, wheat crop in mixed culture contained nitrogen concentration of 1.04% in their shoot organ, compared to 5.91% and 0.84% in varieties 'Sehr-2006 and 'Shafaq-2006', respectively. Averaged across varieties, crop fertilized with 85 kg P_2O_5 ha^{-1}contained 1.06% N in shoot organ compared to 0.74% in crop treated with zero phosphorus fertilizer. Maximum nitrogen concentration of 0.50% was determined in mixed culture in comparison with 0.39% and 0.32% in root organ of varieties ‘Sehr-2006 and 'Shafaq-2006',respectively.The crop fertilized with 85 kg P_2O_5 ha^{-1}maintained nitrogen concentration of 0.54 % in root tissues compared to 0.22% determined in the unfertilized crop (Table 4).

Table.3. Interactive effects of wheat varieties and phosphatic fertilizer levels on grain, and biological yield.

Variety	Phosphorous levels (kg P_2O_5 ha^{-1})			Mean
	0	45	85	
(a) Grain yield (Mg ha^{-1})				
Sehr-2006	2.60 b	4.73 a	5.13 a	4.25 b
Shafaq-2006	2.86 c	5.10 a	5.46 a	4.47 ab
Sehr + Shafaq	3.70 c	5.00 a	5.46 a	4.46 a
Mean	3.05 b	4.96 a	5.35 a	
(b) 1000- grain weight(g)				
Sehr-2006	33.29 f	43.93 d	54.39 ab	43. 87 b
Shafaq-2006	36.25 f	48.61e	52.03 b	45. 63 ab
Sehr + Shafaq	40. 47 e	46.76 cd	55.54 a	47.59 a
Mean	36.67 c	46.43 b	53.98 a	
(c) Straw yield (Mg ha^{-1})				
Sehr-2006	5.2	6.66	7.06	6.31 b
Shafaq-2006	5.26	7.15	7.47	6.72 a
Sehr + Shafaq	5.53	7.26	7.73	6.75 a
Mean	5.33 c	7.02 b	7.42 a	
(d) Total biological yield (Mg ha^{-1})				
Sehr-2006	7.80	11.39	12.19	10.46 b
Shafaq-2006	8.12	12.25	12.93	11.19 a
Sehr + Shafaq	9.23	12. 26	13.19	11.49 a
Mean	8.38 c	11. 98 b	12.77 a	

Means sharing the same letter(s) do not differ significantly at ($p<0.05$) level

Table.4 Interactive effects of wheat varieties and phosphatic fertilizer levels on concentration of nitrogen (%) at stem elongation stage

Variety	Phosphorous levels (kg P_2O_5 ha^{-1})			Mean
	0	45	85	
(a) Shoot				
Sehr-2006	0.76 e	0.94 cd	1.01 c	0.91 c
Shafaq-2006	0.66 f	0.90 d	0.96 cd	0.84 b
Sehr + Shafaq	0.79 e	1.11 b	1.23 a	1.04 a
Mean	0.74 c	0.98 b	1.06 a	
(b) Root				
Sehr-2006	0.25 e	0.43 cd	0.49 bc	0.39 c
Shafaq-2006	0.15 f	0.38 d	0.45 cd	0.32 b
Sehr + Shafaq	0.27 e	0.57 b	0.68 a	0.50 a
Mean	0.22 c	0.46 b	0.54 a	
(c) Grain				
Sehr-2006	1.31	1.84	2.04	1.73 b
Shafaq-2006	1.37	1.83	1.89	1.70 b
Sehr + Shafaq	1.54	2.30	2.49	2.11 a
Mean	1.41 b	1.99 a	2.14 a	
(d) Straw				
Sehr-2006	0.31 e	0.49 d	0.57 c	0.45 b
Shafaq-2006	0.21 f	0.45 d	0.51 c d	0.39 c
Sehr + Shafaq	0.34 e	0.66 b	0.78 a	0.59 a
Mean	0.28 c	0.53 b	0.63 a	

Means sharing the same letter(s) do not differ significantly at ($p<0.05$) level

Data for nitrogen concentration in grain tissues differed significantly due to varieties and P-levels. At stem elongation stage, maximum nitrogen concentration of 2.11% was found in mixed culture crop compared to 1.73% and 1.70% in varieties ‘Sehr-2006 and 'Shafaq-2006', respectively. Averaged across varieties, crop fertilized with 85 kg P_2O_5 ha^{-1} maintained concentration of 2.14% compared to 1.41% in the unfertilized crop. Similarly, maximum N concentration of 0.59% was determined in stem tissues of mixed culture crop in comparison with 0.45% and 0.39% in varieties 'Sehr-2006 and 'Shafq-2006', respectively. Averaged across varieties, maximum nitrogen concentration of 0.62% was found in stem tissues of crop fertilized with 85 kg P_2O_5 ha^{-1} compared to 0.28% in unfertilized crop (Table 4).

The statistical analysis indicated that data for P-concentration in various plant parts at stem elongation stage differed significantly due to various treatments, but was affected non-significantly in their interactive effects. Crop in the mixed culture contained 2.14g kg^{-1} phosphorus concentration in shoot tissues compared 1.77g kg^{-1} and 2.05g kg^{-1} in varieties 'Sehr-2006 and 'Shafaq-2006', respectively. Varieties grown as sole and/or mixed culture were statistically similar in maintenance of P-concentration in the root tissues. However, varieties did differed significantly in maintaining different quantities of phosphorus in their shoot tissues. The root tissues of mixed culture crop maintained 5.58g kg^{-1} compared to 2.27 and 2.51 5g kg^{-1} determined in varieties 'Sehr-2006 and 'Shafaq-2006, respectively. The crop treated with 85 kg P_2O_5 ha^{-1} contained a quantity of 2.85 g P kg^{-1} in root tissues in comparison with 1.74 g P kg^{-1} by unfertilized crop.

The varieties, P-levels and their interactive effects produced significant impact on the maintenance of phosphorus content in the grain tissues. The crop sown in a mixed culture contained 3.25g P kg^{-1} compared to 2.64 and 2.88 g P kg^{-1} maintained by varieties 'Sehr-2006 and 'Shafaq-2006, respectively. Whereas, crop fertilized with 85 kg P_2O_5 ha^{-1} maintained a quantity of 3.63 g P kg^{-1} in the grain tissues compared to 1.64 g P kg^{-1} maintained by unfertilized crop. The higher quantity of 1.12 g P kg^{-1} was determined in straw tissues of mixed culture crop compared to 0.87 and 1.05 P kg^{-1} by maintained varieties 'Sehr-2006 and 'Shafaq-2006, respectively. Averaged across varieties, crop fertilized with 85 kg P_2O_5 ha^{-1} maintained a quantity of 1.40 g P kg^{-1} compared to 0.34 g P kg^{-1} in stem tissues (Table 5).

Data for phosphorus content in the rhizosphere differed significantly in response to varieties, P-levels and their interactive effects. Maximum content of P (20.5 mg kg^{-1}) was determined in the rhizosphere of mixed culture crop compared to 17.20 and 18.63mg P kg^{-1}in rhizosphere of varieties 'Sehr-2006 and 'Shafaq-2006, respectively. Averaged across varieties, maximum quantity of 26.99 mg P kg^{-1} was found in rhizosphere of crop treated with 85 kg P_2O_5 ha^{-1} compared to 10.00 mg P kg^{-1} in unfertilized crop. Furthermore, maximum content of 15.11mg P kg^{-1} in bulk soil was determined in soil under cultivation of varieties 'Sehr-2006 compared to 14.77 mg P kg^{-1} in bulk sample in soil under mixed culture crop, having non-significant differences with each other. The crop fertilized with 85 kg P_2O_5 ha^{-1} contained 16.84 mg P kg^{-1} in bulk soil samples compared to 10.93 mg P kg^{-1} in unfertilized crop. The different P-levels differed significantly amongst each other (Fig. 1).

Table 5. Interactive effects of wheat varieties and phosphatic fertilizer levels on concentration of phosphorous (g kg^{-1}) at stem elongation stage.

Variety	Phosphorous levels (kg P_2O_5 ha^{-1})			Mean
	0	45	85	
(a) Shoot				
Sehr-2006	1.03 d	2.08 b	2.21 b	1.77 b
Shafaq-2006	1.35 c	2.35 ab	2.45 ab	2.05 a
Sehr + Shafaq	1.36 c	2.43 ab	2.64 a	2.14 a
Mean	1.24 b	2.29 a	2.64 a	
(b) Root				
Sehr-2006	1.53 d	2.58 b	2.71 ab	2.27 a
Shafaq-2006	1.55 c	2.78 ab	2.91 a	2.51 b
Sehr + Shafaq	1.86 c	2.89 a	2.98 a	2.58 a
Mean	1.74 b	2.85 a	2.85 a	
(c) Grain				
Sehr-2006	1.26	3.25	3.41	2.64 b
Shafaq-2006	1.73	3.38	3.52	2.88 ab
Sehr + Shafaq	1.95	3.83	3.97	3.25 a
Mean	1.64 b	3.48 a	3.63 a	
(d) Straw				
Sehr-2006	0.31	1.08	1.21	0.87 b
Shafaq-2006	0.35	1.35	1.45	1.05 b
Sehr + Shafaq	0.36	1.43	1.56	1.12 a
Mean	0.34 b	1.29 a	1.40 a	

Means sharing the same letter(s) do not differ significantly at ($p<0.05$) level

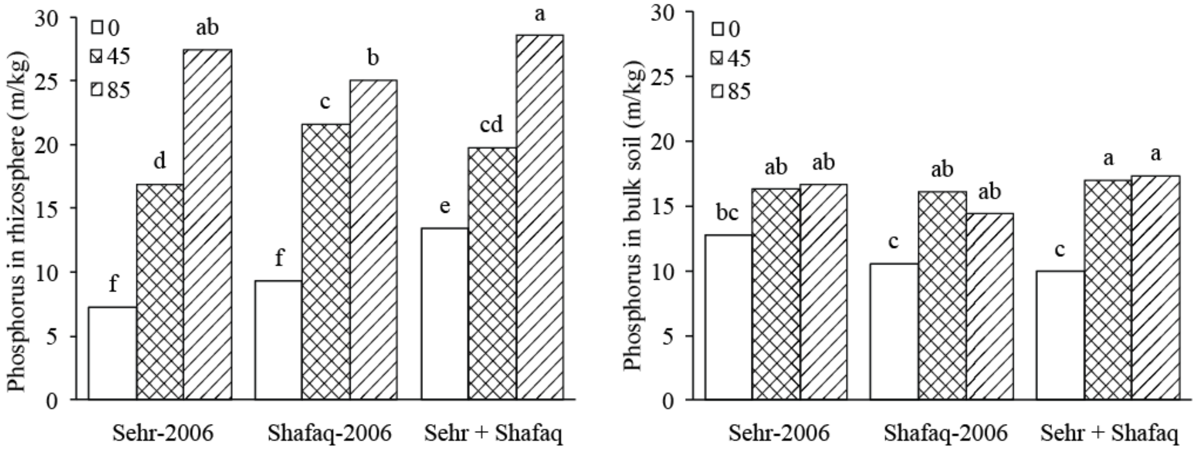

Fig. 1. Interactive effects of wheat varieties and phosphatic fertilizer levels on content of phosphorus (mg kg^{-1}) in rhizophere and bulk soil.

Discussion

The biomass production regarding fresh and dry weights of shoot and root organs were affected to a greater extent in response to varieties, P-levels and at their interaction. Cralle *et al.* (2003) also gathered higher quantities of biomass of wheat crop than Italian ryegrass, when grown in an equal proportion. Similarly Cu *et al.* (2005) found higher quantities of biomass of wheat grown in association with white lupin. Thorsted *et al*. (2006) found that production of higher biomass was outcome of soil-plant interaction. The result of the study are in agreement with those of Yousef *et al.* (1997) that biomass production was complemented with large number of tillers and vigorous growth and development in response to higher desorption of P from the labile-pool in association with symbiotic root system of different crop species. Similarly Wang *et al.* (2007) also reported that growing together of two wheat varieties (Goldmark plus Janz) caused increase in biomass of shoot and root organs. It also resulted in extensive proliferation of rooting system, greater utilization of P by root and shoot organs and thus maintaining higher P-concentration in shoot and grains organs.

The attainment of higher plant height was resultant of soil-plant interaction i.e inducing greater release of rooting system of exudates through inter-signaling of complementary crop species and/ or varieties (Cu *et al.*, 2005), Arihara *et al*. (1991) reported that wheat and sorghum attained higher growth and development, when mixed crop with white lupin and pigeonpea crops. The attainment of higher plant height attributed to differential genetic make-up and efficiency of P-uptake from the soil. The result of the study are in harmony with those of Cue *et al.* (2005) that mixed culture of wheat and white lupin resulted in greater uptake of P by shoot organs and simultaneous increase in shoot growth by 45% and 33% respectively.

The results of the present study indicate that grain yield of wheat improved successively with each increment of P-levels. Rehman (1984) obtained higher grain yield of wheat and lentil crops, when grown in mixed culture other than sole species. Similarly, Prasad *et al.* (1998) harvested higher grain yield in the mixed culture of wheat and barley compared to sole crop cultivation. The result of the study corroborate with those of Sinha *et al.* (1989) and Kumar *et al.* (2003) that wheat yield was improved by 9.8% by application of 90 kg P_2O_5 ha^{-1} compared to untreated check. Kumar & Kumar (1997) also reported increase in wheat grain yield linearly with each additive P-dose. Furthermore, Li *et al*. (2001) reported yield of wheat-soyabean and wheat-maize mixed culture crops was 28-30% and 40-70%, respectively compared to mono crop pattern. The various researches (Shammri & Soni, 1981; Alam & Shah., 2003; Khan *et al.*, 2007) also found significant increase in grain yield by application of 90 kg P_2O_5 ha^{-1} to wheat crop. Thorsted *et al.* (2006) found greater production of biological yield in mixed culture of wheat and white lupin due to improved sharing of nutrients between rooting systems of both crops. Brooker *et al*. (2008) found that different species could fetch benefits from each other, when grown in intercropping system.

The various parts of wheat crop assimilated greater quantity of nitrogen under differential phosphorus fertilizer levels and alone or mixed cropping system. Zhang *et al*. (2001) reported increased uptake of nitrogen nutrient by wheat/soybean and wheat/maize crops in the order of 23.0 and 19.0% and 50.0 and 59.0%, respectively. Wenxue *et al.* (2003) found that mixed culture of wheat-maize and wheat-fababean crops absorbed higher amount of nitrogen compared to mono-cropping system. The result of the study are in agreement those of Jing *et al.* (2010) that addition of P-fertilizer accelerated acidification of P in the rhizosphere and proliferation of roots in alkaline medium, thereby improved greater absorption of nitrogen by maize crop.

The addition of different levels of P-fertilizer resulted in increased uptake of P nutrient by various plant organs. Similarly Betencourt *et al.* (2011) found that mixed culture of wheat-chickpea caused greater uptake of P from soil due to soil-root interaction. The reason being that organic compounds mainly composed of citrate and oxalate compounds solubilized native P-reservoirs and thereby enhanced its greater uptake by plants. Hinsinger (2001) found that root released low molecular weight organic acids accompanied by H^+ extrusion and phosphatase enzymes for mineralization of organic-P. Moreover, variability existed between P-proficient and P-efficient genotypes in the release of carboxylate compounds (Li *et al.,* 1995). The results inferred from the study indicated that P-content increased in the rhizosphere in response to mixed cropping and added P-fertilizer. Grinsted *et al*., (1982) found greater amount of P in the rhizosphere and bulk soil at maturity of maize crop. Various researchers (Gahoonia & Nielson, 1992; Hinsinger, 2001) found that P-dynamics with regard to internal charge balance is altered by higher uptake of cation and discharge of protons (H^+) in rhizosphere. The result of the study agree with those of Grinsted *et al.* (1982) and Hinsinger (2001) that dynamics of P-adsorptio- desorption reactions is modulated by solubility of in-organic P by exudation of oxalates in the rhizosphere.

Conclusion

The cultivation of wheat varieties in a mixed culture proved highly efficient in enhancing the wheat grain yield in comparison with growing of a sole crop. The wheat crop responded highly to application of phosphorus fertilizer for maximizing yield productivity. The greater amount of phosphorus nutrient was desorbed from the soil reserves in the rhizospher compared to bulk soil under the mixed cropping of wheat varieties rather than growing them as a sole entity.

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