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FERTIGATION HELPS IN INCREASING PHOSPHORUS USE EFFICIENCY OF WHEAT (*Triticum aestivum* L.) COMPARED TO CONVENTIONAL METHOD

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Phosphorus use efficiency is low and ranges between 10-20% among macro fertilizers. It fixes into the soil hence decreases its availability to current crops. The hiking prices of phosphatic fertilizer and shortage at sowing of wheat limited its application. Many efforts have been made to improve its efficiency. Fertigation among these efforts offers a practical solution to improve its efficiency. Therefore this study was planned to compare the efficiency of P fertigation at first and second irrigation with P broadcasting at sowing time (farmers' conventional practice). Recommended dose (90 kg ha^{-1}) of phosphorus fertilizer was applied and treatments used in this experiment included, control, recommended dose (RD) of P through broadcast before sowing, ½ of RD of P through soil at sowing and ½ fertigation at first irrigation, ½ of RD of P through fertigation at second irrigation, ¾ of RD of P through fertigation at first irrigation and RD of P through fertigation at first irrigation. The three years results revealed that phosphorus application through fertigation at first irrigation increased number of spikes m^{-2}, number of grains per spike, 1000-grain weight, phosphorus use efficiency (PUE) and significantly higher wheat grain yield (4.64 t ha^{-1}) as compared to when it was applied through broadcast before sowing. The findings imply that P fertigation at first irrigation is equally significant even by application of ¾ recommended dose of P as compared to full recommended dose of P application through broadcast before sowing.
Keywords: Fertigation, broadcasting before sowing, P use efficiency, grain yield

INTRODUCTION

Wheat (*Triticum aestivum* L.) is not only the most important cereal crop in the world but also the major source of staple food for the people of Pakistan (Tunio, 2006; Malik, 2006). In Pakistan it contributes 10.1 percent to the value added in agriculture, 2.2 percent to GDP and cultivated in an area of 8693 thousand hectare during 2012-13 (Anonymous, 2013). Despite its higher yield potential, yield per hectare is very low in Pakistan as compared to other wheat producing countries (Sarwar *et al.*, 2010). There are many reasons of low yield but the most important is the injudicious use of phosphorus fertilizer. Phosphorus (P) is an important inorganic nutrient for plant growth, and its deficiency often limits primary productivity in cropping systems (Vance *et al.*, 2003). Being non-renewable resource, the global P reserves are being depleted, with half depletion predicted to occur between 2040 and 2060 (Lambers *et al.*, 2006). As P is less mobile, less soluble and highly susceptible to soil fixation; effectiveness of applied P depends on the properties of soil being fertilized, fertilizer itself, time and method of its application (Iqbal *et al.*, 2003; Ali *et al.*, 2012; Khan *et al.*, 2012; Muhammad *et al.*, 2013). More than 80% of added P gets fixed by adsorption and precipitation reaction and only a part of it goes to soil solution which may be taken up by crops (White, 1982; Jones, 1998; Ahmad and Rashid, 2003; Leytem and Mikkelsen, 2005). The remaining fraction available to subsequent crops by desorption and dissolution reactions. With time, adsorbed P becomes difficult to release into soil solution and consequently efficiency of P fertilizer in calcareous soils remains low (Saleem, 1992; Delgado *et al.*, 2002). In Pakistan, mostly soils are P deficient, containing <10 mg kg^{-1} Olsen P (Memon, 2005) and hence phosphorus fertilization is necessary for crop production, as it plays a crucial role in energy storage and transfer within the cells, speeds up root development, facilitates greater nitrogen uptake and results in higher grain yield and grain protein contents (Rehim *et al.*, 2012, Hayyat and Ali, 2010, Alam *et al.*, 2003, Shah *et al.*, 2003; Clark, 1990). Salinity also affects growth and nutrition of crops (Ahmad et al., 2012; Arshad *et al.*, 2012). The consistently increasing prices of P fertilizers and their shortage at the right time of application mostly accounts for low fertilizer usage (Shahbaz *et al.*, 2006, Alam *et al.*, 2005). Therefore, improving PUE has been a subject of great concern and P application through irrigation, termed as fertigation, has recognized as an important and cost-effective P fertilization technique due to its encouraging results (Latif and Iqbal, 2002; Alam *et al.*, 2005). P application before wheat sowing is of negligible advantage until first irrigation to crop (Latif *et al.*, 1994). Rapid P uptake took place only after first irrigation i.e. 3-4 weeks after germination due to higher demand for P at this time of growth as compared to other growth stages (Romer and Schilling, 1986; Alam *et al*., 1999). Shortage and high price of P fertilizer at the time of wheat sowing becomes a burning issue, due to general understanding that P must be applied at sowing time. Hence fertilizer use becomes halved to that of recommended and most poor farmers fail to apply P at all; while fertigation method involves the addition of fertilizers to irrigation water instead of the conventional method of broadcasting fertilizer on the soil surface. The potential advantages of fertigation include flexibility in timing of fertilizer use in relation to crop demand, improved P use efficiency, and reduce the cost of crop production through savings in fertilizer expenditure. Keeping in view the advantages of fertigation, the present study was planned to compare the conventional P application method of broadcasting and incorporation to soil at the time of sowing with that of P fertigation at first irrigation on the growth and P use efficiency of wheat.

MATERIALS AND METHODS

The present field experiment was conducted at the farm area of Soil Chemistry Section, Institute of Soil Chemistry and Environmental Sciences, Ayub Agricultural Research Institute Faisalabad, Pakistan for three continuous years. The experiment was performed by using Randomized Complete Block design having plot size of 5m × 7m and was replicated thrice. Fertilizer application was done at the rate of 120 kg ha^{-1} nitrogen, 90 kg ha^{-1} phosphorus and 60 kg ha^{-1} potash. Before sowing, a composite soil sample was collected from the field and was analyzed for physicochemical properties (Table 1).

Table 1. Physico-chemical properties of soil before the start of study

Characteristics	Units	Value
Sand	%	54.91
Silt	%	21.03
Clay	%	24.06
Textural class		Sandy clay loam
Saturation percentage	%	35.2
pH_s	---	8.11
EC_e	dS m^{-1}	1.83
Organic matter	%	0.63
Total nitrogen	%	0.02
Available phosphorus	mg kg^{-1}	7.34
Extractable potassium	mg kg^{-1}	194

Soil texture was determined by hydrometer method as described by Moodi *et al*., (1959). For determining pH of soil, about 250g soil was saturated with distilled water. The paste was allowed to stand for one hour and pH was recorded by pH meter with glass electrodes using buffer of pH 4.0 and 9.0 as standard according to the methods described by the U.S. Salinity Lab. staff 1954 and Mclean, 1982. For determining EC_e, extract of each soil paste was obtained by using vacuum pump and EC_e was noted with conductivity meter Corning 220. Soil organic carbon (SOC) content was estimated following the method described by Ryan *et al.* (2001), and available phosphorus was estimated by Olsen's method (Jackson, 1962). While for potassium, soil extraction was done with ammonium acetate (1 N of pH 7.0) and potassium was determined by using PFP-7 Janway Flame photometer (Rowell 1994). Meteorological data during the year of 2009-10, 2010-11 and 2011-12 is given in Figure 4.

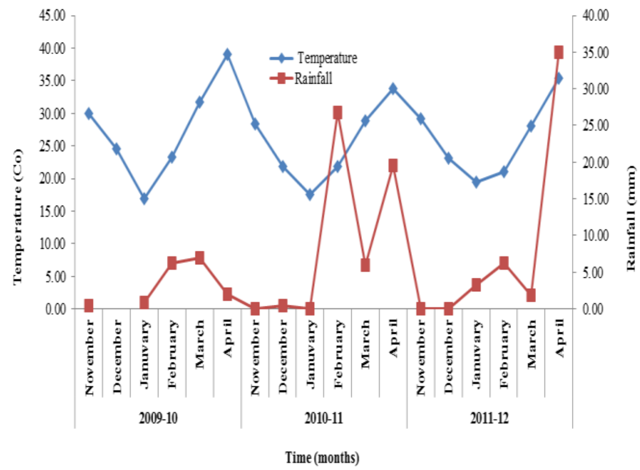

Figure 4. Meteorological data showing mean monthly maximum temperature and rainfall during the growing seasons of wheat crop (2009-10, 2010-11 and 2011-12)

Wheat cultivar, Faisalabad-2008 was sown with recommended method, seed rate (124 kg ha^{-1}) and row to row distance (22.5 cm × 22.5 cm). The treatments used in this experiment included T1, control, T2, recommended dose of P (90 $kgha^{-1}$) through broadcast before sowing, T3, ½ of RD of P through soil at sowing and ½ fertigation at first irrigation, T4, ½ of RD of P through fertigation at second irrigation, T5, ¾ of RD of P through fertigation at first irrigation and T6, RD of P through fertigation at first irrigation. Half N and full dose of K was applied at sowing and remaining half N was applied with first irrigation by broadcasting. Phosphorus through fertigation at first irrigation was applied after thirty days of crop emergence. The solution of triple supper phosphate (TSP) fertilizer was prepared at 1:5 fertilizers to water ratio in small plastic drums fitted with water tap at the bottom and placed at inlet of irrigation water flowing from water channel to the sub plots receiving P through fertigation. At the beginning of the irrigation, the out lets of plastic drums were regulated in such a manner that the whole solution was delivered just before the termination of irrigation. Overall five irrigations were given to crop according to its requirement. Weeds were controlled chemically by spraying broad and narrow leaves weedicides.

At harvest data regarding agronomic traits as number of spikes m^{-2}, number of grains per spike, 1000-grain weight (g), plant height (cm), spike length (cm), grain yield (Mg ha^{-1}) and harvest index (%) were recorded. Area of nine meters square was harvested at maturity randomly from the center of each plot. The harvest of each plot was collected, labeled, sun-dried and threshed individually. Grain and straw samples were taken and dried in an oven at 70°C. The dry grain and straw samples were ground and 0.5g sample was digested with Tri-acid mixture of HNO_3-H_2SO_4-$HClO_4$ for the determination of total phosphorus by metavanadate yellow color method as described by Jackson (1979**)**. The total phosphorus content in plant was measured on a spectrophotometer (IRMECO Model U 2020) at 410-nm wavelength. Then from the standard curve, P contents (%) in grain and straw were calculated. Total P uptake by straw, grains and phosphorus use efficiency (PUE) was calculated according to formulae given by Rehim *et al.* (2012) and Fageria *et al.* (1997).

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

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

The three years data were pooled and analyzed statistically by using Statistics 8.1 versions. Least Significance Difference (LSD) technique was used for comparing treatment means (Steel and Torrie, 1997).

Economic analysis: A benefit-cost analysis was conducted to estimate the economic feasibility of different rates and methods of P application to increase wheat production and net economic returns as described by CIMMYT (1998).

RESULTS AND DISCUSSIONS

Compared to different methods and time of P application showed that fertigation of RD of P fertilizer at first irrigation (T6), resulted in highest increase (4.88, 4.76, 8.60 and 9.17 %) in plant height, spike length, number of spikes m^{-2} and harvest index over (T2), where RD of P fertilizer was applied through broadcast (farmers' practice) before sowing (Fig. 2). The numbers of grains $spikes^{-1}$and 1000 grains weight are also important to predict the yield of wheat grain. The highest numbers of grains $spike^{-1}$ (43) and 1000 grains weight (41.7g) was found in treatment where RD of P fertilizer was applied through fertigation at first irrigation. While the numbers of grains $spike^{-1}$ (39) and 1000 grains weight (40g) was found in treatment where RD of P fertilizer was applied through broadcast before sowing (Table 3). Results showed that maximum grain yields (4.64 and 4.57 Mg ha^{-1}) were obtained by the application of RD of P through fertigation at first irrigation (T6), and where 1/2 RD of P was applied through soil and 1/2 fertigation at first irrigation (T3), which were statistically significant to all other treatments. Similarly, the grain yield (4.43 Mg ha^{-1}) attained by the application of 3/4 RD of P through fertigation at first irrigation (T5) was also statistically significant over (T2), where RD of P fertilizer was applied through broadcast before sowing (Fig. 1). Similar results were explained by Vishandas *et al.* (2006) and Alam*et al.* (1999) that lower P rates applied through fertigation resulted in equivalent grain yield as compared to higher P rates applied by broadcast method. The comparison of fertigation and conventional method of P broadcasting showed that RD of P through fertigation at first irrigation (T6), resulted in (9.95, 15.38, 10.26 and 40.38 %) increase of grain yield, grain P contents, number of grains $spike^{-1}$ and PUE over (T2), where RD of P fertilizer was applied through broadcast (farmers' practice) before sowing (Fig. 2). Higher grain

Table 3. Effect of phosphorus application methods at varying rates on 1000 grain weight, number of grains $spike^{-1}$ and P use efficiency of wheat

Treatments	1000-grain weight (g)	Number of grains per spike	Grain P contents (%)	Straw P contents (%)	P uptake in grain (kg ha^{-1})	P uptake in straw (kg ha^{-1})	Total P uptake (kg ha^{-1})	P use efficiency (%)
T1	22.0 d	21 d	0.18 d	0.02 d	3.23 e	0.50 e	3.73 e	0.00 e
T2	40.0 b	39 b	0.26 c	0.05 bc	11.25 c	3.01 c	14.26 c	11.69 d
T3	41.3 ab	42 a	0.30 a	0.07 a	13.67 a	4.61 a	18.28 a	16.16 c
T4	38.3 c	36 c	0.27 bc	0.04 c	10.67 d	2.20 d	12.87 d	20.31 a
T5	41.3 ab	40 b	0.29 ab	0.06 ab	12.78 b	3.97 b	16.75 b	19.28 b
T6	41.7 a	43 a	0.30 a	0.07 a	14.03 a	4.47 a	18.50 a	16.41 c
LSD	1.62	1.00	0.02	0.01	0.39	0.29	0.52	0.87

Means in a column not sharing the same letters differ significantly from each other at 5% probability level.

harvests with fertigation of P is possibly an indication of increased P availability at peak demand period of crop, most probably because of the lesser contacts of fertilizer P with alkaline earth carbonates and soil colloids which are partially responsible for precipitation, fixation and retention of phosphorus fertilizer (Memon *et al.*, 2011).

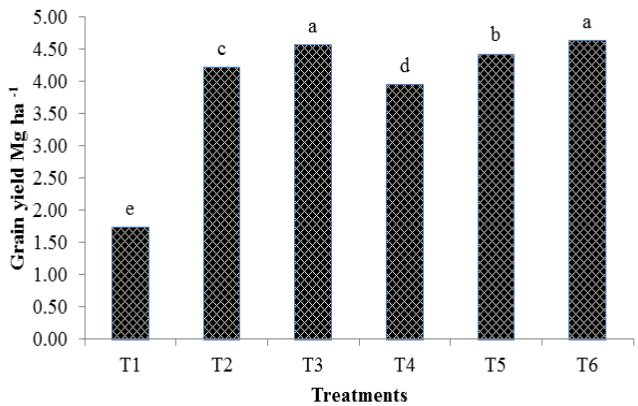

Figure 1. Effect of phosphorus application methods at varying rates on grain yield of wheat

The results revealed that P uptake by grain, straw and their total was highest, where P was fertigated at first irrigation (T6), i.e. (14.03, 4.47 and 18.50 kg ha^{-1}) respectively (Table 3).

In contrast, where P was applied following conventional method of broadcasting before sowing (T2), the P uptake in grain, straw and their total were recorded comparatively low, i.e. (11.25, 3.01 and 14.26 kg ha^{-1}), respectively (Table 3). The results (Figure 2) showed that corresponding increases in P uptake by grain, straw and their total by T6 over T2 were 24.71, 48.50 and 29.73 %, respectively.

Table 4. Effect of phosphorus application methods at varying rates on net income and benefit-cost ratio of Wheat.

Treatments	Total expenditure (Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit-cost ratio (BCR)
T1	41900	49020	7120	1.17
T2	55986	114510	58524	2.05
T3	56286	123900	67614	2.20
T4	49243	107790	58547	2.19
T5	52764	118605	65841	2.25
T6	56286	122940	66654	2.18

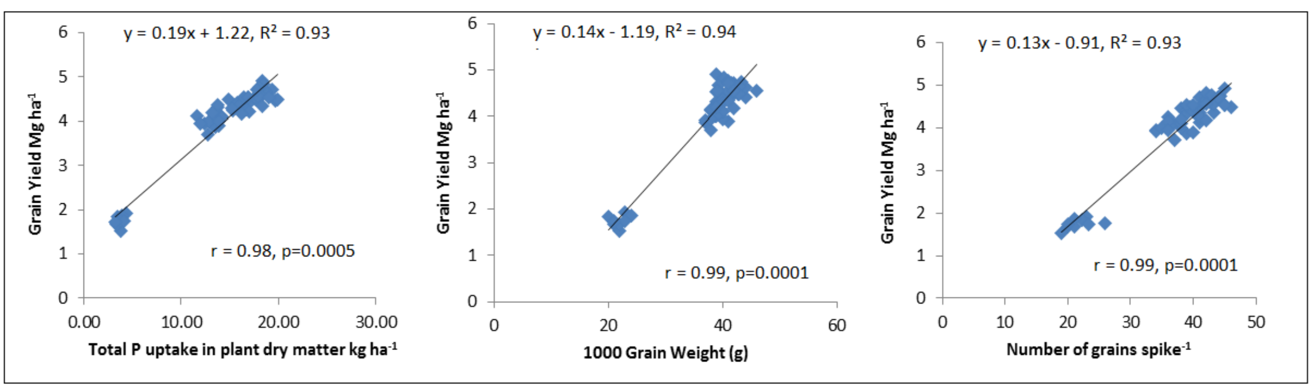

Figure 3. Pearson correlations between number of grains $spike^{-1}$, 1000 grain weight and total P-uptake with grain yield

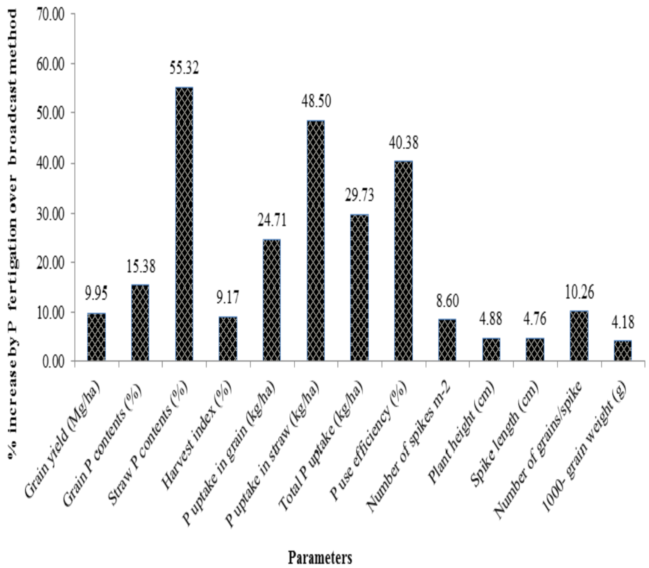

Figure 2. Percent increase in various parameters of wheat by P fertigation over conventional broadcast method.

Improvement in grain and straw P content seems due to readily available P through fertigation to the developing roots and thereby result in improved P use efficiency (Hussein, 2009). Low recovery of broadcast P is an indication of relatively high P fixation and conversion of applied phosphates to less available form owing to alkaline calcareous nature of the soil (Memon *et al.*, 2011). Similarly, Latif *et al.*, 1997 and Hussein, 2009 reported that maize plant receiving P in solution form at first irrigation contained significantly higher P content as compared to P applied by broadcast at sowing. Higher PUE at lower P level might be the result of intense root competition and thereby an efficient exploitation of applied P fertilizer. Similar results were explained by Rahim *et al.* (2012) that at higher P application rates plants used smaller proportion of fertilizer P that resulted in low PUE. There was a better efficiency of applied nutrients (PUE) and higher grain yield, during 2010-11, 2011-12 than in 2009-10. This might have resulted from better plant root growth due to more rainfall and less temperature during the crop growth period (Fig. 4). Correlations were also studied between total P uptake, 1000 grain weight and number of grains spike^{-1} with grain yield. The data set for correlations consisted of 54 observations for each parameter. A positive and strong correlation of growth attributes with grain yield produced was found (Fig. 3).

The potential advantages of fertigation include improved fertilizer use efficiency, flexibility in timing of fertilizer use in relation to crop demand, increased crop yields and improved quality of the produce. Our findings correlate with the previous findings of Latif and Iqbal (2002), Latif *et al.* (1994), Alam *et al.* (1999) and Hussein (2009) who observed that phosphorus applied by fertigation resulted in improving the P efficiencies as compared to its soil mixing at sowing.

The cost benefit ratio (Table 4) indicates that fertigation of P fertilizer at first and second irrigation as compared to broadcasting before sowing gave maximum return. Similarly Vishandas *et al.* (2006) and Alam *et al.* (2005) reported that P fertigation at first irrigation improved grain yield, P use efficiency and profitability of wheat. Higher net income and BCR by the fertigation of P was the direct result of better grain yield due to more efficient utilization of applied fertilizer. Phosphorus fertigation at first irrigation is a feasible option of P fertilization for improved P use efficiency, and reduce the cost of crop production through savings in fertilizer expenditure.

***Conclusion*:** In conclusion, in this study wheat yield and its components increased significantly with the use of P through fertigation as compared to broadcast method. PUE of fertigated P at lower rates was relatively more than its higher rates and broadcasted. On overall basis fertigation seemed a more efficient method of P application and is the best option to harvest maximum wheat productivity, PUE and net economic returns.

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