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Phosphorus fertigation: A technique for enhancing P fertilizer efficiency and yield of wheat and maize

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Abstract

Methods of application of fertilizer are one of the major causes for low fertilizer Phosphorus (P) use efficiency in alkaline calcareous soils. Three-year field studies, on wheat and maize were undertaken to compare the response of P applied in the irrigation water with broadcast method. The treatments include: control (no applied P), P applied with broadcast method (farmer practice) and P applied with irrigation water (Fertigated P). Generally fertigated applied P proved to be very suitable to increase grain yield, P-uptake, agronomic efficiency and P use efficiency both in wheat and maize. In wheat, fertigated P increased grain yield by 12 to 18%, P uptake by 4 to 32%, agronomic efficiency by 11 to 20% and P use efficiency by 2 to 13% during three cropping seasons as compared to broadcast method. Similarly fertigated P caused an increase of 11% in grain yield, 18% in P-uptake, 65% in agronomic efficiency and 90% in P use efficiency over broadcast method in maize. In conclusion, the use of P fertilizer through fertigation could be a useful technique to increase grain yield and P use efficiency in cereals.

Keywords: *P-fertigation, wheat, maize, grain yield, agronomic efficiency, P use efficiency*

Introduction

It is anticipated that the world population will increase from 6 (in 1999) to at least 9 billion by the year 2044, an increase of 50 percent in 45 years (International Data Base, 2010). However, in contrast to population growth, option of expansion of cultivated land is limited. Because of this, we will invariably move to more intensive agriculture aimed at increasing food production, where chemical fertilizers will be extensively used. However, there is an increasing concern about the effective and efficient utilization of fertilizers (Ali *et al.,* 2012). The promotion of efficient and effective fertilizer use, which means best management of fertilizers at farmer's level, was identified as an important contribution to the strategy needed to address problems faced due to intensive agriculture.

Phosphorus is one of the most important nutrients for crop production after nitrogen. Rock phosphate a non-renewable resource which is exclusive parent material for developing commercial P fertilizers is likely to deplete in 50-100 years (Jasinski, 2006). P fertilizers are considered different from the other nutrient carriers in that they are less mobile, less soluble and highly prone to fixation by the soil constituents, hence they are used at sowing time as broadcast applied to the surface once per year at recommended dose to the crops like wheat, maize, berseem etc. P use efficiency is relatively low with this method because P is highly immobile in the soil, and does not positionally match up with plant rooting system. Little utility of applied P before sowing until first irrigation to wheat crop was reported by Latif *et al.* (1994). Rapid P uptake took place after irrigation; 3-4 weeks after germination (Ali *et al.,* 1988, Alam *et al.,* 1999). The demand for P at this stage of growth is much higher compared to other stages of growth (Romer and Schilling, 1986). Emphasis is being given on the efficient use of P fertilizer for sustainable crop production (Ryan, 2002).

Fertilizer application in irrigation water (flood fertigation) of nitrogen is being practiced by farmers since many years but phosphate fertilizers are considered unsuitable for fertigation. Soluble P fertilizers are mostly used in drip irrigation system (Memon, 1985; Munir *et al.,* 2004). Flood P-fertigation (P fertilizer through irrigation water) seems to be an innovative technique where nutrients in the form of solution are applied through irrigation water to reach the crop roots rapidly, which is also an effective means of controlling the time and placement of fertilizers and improving fertilizer use efficiency by reducing nutrient losses from leaching, and/or fixation in the soil to less available forms. Overall, inefficient P use with surface application of dry P fertilizer results in excessive P fixation in soil and less consumption by crops and increases production costs. Thus much applied P is fixed by soil minerals, particularly on the crops where the soil is derived from volcanic ashes. Fertigation P is the practice of applying P fertilizers with the irrigation water by injecting fertilizer solutions (mixing SSP with water and then decanting the P solution) into the flowing water of an

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irrigation system. Keeping in view the importance of fertigation, the present study was undertaken to evaluate the usefulness of fertigated P on yield, P-uptake, P use efficiency (PUE) and agronomic efficiency (AE) of maize and wheat crops.

Materials and Methods

Experimental planning

Three-year field experiments were conducted on wheat and maize at farm of Nuclear Institute for Agriculture and Biology (NIAB), Faisalabad. Some selected properties of the soils collected from experimental fields determined by the standard methods are given in Table 1. Nitrogen was applied as basal dose at recommended rates (120 kg N ha^{-1} for wheat and 150 kg N ha^{-1} for maize) to the whole field and to all the crops. The source of N was urea. P fertilizer was applied as treatments; control, broadcast and fertigation for method evaluation. The source of P was single super phosphate (SSP). The treatments were replicated four times and arranged in a randomized complete block (RCB) design in all the experiments. In case of wheat, P fertilizer was applied at 44 kg P ha^{-1} while, for maize crop it was at 33 kg P ha^{-1}. SSP in broadcast method was spread over respective plots and incorporated in soil at the time of sowing of wheat and maize crops. In case of fertigation treatment, SSP fertilizer was dissolved in sufficient water and its dissolved portion was used for fertigation.

Table 1: Properties of soils collected from different sites

	Wheat field experiment	Maize field experiment
pH (2:1)	7.75-8.01	7.81-7.92
Organic matter, %	0.57-0.96	0.81-0.89
ECe, mS cm^{-1}	0.39-0.41	0.33-0.38
P Olsen's, $mgkg^{-1}$	5.05-10.06	7.10-12.02
Textural class	Loam	Loam

The solution quantity was adjusted so as to go into irrigation water uniformly in whole treatment plot. For wheat, fertigated-P was applied as a single full dose at the time of 1st irrigation. For maize, fertigated-P was applied in two splits; half at 1st irrigation and half at 2nd irrigation. Wheat variety Inqlab-91 and maize variety Akbar was grown during all the cropping seasons. Without P fertilizer plots were used as control. Wheat was sown with tractor drill at a seed rate of 120 kg ha^{-1} and maize at a distance of 75 cm from row to row and 20 cm from plant to plant. The plot size was 15 m x 6 m for wheat and 6 m x 3 m for maize. At maturity, area of 6 m^2 from 3 places from wheat plots was harvested and grains were separated for yield record. Inner two rows from maize plots were harvested at maturity, cobs were removed, dried and grains were separated to record yield. Grain and Straw/stalk samples were collected for analysis for their P contents. Phosphorus in the grain and straw was determined by yellow colour methods (Jackson, 1962) for calculating total P uptake in crops. The data were statistically analyzed by analysis of variance as factorial arrangement of treatments in randomized complete block (RCB) designed (Steel and Torrie, 1960). The comparison among treatment means was made by Duncan's Multiple Range Test (Duncan, 1955).

Phosphorus use efficiency (PUE) and Agronomic Efficiency of P (AEp) were calculated according to the following equations:

$$\text{PUE} = \frac{Pf - Pc}{P} x100$$

Pf is total P uptake by fertigated or broadcast plots, *Pc* is total P uptake by check (control) plots and *P* is the applied P in $kgha^{-1}$.

$$\text{AE}_\text{P} = \frac{Yp \quad - \quad Yc}{Ap}$$

Yp is grain yield of P fertigated or broadcast plots, *Yc* is grain yield of check plots and Ap is the amount of applied P in kg ha^{-1}(Saleem, 1994).

Results and Discussion

Wheat grain yield

Phosphorus application, irrespective of method of application significantly increased the grain yield of wheat over control during all the three cropping seasons (Figure 1). Maximum grain yield 5.692 ± 0.319, 5.249 ± 0.602 and 4.161 ± 0.19 t ha^{-1} (Mean, 5.033 ± 0.370 t ha^{-1}) was obtained in treatment where P was applied as fertigated-P in 1st, 2nd and 3rd year, respectively, while the corresponding grain yield with broadcast method was 4.810 ± 0.451, 4.665 ± 0.525 and 3.687 ± 0.489 t ha^{-1} (average 4.387 ± 0.488 t ha^{-1}) . The grain yield of fertigated plots was from 12 to 18% greater than broadcast method and from 32 to 39% greater than control treatment during three year cropping seasons (Table 2). Irrespective of the P treatments maximum grain yield was recorded during 1st cropping year, and it could be ascribed to the maximum organic matter in the soil (Table 1) at 1st cropping year that might be due to ploughing under of wheat straw in soil in previous year before the start of experiment. The increase in grain yield of wheat by the application of organic matter along with synthetic fertilizer is reported in recently conducted studies (Yassen *et al.,* 2010; Tahir *et al.,* 2011).

Table 2: Increase in grain yield, P-uptake, agronomic efficiency and P use efficiency of wheat by fertigation over broadcast method during three cropping season

Copping season	Grain yield	P-uptake	PUE	AEp
	Increase by fertigation (%) over broadcast			
Year-1	18.30	26.94	12.84	20.00
Year-2	12.51	3.68	1.59	13.27
Year-3	12.86	32.32	8.90	10.77

Nitrogen fertilizer is more widely used in the fertigation than any other nutrients (Singandhupe *et al.*, 2003). Phosphorus, the important plant nutrient, when applied as broadcast method of application, predominantly remain in the top layer and it cannot move into the plant roots if the moisture content is reduced. In case of flood fertigation, phosphorus moves to the roots with sufficient quantity of moisture. Similar results were reported by Shaymaa *et al.* (2009) that fertigation with 100% NPK water-soluble fertilizers increased tomato fruit yield significantly over furrow irrigated control. Uptake of NPK, recovery and fertilizer use efficiency was higher, on an average across fertigation rates over furrow and drip irrigation.

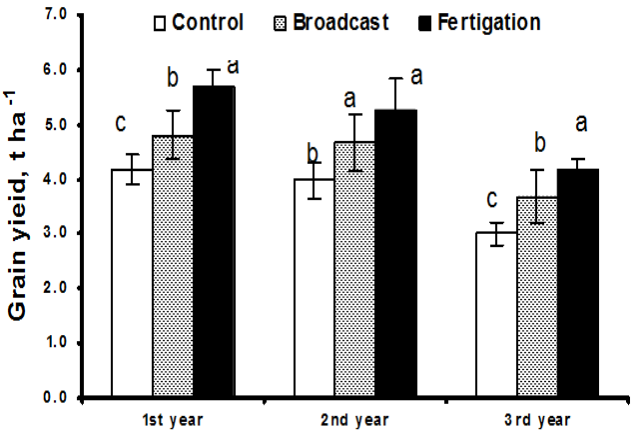

Figure 1: Effect of method of P application on grain yield of wheat during three cropping season

Wheat P-uptake and efficiency parameters

Total P uptake by wheat grain significantly increased over control due to P application and maximum was with fertigated-P, however, P-uptake was higher in 1st cropping year (Figure 2). P-uptake data shows an increase of 4 to 32% in P-uptake by fertigation over broadcast method during the three cropping years with the maximum (32%) in 3rd cropping season (Table 2). Higher P-uptake in 1st year could be ascribed to the higher grain yield in this year. With fertigation method, agronomic efficiency was 10 to 16% higher and P use efficiency was 2 to 9% higher compared to broadcast method during these years (Table 2). Several workers have compared the efficiency of soil applied P with fertigation (Earl and Jerry, 1977; Chase, 1985; Mikkelsen and Jarrell, 1987) and in most cases demonstrated greater efficiency of fertigated P as compared to broadcast applied P. The efficiency of fertilizer sources can be calculated in terms of yield and its P uptake per unit of fertilizer application. Generally phosphatic fertilizer sources have been compared with regard to their yield performance (Malik *et al.,* 1992). However, the yield of a crop depends on several other factors; comparison of efficiency of sources may be made on P uptake basis. Highest P use efficiency and agronomic efficiency with fertigated-P was observed in wheat as compared to broadcast method (Iqbal *et al.,* 2003).

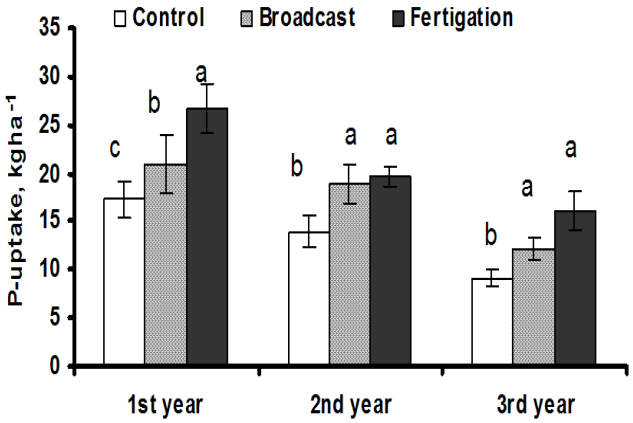

Figure 2: Effect of method of P application on grain P uptake of wheat during three cropping seasons

A long time reaction of soluble P with soil makes its reaction doable with solid phase of soil (Kardos, 1964) or with calcium carbonate and formation of relatively insoluble products with Ca, Fe and Al leading to P fixation (Brady, 1984). All these processes are dawdling down when P fertilizer is applied through fertigation as plant absorbs P quickly and directly from solution applied through fertigation or the positive effect of fertigation might be due to optimum moisture in soil at fertigation

time, which facilitated maximum utilization of applied P by wheat.

Maize grain yield

Fertigation gave significantly higher grain yield ($p<0.05$) as compared to the yield obtained with the same dose of P applied by broadcast method during three cropping seasons (Figure 3). Fertigated P yielded 9.242 ± 0.489, 9.532 ± 0.213 and 10.249 ± 0.190 t ha^{-1} grain (Mean, 8.515 ± 0.843 t ha^{-1}) over the three cropping seasons while corresponding grain yield by broadcast method was 8.209 ± 0.525, 8.085 ± 0.325 and 9.779 ± 0.602 t ha^{-1} (averaged 8.691 ± 0.484 t ha^{-1}) respectively (Figure 3). This indicated the relatively higher performance of fertigated applied P as compared to broadcast method. Higher grain production with fertigation is possibly by the increased P availability at proper time of demand of the maize crop and most likely the lesser contact of P fertilizer with alkaline calcareous soil which are partially responsible for precipitation and fixation of P fertilizer (Shah *et al.*, 2001). SSP was used in these trials, which is acidic and performed very efficiently in soil. Higher corn production was also reported by Raun *et al.* (1987) by using water soluble fertilizer; Urea phosphate applied through sprinkler fertigation.

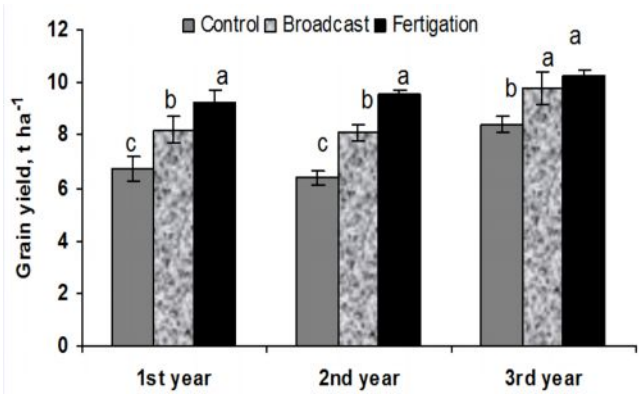

Figure 3: Effect of method of P application on grain yield of maize during three cropping season

Maize P-uptake and efficiency parameters

Fertigation applied P gave significantly higher P uptake (Figure 4) as compared to the P taken-up by broadcast method during three cropping seasons. With fertigated applied P an increase of 17, 65 and 90% was noted in mean P-uptake, agronomic efficiency and P use efficiency, respectively, over broadcast method across the three crop seasons (Table 3).

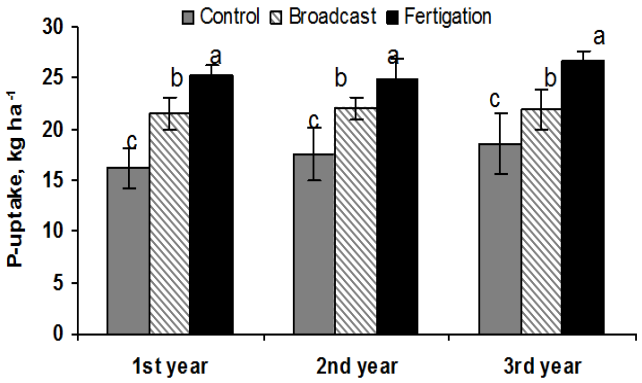

Figure 4: Effect of method of P application on P-uptake by maize during three cropping season

Table 3: Grain yield, P-uptake, agronomic efficiency and P use efficiency of maize (means of 3 years cropping seasons)

Method of application	Grain yield	P-uptake	AEp	PUE
	t ha^{-1}	kg ha^{-1}	kg kg^{-1}	%
Control	7.179	17.47	-	-
Broadcast	8.691	21.77	45.82	13.03
Fertigation	9.674	25.62	75.60	24.70
Benefits with fertigation (%)	11.31	17.68	65.00	89.54

The P use efficiency by fertigation was 24.70% as compared to as low as 13.03% with broadcast method of application. These indicated the relatively higher performance of fertigated P application as compared to broadcast method. Papadopoulos (1994) reported that in calcareous soil having high pH, fertigation was superior to conventional soil P application. Latif *et al.* (1997, 2002) and Alam *et al.,* (1998) also demonstrated the fertigation as a more efficient method of nutrient management than broadcast method. Latif *et al.* (2001) reported that lower dose of nitrogen along with full dose of P when applied through fertigation gave equal P uptake to that by full dose of N and same dose of P. It shows that crop benefited maximum from balanced P supply through fertigation. Rauschkolb *et al.* (1976) also reported similar results.

Conclusion

From the results of this study it is concluded that fertigated-P increase the yield of wheat and maize over conventional broadcast method.

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