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Evaluating the Interactive Effects of Rates and Methods of Phosphorus Application on Wheat Productivity

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Abstract: Wheat (*Triticum aestivum* L.) is one of the major cereal crops of the world, which is grown under diverse climatic conditions across the globe. It is consumed as a staple food by the people of Pakistan. However, its productivity is low as compared to the potential of varieties being cultivated. Phosphorus (P) application is very important to increase the yield of wheat. In this study, wheat productivity was evaluated under different P application rates and techniques. It was applied through band-placement, broad-casting and fertigation at seven different levels (viz. 0, 25, 50, 75, 100, 125, 150 kg P_2O_5 ha^{-1}). The results revealed that P fertigation improved yield parameters, straw and grain P contents, P uptake and protein in wheat grain as compared to other techniques. Moreover, the high Olsen P was found for broad-casting technique. The applied P at higher rates increased the P contents, its uptake, Olsen P and wheat yield; P fertigation at 125 kg P_2O_5 ha^{-1} was more appropriate and economically viable for increasing the wheat yield.

Key words: Application techniques, Benefit-cost-ratio, Olsen P, Protein, *Triticum aestivum* L.

INTRODUCTION

Plant nutrients play a key role in plant growth and its development. Among the macronutrients, P is very important for growth but it is the least available macronutrient to plants in soil (Vance *et al.*, 2003; Miguel *et al.*, 2015). It is essential for the transformation of energy and plays an important role in different metabolic processes in plants. For example, it acts as a major component in cellular energy storage and root growth, and is also necessary for cell differentiation and tissues development in plants (FAO, 2000; Nemery and Garnier, 2016; Imran *et al.*, 2016). Furthermore, P is the central part of energy rich compound (ATP) and vital for the growth of crops from seed to the harvest. It is reported that chemical fertilizers boost the crop yield and productivity when applied at an optimum rate; but farmers usually apply sub-optimal doses of P (Hussain *et al.*, 2008; Hussain *et al.*, 2016) and potassium as compared to nitrogen (NFDC, 2002; Iqbal *et al.*, 2016). In Pakistan, the NPK ratio, applied by the farming community in the recent decade, was 1:0.28:0.01 (Ahmad and Rashid, 2004), that is much lower as compared to recommended ratios 1:1:0.50 (Shah, 1994). This sub-optimal dose of P and K in crop plants may drastically reduce the plant growth, development and finally the yield (Kavanova *et al.*, 2006; Sarker *et al.*, 2015). In a study, Grant *et al.* (2005) found that P requirement starts since the inception of plant growth.

The phosphorous use efficiency of crops in Pakistan is also very low. Akhtar *et al.* (2016) reported sever P deficiency in Pakistani soils (> 90%) due to its fixation problem in calcareous soil having high pH (Sharif *et al.*, 2000). Studies reported that more than 80% of applied P became fixed and thus remained unavailable to plants; the remaining 20% became a part of soil solution or partially precipitated (Leytem and Mikkelsen, 2005). The release of adsorbed P in calcareous soils towards soil solution becomes difficult with the passage of time (Delgado *et al.*, 2002; Miller and Arai, 2017).

To achieve the production targets for burgeoning population, optimization of P rates and application techniques for improving the fertilizer use efficiency along with net returns by the farmers is direly needed.

Indeed, P application time and technique play a vital role for improving phosphorus-use-efficiency

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(PUE). Broad-casting of P at the time of seed bed preparation is a common practice in Pakistan. However, the P applied through broadcasting may be converted to insoluble P due to more contact of P with soil particles that results reduction in its efficiency (Shah *et al.*, 2006). In this scenario, banding of P is a more preferable application technique to reduce P fixation (Rehman *et al.*, 2006). In an earlier study, Rehim *et al.* (2012a) observed high PUE and wheat yield under band-placement of P. In another study, Alam *et al.* (2002) found high PUE, P uptake and wheat yield by top-dressing or fertigation than broad-casting of P. Although, P application through fertigation increases the growth and yield; the P application rates for different application techniques need to be adjusted. Thus, this experiment was planned to compare various P application techniques with variable rates on wheat productivity, P uptake and PUE.

MATERIALS AND METHODS

This study was conducted at the research farm of Faculty of Agricultural Science and Technology, Bahauddin Zakariya University, Multan, during the years 2011 and 2012. Multan is located in the arid and subtropical region of Pakistan. Soil samples were collected and analyzed for physico-chemical properties given (Table 1). The triple super phosphate was the source of phosphorus that was applied by three methods, i.e., broadcasting, band-placement and fertigation, at different levels, viz., 25, 50, 75, 100, 125 and 150 kg P_2O_5 ha^{-1}. The experiment was arranged in randomized plot design with split plot arrangement (P application methods in main plot; P rates in sub plots), with a net plot size of 2.7 m × 4 m, replicated thrice. The agro-metrological components of the study site are presented in Table 2. The wheat cultivar used in this experiment was Sehar-2006. The wheat crop was sown in rows (22.5 cm) on 25th of November, 2011, using hand-drill, with the seed rate of 125 kg ha^{-1}. The nitrogen (urea) and potassium (sulphate of potash) were applied at a rate of 120 and 55 kg ha^{-1}, respectively. The nitrogen was added in two splits (sowing and 1st irrigation) but full potassium was added at sowing. Further, the band-placement and broadcasting of phosphorus was carried out at sowing, while the fertigation was done at 1st irrigation. The weeds were controlled by manual method. The total amount of water applied to crop during whole growth cycle was 300 mm. The crop was harvested at maturity on April 18, 2012. The data regarding the entire yield related traits were recorded following the study of Farooq *et al.* (2017). The grain and straw P concentration was determined after harvesting (Method 54a, US Salinity Lab. Staff, 1954). The grain protein contents (%) were estimated as described by Chapman and Parker (1961). Olsen P was also determined from soil samples at harvesting (Olsen *et al.*, 1954). Total P concentration in grains and straw was estimated by given equation (Rehim *et al.*, 2012b):

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

PUE was recorded as described by Fageria *et al.* (1997).

$$\text{PUE (\%)} = \frac{\left[\text{Total P uptake (kg ha}^{-1}\text{) in fertilized plot}\right] - \left[\text{Total P uptake (kg ha}^{-1}\text{) in control plot}\right]}{\text{P dose applied (kg ha}^{-1})}$$

Table 1: Pre-sowing physico-chemical soil analysis.

Determination		Unit	Value	
			0-15 cm	16-30 cm
A	**Physical analysis**			
	Sand	%	28	30
	Silt	%	54	51
	Clay	%	18	19
	Textural class	Silty clay loam		
B	**Chemical analysis**			
	pH		7.80	8.00
	Saturation percentage	%	35.00	36.00
	EC	dS m^{-1}	3.12	2.47
	Organic matter	%	0.78	0.45
	Total nitrogen	%	0.04	0.03
	Available phosphorus	Ppm	6.10	5.20
	Available potassium	Ppm	190	110
	$CaCO_3$	%	8.90	9.10

Table 2: Weather data during the whole course of experiment.

Month	Mean monthly temperature (°C)	Mean monthly relative humidity (%)	Total monthly rainfall (mm)
November	19.15	56.70	0.00
December	15.45	76.75	0.00
January	12.20	76.30	2.10
February	15.80	54.80	2.40
March	23.50	53.45	45.10
April	30.40	24.45	6.50

Source: Agricultural Meteorology Cell, Central Cotton Research Institute, Multan, Pakistan.

Statistical and economic analysis: Data obtained from experimental results was statistically analyzed by Fisher's analysis of variance. The analyzed data was compared by LSD test at 5% probability level (Steel *et al.*, 1997). The economic analysis was also done to judge the feasibility of treatments for the end users (farmers) (Khan *et al.*, 2012).

RESULTS AND DISCUSSION

Interactive effect of phosphorus (P) levels with methods of P application was significant for number of grains per spike, productive tillers and 1000-grain weight of wheat (Table 3). Band placement and fertigation of P at 100, 125 and 150 kg ha^{-1} substantially enhanced the population of productive tillers of wheat while the minimum productive tillers were observed in control (0 kg ha^{-1} of P) and at lower level of P (25 kg ha^{-1}) under all methods of P fertilization (Table 3). Likewise, P application at 100, 125 and 150 kg ha^{-1} improved the number of grains per spike under all application methods, while control (0 kg ha^{-1} of P) and lower level of P (25 kg ha^{-1}) had the minimum number of grains per spike (Table 1). Fertigation of P at 125 and 150 kg ha^{-1} produced statistically higher 1000-grain weight than other treatments (Table 3).

The interaction of P levels with methods of P application was also significant for grain yield, straw yield and grain protein contents (Table 4). Maximum grain yield and straw yield was obtained in plots, where P_2O_5 was fertigated at 125 and 150 kg ha^{-1}; however the minimum yield was observed in control (0 kg ha^{-1} of P) plots, that was statistically at par for grain yield with plots, where lower level (25 kg ha^{-1}) of P was broadcasted (Table 4). Similarly, the higher grain protein contents of wheat were noted at higher levels, i.e., 125 and 150 kg ha^{-1} of P_2O_5, under fertigation; while the lower grain protein contents were recorded in control (0 kg ha^{-1} of P) plots but it was at par with lower P level (25 kg ha^{-1}) under broadcasting (Table 4).

Table 3: Interactive effect of rate and method of P application on yield related traits of wheat.

Treatment	Number of productive tiller (m^{-2})			Number of grains per spike			1000-grain weight (g)		
Phosphorus levels kg ha^{-1}	Broadcast	Band placement	Fertigation	Broadcast	Band placement	Fertigation	Broadcast	Band placement	Fertigation
0	242 j	242 j	242 j	28.3 h	28.3 h	28.3 h	29.4 h	29.4 h	29.4 h
25	247 ij	251 h-j	255 g-j	29.3 h	29.7 h	30.0 h	31.2 l	32.9 k	34.1 j
50	254 g-j	261 f-i	264 f-h	32.3 g	33.0 fg	33.7 e-g	33.5 jk	34.3 ij	35.6 gh
75	261 f-i	272 d-f	275 b-f	34.3 d-f	34.3 d-f	34.7 d-f	35.3 hi	36.3 f-h	37.1 d-f
100	264 f-h	281 a-e	285 a-e	35.3 c-e	35.7 b-d	36.0 b-d	36.4 e-g	37.9 d	39.4 bc
125	272 c-f	290 ab	294 a	38.0 a	38.3 a	38.3 a	37.9 d	39.6 bc	41.0 a
150	270 e-g	286 a-d	288 a-c	37.3 ab	37.0 a-c	37.3 ab	37.3 de	39.2 c	40.3 ab
LSD at 5%	12.92			3.38			0.40		

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

Table 4: Interactive effect of rate and method of P application on yield and grain protein contents of wheat.

Treatment	Grain yield (t ha^{-1})			Straw yield (t ha^{-1})			Grain protein contents (%)		
Phosphorus levels kg ha^{-1}	Broadcast	Band placement	Fertigation	Broadcast	Band placement	Fertigation	Broadcast	Band placement	Fertigation
0	2.26 h	2.26 h	2.26 h	3.93 g	3.93 g	3.93 g	7.40 k	7.40 k	7.40 k
25	2.50 gh	2.67 g	2.68 g	4.66 f	4.73 f	4.79 f	7.75 jk	7.93 j	8.10 j
50	3.10 f	3.21 f	3.30 f	5.07 ef	5.45 de	5.57 c-e	8.61 i	8.95 hi	9.03 h
75	3.72 e	3.90 de	3.97 c-e	5.41 de	5.63 cd	5.7 cd	8.98 hi	9.49 g	10.17 f
100	3.88 de	4.02 c-e	4.28 bc	5.86 cd	6.02 bc	6.37 ab	10.41 f	10.91 e	11.14 de
125	4.08 cd	4.31 a-c	4.64 a	6.49 ab	6.68 a	6.81 a	11.49 cd	11.87 bc	12.68 a
150	4.01 c-e	4.26 bc	4.53 ab	6.38 ab	6.67 a	6.72 a	11.52 b-d	11.89 b	12.70 a
LSD at 5%	0.23			0.77			0.40		

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

The interaction of P levels with methods of P application was significant for total P uptake, Olsen P, grain and straw P contents and PUE of wheat (Tables 5-6). A linear rise in total uptake of P by crop, grain and straw P contents and in Olsen P was recorded with increasing P level (Table 5). Fertigation seemed to be the best methods; as P fertigation at 150 kg P_2O_5 ha^{-1} showed significantly high grain and straw P contents and as well as total P uptake. However, maximum Olsen P was observed at 150 kg ha^{-1} of P_2O_5 with broadcasting (Table 6). Moreover, P fertigation at 125 kg P_2O_5 ha^{-1} also had the highest PUE, while broadcasting of P at all levels showed minimum PUE (Table 6).

Economic analysis affirmed the supremacy of higher levels of P application (up to 125 kg ha^{-1}) with fertigation as compared with all other combinations (Table 7). The P fertilization at 125 kg P_2O_5 ha^{-1}, using fertigation method, provided higher net income and benefit-cost ratio (BCR). Although, the band placement of P observed higher expenses but net income and BCR was low in case of broadcasting of P (Table 7).

Table 5: Interactive effect of rate and method of P application on grain and straw P contents and total P uptake of wheat.

Treatment	Grain P contents (%)			Straw P contents (%)			Total P uptake (kg ha^{-1})		
Phosphorus levels kg ha^{-1}	Broadcast	Band placement	Fertigation	Broadcast	Broadcast	Broadcast	Broadcast	Band placement	Fertigation
0	0.180 m	0.183 lm	0.183 lm	3.96 o	3.96 o	3.96 o	6.63 l	6.63 l	6.64 l
25	0.197 kl	0.200 jk	0.213 ij	5.45 n	5.45 n	5.45 n	8.03 k	8.83 jk	9.39 ij
50	0.213 ij	0.227 hi	0.233 h	7.14 k	7.14 k	7.14 k	10.49 i	12.00 h	13.44 g
75	0.237 h	0.253 g	0.260 g	10.85 i	10.85 i	10.85 i	14.03 g	15.86 f	16.98 ef
100	0.263 fg	0.277 ef	0.290 c-e	12.30 g	12.30 g	12.30 g	16.46 f	17.92 e	20.25 cd
125	0.283 de	0.300 c	0.323 b	15.49 d	15.49 d	15.49 d	19.13 d	20.97 c	24.30 a
150	0.297 cd	0.317 b	0.340 a	18.42 a	18.42 a	18.42 a	19.78 d	22.39 b	25.27 a
LSD at 5%	0.013			0.012			1.19		

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

Table 6: Interactive effect of rate and method of P application on Olsen P and PUE of wheat.

Treatment	Olsen P (mg kg^{-1})			PUE (%)		
Phosphorus levels kg ha^{-1}	**Broadcast**	**Band placement**	**Fertigation**	**Broadcast**	**Band placement**	**Fertigation**
0	3.96 o	3.96 o	3.96 o	0.00 l	0.00 l	0.00 l
25	5.45 n	5.22 n	5.00 n	5.60 k	8.80 i	11.00 ef
50	7.14 k	6.54 l	6.05 m	7.72 j	10.74 fg	13.60 b
75	10.85 i	10.06 j	9.75 j	9.87 h	12.31 c	13.79 ab
100	12.30 g	11.68 h	10.96 i	9.83 h	11.29 de	13.61 b
125	15.49 d	14.70 e	13.88 f	10.00 h	11.47 d	14.13 a
150	18.42 a	17.33 b	16.55 c	8.77 i	10.51 g	12.42 c
LSD at 5%	0.48			0.40		

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

Table 7: Interactive effect of rate and method of P application on net income and BCR of wheat.

Treatment	Total expense (US$ ha^{-1})			Gross income (US$ ha^{-1})			Net income (US$ ha^{-1})			Benefit: cost ratio (BCR)		
Phosphorus levels kg ha^{-1}	Broadcast	Band placement	Fertigation	Broadcast	Broadcast	Broadcast	Broadcast	Band placement	Fertigation	Broadcast	Band placement	Fertigation
0	666	690	666	762	762	762	96	72	96	1.14	1.10	1.14
25	708	732	708	852	903	908	144	171	200	1.20	1.23	1.28
50	750	774	750	1036	1078	1108	286	304	358	1.38	1.39	1.48
75	792	816	792	1223	1280	1302	431	464	510	1.54	1.57	1.64
100	834	858	834	1282	1326	1411	448	468	577	1.54	1.55	1.69
125	876	900	876	1358	1429	1527	482	529	651	1.55	1.59	1.74
150	918	942	918	1334	1414	1493	416	472	575	1.45	1.50	1.63

P_2O_5 cost was Rs. 140 kg^{-1} and wheat grain and straw cost was Rs. 23.75 and 2.5 kg^{-1}, respectively (1 Rs. = 0.012 US$).

The results showed that interaction of different P fertilization methods with different rates have improved the wheat yield, net income and P use efficiency. The fertigation of P at a rate of 125 kg ha^{-1} proved to be the best; however, Olsen P was maximum in broadcasting method (Tables 3-7). The grain yield is the result of productive tillers and 1000 grain weight. In this study, the high grain yield in fertigation method with P applied at 125 kg ha^{-1} was due to more productive tillers and 1000-grain weight, while the number of grains spike^{-1} remained unaffected (Table 3) (Jabran *et al.*, 2011; Oberson *et al.*, 2011). Moreover, the increase in number of tillers might be due to improvement in radicle and seminal root germination due to P fertilization (Rehim *et al.*, 2012a). The improvement in P uptake in band placement and fertigation was due to the availability of P in proximity of roots during early growth period. The availability of P at early growth stages in banding and more P uptake in fertigation under varying P levels resulted in heavier grains which might be due to role of P in grain formation (Table 5). The P placement application method with high rates has effectively enhanced soil P accumulation and crop yield (Mallarino and Sievers, 2016). Similar result was observed by Jabran *et al.* (2011), where yield parameters were improved by fertigation and banding method of P.

In fertigation method, P has less contact with $CaCO_3$ and soil exchange complex, which result in less P precipitation and ultimately more soil solution P with high application rate of P (Shah *et al.*, 2006; Wang *et al.*, 2017) as was observed in this study. These results also demonstrated a high grain and straw yield with fertigation method of P at 125 and 150 kg ha^{-1}. The high PUE in fertigation method thus improved the P uptake in wheat crop in this study (Table 6). Similar results were found, in which the methods for P fertilizer application with increased rates have increased the yield (Tarkalson and Bjorneberg, 2016). At high P application rates, the PUE was decreased as the plants consumed less portion of P when applied at higher amount (Rehim *et al.*, 2012a; Rehim *et al.*, 2016).The production of tillers was found to decrease in P deficient conditions, which might be due to low amount of P change affect the usual pattern of tiller emergence through preventing the leave emergence on main stem (Daniel *et al.*, 1998; Sanford and Larson, 2016).

Phosphorus plays an important role in grain formation and its development. In this study, the uptake of P was more at higher rates, i.e., 125 and 150 kg P_2O_5 ha^{-1} with fertigation, which resulted in an increase in grain weight and number of grains spike^{-1} (Table 3). The increase in yield contributing parameters consequently increases the grain yield at higher P rates (Hussain *et al.*, 2008; Anwar *et al.*, 2016) and the same was observed in this study.

In broadcasting method, there was observed more Olsen P owing to fixation of more P in soil due to enhanced fertilizer-soil (Rehman *et al.*, 2006). Furthermore, in fertigation method, high P contents in grains and straw, as compared to broadcasting and band-placement methods, was due to less P fixation in fertigation method (Hussein, 2009). The protein contents of grains were high with P fertigation (Table 5). Since P is an integral component of DNA and RNA and phosphate group bonds with RNA or DNA, its economic analysis is important for the adaptation of any new technology (Shah *et al.*, 2013). The net income return and benefit: cost ratio (BCR) was high in fertigation method at higher P rate (125 kg P_2O_5 ha^{-1}), which was due to more grain production and high PUE (Tables 5-7).

CONCLUSION

Fertigation method of P increased the wheat grain yield, quality and PUE compared to broadcasting and band-placement methods. Similarly, wheat performance was significantly enhanced with the addition of P fertilizer. P application at 125 kg P_2O_5 ha^{-1} was an economical and more viable source of P which improved wheat yield and quality.

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