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PHOSPHORUS FERTIGATION AT FIRST IRRIGATION DUE TO ITS UNAVAILABILITY AT SOWING TIME PREVENTS YIELD LOSSES IN *TRITICUM AESTIVUM* L.

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Abstract

Phosphorus (P) deficiency is a widespread problem in modern agriculture that is playing havoc with the crop yields. The shortage and black-marketing of P fertilizers at sowing time is a burning issue. P fertigation offers a practical solution of this problem. We conducted this field experiment to compare the efficacy of P fertigation at first irrigation to P broadcasting at sowing time (farmers' conventional practice). P fertigation at first irrigation proved superior to P broadcast at sowing time, even at 2/3rd recommended rate. Fertigation increased plant height (7.7%), tillers plant^{-1} (27.7%), spike length (4.6%), grains spike^{-1} (3.2), grains plant^{-1} (30.2%), seed index (4.9%), straw yield (5.4%), grain yield (9.3%), P uptake in straw (14.6%), grain (22.8%) and their total (19.8%), P fertilizer efficiency (68.1%), grain:nutrient ratio (54.3) and value:cost ratio (42.4). Wheat grain yield was significantly correlated with all the parameters in order of plant height (0.83*), seed index (0.84*), number of grains plant^{-1} (0.87*), P uptake in straw (0.87*), P fertilizer efficiency (0.89*) > spike length (0.89**), total P uptake (0.91**), grain P uptake (0.92**) > number of grains spike^{-1} (0.95***), VCR (0.97***) and GNR (0.98***). Our results conclude that P fertigation at first irrigation is equally significant even at lower P rates and is more advantageous at equal P rates to farmers' conventional practice of P broadcasting at sowing time.
Key words: Phosphorus, fertigation, broadcast, P fertilizer efficiency, *Triticum aestivum* L., value:cost ratio

Introduction

Phosphorus (P) is an important inorganic nutrient for plant growth, and its deficiency often limits primary productivity in natural and 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). About 80–90% of P applied as fertilizer is sorbed by soil particles, rendering it unavailable especially for P-inefficient plants (Jones, 1998).

In Pakistan, the majority of soils are P deficient, containing <10 mg kg^{-1} Olsen P (Memon, 2005) and hence phosphatic fertilization is indispensable for crop production. Moreover, the P fertilizer efficiency (PFE) is not more than 25% in Pakistan (Ahmad & Rashid, 2003). Thus, improving PFE has been a subject of great concern and P application through irrigation, termed as fertigation, has recognized as an important and

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cost-effective P fertilization technique in Pakistan due to its encouraging results (Latif & Iqbal, 2002; Alam *et al.*, 2005).

Fertigation involves the addition of fertilizers to irrigation water instead of the conventional method of broadcasting fertilizer on the soil surface. The potential advantages of this method include improved fertilizer use efficiency, flexibility in timing of fertilizer use in relation to crop demand, increased crop yields, improved quality of the produce and saving in labour (Latif & Iqbal, 2002).

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 (Alam *et al*., 1999), due to much higher demand for P at this time of growth as compared to other growth stages (Romer & Schilling, 1986). P application at first irrigation instead at sowing is reported to be more beneficial (Nisar *et al.*, 1992).

In Pakistan and elsewhere, the black marketing problem of phosphatic fertilizers at the time of wheat sowing becomes a burning issue. This is because of general consensus of their indispensable application at the sowing time. Employing previous research results, we hypothesize that P fertigation at first irrigation, in case of the unavailability of phosphatic fertilizers at sowing time; may prevent yield losses of wheat. In this field experiment we compared the farmers' P application method of broadcasting and incorporation to soil at the time of sowing with that of fertigation at first irrigation for their effect on the growth and yield of wheat crop, involving different rates and timings.

Material and Methods

A field experiment was conducted at the research area of Soil Fertility Section, Agriculture Research Institute, Tandojam, Sindh. A piece of land (approximately one acre), previously under cotton crop, was ploughed twice followed by three times working with cultivator and leveling. The soil under study was heavy (47% clay), free from salinity hazard (EC: 0.40 dS m^{-1}), alkaline in reaction (pH: 8.3), calcareous in nature ($CaCO_3$: 13.0%), low in organic matter (0.79%) and Olsen's available P (8.6 mg kg^{-1}). A soaking dose of irrigation was applied to the field. At proper moisture condition, wheat *cv.* TJ-83 was drilled at the rate of 125 kg ha^{-1} in plots of 123 m^2 each (11.5 m x 10.7 m), employing randomized complete block design. In total, there were 28 plots comprised of seven quadruplicated treatments. The treatments included T1: control (No P), T2: Recommended P (RP, 85 kg ha^{-1}) applied through broadcasting at sowing, T3: RP applied in two equal splits each through broadcasting at sowing and first irrigation, T4: RP applied through fertigation at first irrigation, T5: 2/3rd RP (64 kg ha^{-1}) applied through fertigation at first irrigation, T6: RP applied in two equal splits each through broadcasting at sowing and fertigation at first irrigation, T7: RP applied in two equal splits each through fertigation at first and second irrigation. Nitrogen (N) was applied to all the treatments at a uniform rate of 170 kg ha^{-1} in the form of urea (46% N) in two equal splits, i.e. half at the time of field preparation by soil incorporation through ploughing and planking and half at first irrigation by top-dressing. The P was applied at the rate of 85 kg ha^{-1} in the form of DAP (46% P_2O_5 and 18% N). It was broadcasted and incorporated into the soil by ploughing and planking at the time of field preparation at 100% (T2) or 50% (T3, T6) RP and/or fertigated at first irrigation at 100% (T4), 75% (T5) or 50% (T7) RP and at second irrigation at 50% (T7) RP.

For fertigation, a solution of DAP fertilizer was prepared and a measured quantity was transferred to sixteen small plastic drums, fitted with bibcocks at the bottom. These drums were placed at the corner of each plot receiving P through fertigation at first (T4, T5, T6, T7) or second irrigation (T7). To ensure an equal distribution of the P solution to the plots and to avoid its downward movement, the bibcocks were opened after the irrigation water reached at the center of each plot. The out lets of drums were regulated in such a manner that the whole solution was delivered just before the termination of irrigation.

Four irrigations were given to the crop according its requirement by flooding. First irrigation was applied at day 25 of sowing and then after almost each 25-day interval. The crop was kept free of weeds by chemical spray after first irrigation and then by hand plucking through out crop life. All the other recommended agronomic practices were followed throughout the life span of the crop.

The data for plant height (cm), number of tillers plant^{-1}, spike length (cm), number of seeds spike^{-1}, number of seeds plant^{-1} and seed index, i.e. 1000-grain weight (g) were recorded from ten randomly selected plants, which were properly tagged and numbered. Harvesting was done at maturity by taking five samples of three square meters at random from the center of each plot. The harvest of each plot was pooled, labeled, sun-dried and threshed separately. The grain and straw yields were then recorded for each treatment.

The grain and straw samples were ground in a Wiley Mill and the sub-samples (one-gram portions) were digested with Tri-acid mixture of HNO_3-H_2SO_4-$HClO_4$ for the determination of P content by developing yellow colour with Barton's reagent (Jackson, 1962). The P content was measured on a spectrophotometer (ANA-720W Tokyo, Japan) at 440-nm wavelength.

The P content of grain and straw were multiplied to grain and straw yields to calculate P uptake (kg ha^{-1}). The P fertilizer efficiency (PFE, %) was calculated by the formula: PFE = [(Puf – Puc)/P] x 100, where Puf and Puc represent the total P uptake from fertilized and control plots, respectively, while P is the total amount of P applied. The grain to nutrient ratio (GNR) was calculated by the formula: GNR = [(Gyf – Gyc)/P], where Gyf and Gyc represent the grain yields of fertilized and control plots, respectively, while P is the total amount of P applied. The value cost ratio (VCR) was calculated by the formula: VCR = [(Vyf – Vyc)/VP], where Vyf and Vyc represent value of the yields of fertilized and control plots, respectively, while VP is the total value of P applied.

Statistical analysis: Data were subjected to statistical analyses according to standard procedures (Steel & Torrie, 1980) using analytical software Statistix® for Windows version 8.1 (Analytical Software ©), following the methods described by Gomez & Gomez (1984). Randomized complete block design was employed for analysis of variance (ANOVA). The treatment means were subjected to multiple comparisons following all-pairwise comparisons option of the software.

Results

The mean squares of ANOVA for plant height, number of tillers plant^{-1}, spike length, grains plant^{-1}, straw yield, P uptake in straw, total P uptake and PFE were significant. However, for the remaining parameters, viz. grains spike^{-1}, seed index, grain yield and P uptake in grain, the mean squares of ANOVA were non-significant (Table 1). Maximum

Table 1. Mean squares and p-values of analysis of variance for various parameters

Parameter	Mean squares	P
Plant height (cm)	67.89	0.0060
No of tillers plant^{-1}	1.22	0.0350
Spike length (cm)	0.77	0.0307
No. of grains spike^{-1}	13.36	0.4997
No. of grains plant^{-1}	3945.42	0.0098
Seed index (g)	4.27	0.1212
Grain yield (kg ha^{-1})	691023	0.3346
Straw yield (kg ha^{-1})	4077695	0.0071
Grain P (kg ha^{-1})	21.26	0.0901
Straw P (kg ha^{-1})	13.24	0.0003
Total P (kg ha^{-1})	65.33	0.0008
PFE (%)	89.02	0.0011

Table 2. Effect of dose, method and timing of P application on plant height, number of tillers plant^{-1}, spike length and number of grains spike^{-1}

Treatment	P (kg ha^{-1})	Method	Time	Plant height (cm)	No. of tillers plant^{-1}	Spike length (cm)	No. of grains spike^{-1}
T1	0	Nil	Nil	73.98±1.30c	2.40±0.36c	9.80±0.21b	44.22±1.99b
T2	85	Broadcast	Sowing	81.39±2.81b	3.25±0.24abc	10.71±0.28a	48.57±1.23ab
T3	42.5	Broadcast	Sowing	82.69±1.90ab	3.30±0.31abc	10.90±0.50a	48.58±3.19ab
	42.5	Broadcast	1st irrigation				
T4	85	Fertigation	1st irrigation	87.62±0.81a	4.15±0.46a	11.20±0.20a	50.10±1.22a
T5	64	Fertigation	1st irrigation	79.89±2.86b	2.90±0.19bc	10.70±0.18a	47.45±1.44ab
T6	42.5	Broadcast	Sowing	83.46±2.40ab	3.50±0.39ab	10.81±0.32a	47.41±1.75ab
	42.5	Fertigation	1st irrigation				
T7	42.5	Fertigation	1st irrigation	81.39±2.60b	2.90±0.21bc	10.52±0.28ab	46.83±2.30ab
	42.5	Fertigation	2nd irrigation				

Means followed by different letters in a column are significantly different at $P < 0.05$

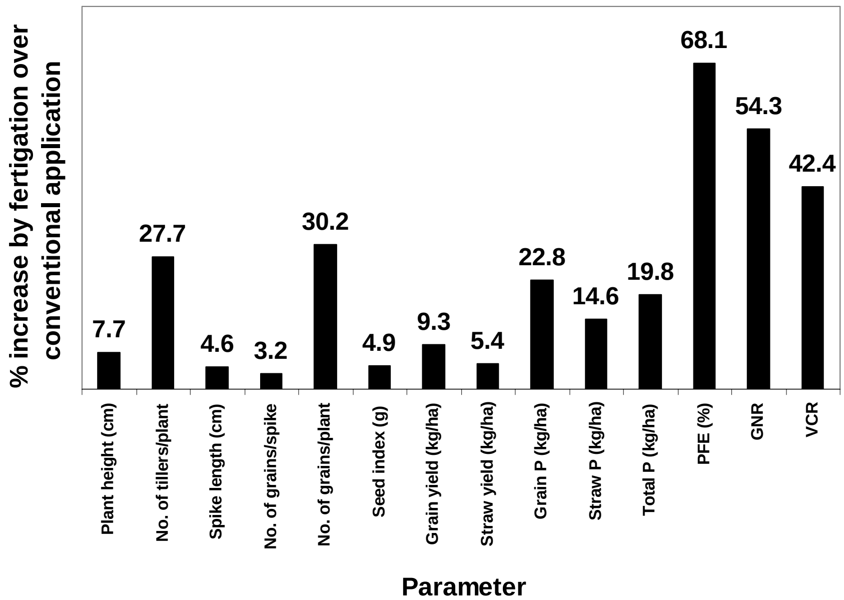

Fig. 1. Percent increase in various parameters of wheat by P application at first irrigation v/s P broadcasting and incorporation at sowing time (farmers' conventional practice).

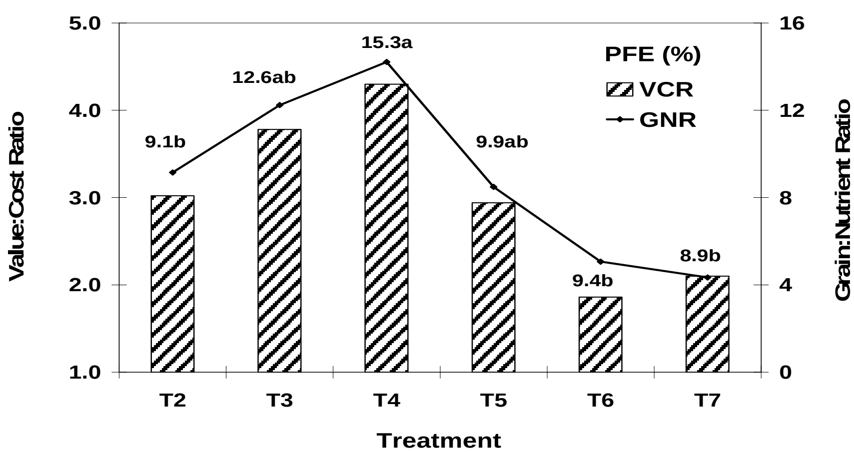

Fig. 2. Phosphorus fertilizer efficiency (PFE), the values above bars and line, value cost ratio and grain:nutrient ratio of wheat as affected by various treatments. T2: Recommended dose, RP (85 kg P ha^{-1}) at sowing through broadcasting (farmers' practice), T3: RP in two equal splits at sowing and first irrigation through broadcasting, T4: RP at first irrigation through fertigation, T5: $2/3^{rd}$ RP (64 kg P ha^{-1}) at first irrigation through fertigation, T6: RP in two equal splits each at sowing through broadcasting and at first irrigation through fertigation, and T7: RP in two equal splits each at first and second irrigation through fertigation.

plant height (87.62 cm) was obtained by the application of P through fertigation at first irrigation (T4), followed by the plant height (83.46 cm) acquired by the application P fertilizer in two equal splits at sowing and first irrigation (T6). Minimum plant height (73.98 cm) was noted in case of T1 (control), followed by the plant height obtained at T5 (79.89 cm) where $2/3^{rd}$ P was applied at first irrigation (Table 2). Fertigation at first irrigation (T4) resulted in highest increase (7.7%) in plant height (Fig.1) as compared to the plant height (81.39 cm) obtained by T2 where farmers' practice of applying P through broadcasting at sowing was followed (Table 2). Maximum number of tillers plant^{-1} (4.15) was also obtained by T4, followed by T6 (3.50). Whereas, T1 (control) and T7 (P application in two equal splits at first and second irrigation) produced minimum number of tillers plant^{-1} (2.40 and 2.90, respectively) (Table 2). P Fertigation (T4) produced 27.7% more number of tillers plant^{-1} (Fig. 1) compared to P broadcasting (T2). Similarly, maximum spike length was recorded at T4 (11.20 cm) followed by T3 (10.90 cm), however, these both treatments were non-significant to each other and to T2, T5 and T6. The minimum spike length was noted in case of T1 (9.80 cm), followed by the spike length (10.52) recorded at T7 (Table 2). P fertigation increased spike length up to 4.6% compared to broadcasting (Fig.1).

Number of grains per spike^{-1} were found maximum (50.10) at T4, whereas, control (T1) produced minimum (44.21). Both of these treatments were significantly ($P<0.05$) different to each other and to other treatments. However, all the other treatments were non-significant to each other (Table 2). P application in two equal splits did not affect number of grains spike^{-1}, irrespective of method and time of application. P fertigation (T4) increased number of grains spike^{-1} up to 3.2% compared to broadcasting (Fig. 1). Number of grains plant^{-1} were maximum (206.5) at T4, followed by T6 (166.05) and T3 (161.15). All these treatments were non-significant to each other. Minimum number of grains plant^{-1} (105.4) was noted for control (T1), followed by T7 (135.45). However, the numbers of grains plant^{-1} were statistically similar in two split application of P, i.e. T6 (166.05) and T3 (161.15). Moreover, T5 and T7 gave significantly less grain plant^{-1} as compared to those obtained by T3 and T6 (Table 2). P fertigation (T4) increased number of grains plant^{-1} up to 30.2% as compared to broadcast application (T2) of P (Fig.1).

The effect of various treatments on seed index (1000 grain weight) was almost similar to that observed in case of number of grains spike^{-1}. Again, T4 was the superior treatment among all resulting in highest seed index (38.62 g), whereas the minimum seed index (35.30) was noted in case of T1, followed by T7 (35.96). Latter both treatments were non-significant to each other, but significantly different to other treatments. All the other treatments produced non-significantly different seed index, irrespective of the method and time of P application (Table 2). Fertigation (T4) remained superior to broadcast (T2) and increased the seed index up to 4.9% (Fig.1).

Grain yield was maximum (5074 kg ha^{-1}) at T4 and minimum (3866 kg ha^{-1}) at T1. Both of these treatments were significantly ($P<0.05$) different to each other and to rest of treatments (Table 2). The grain yield produced by all other treatments was non-significant to each other, revealing that irrespective of single or split application of P and the method and time of application, the treatments did not affect grain yield significantly. A 9.3% increase was offered by T4 compared to T2, advocating the superiority of P fertigation over that of broadcasting (Fig.1). The straw yield produced by all the treatments was significantly ($P<0.05$) different from control (T1), however, non-significant to each other. Nonetheless, maximum straw yield (8676 kg ha^{-1}) was produced by T4 which was 14.6% more (Fig.1) than the straw yield (8232 kg ha^{-1}) produced by T2 (Table 2).

Table 3. Effect of dose, method and timing of P application on number of grains plant^{-1}, seed index, grain yield and straw yield

Treatment	P (kg ha^{-1})	Method	Time	No. of grains plant^{-1}	Seed index (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
T1	0	Nil	Nil	105.40±14.48c	35.30±0.36b	3866±576b	5760±295b
T2	85	Broadcast	Sowing	158.55±14.74b	36.83±1.11ab	4643±209ab	8232±821a
T3	42.5	Broadcast	Sowing	161.15±20.25ab	36.82±1.10ab	4906±530ab	8470±638a
	42.5	Broadcast	1st irrigation				
T4	85	Fertigation	1st irrigation	206.50±18.72a	38.62±0.53a	5074±156a	8676±381a
T5	64	Fertigation	1st irrigation	138.35±12.84bc	37.12±0.71ab	4409±485ab	7716±1088a
T6	42.5	Broadcast	Sowing	166.0±19.26ab	37.01±0.57ab	4296±272ab	7579±529a
	42.5	Fertigation	1st irrigation				
T7	42.5	Fertigation	1st irrigation	135.4±10.53bc	35.96±0.16b	4234±483ab	8516±444a
	42.5	Fertigation	2nd irrigation				

Means followed by different letters in a column are significantly different at $P < 0.05$

Table 4. Effect of dose, method and timing of P application on P uptake in grain, straw and their total

Treatment	P (kg ha^{-1})	Method	Time	Grain (kg ha^{-1})	Straw (kg ha^{-1})	Total (kg ha^{-1})
T1	0	Nil	Nil	13.20±3.41b	5.22±0.56c	18.43±3.28c
T2	85	Broadcast	Sowing	16.60±1.35ab	9.61±0.97ab	26.20±1.43b
T3	42.5	Broadcast	Sowing	19.32±2.68a	9.81±1.08ab	29.13±1.99ab
	42.5	Broadcast	1st irrigation			
T4	85	Fertigation	1st irrigation	20.39±2.12a	11.01±0.8a	31.40±2.34a
T5	64	Fertigation	1st irrigation	16.46±2.58ab	8.32±1.05b	24.78±3.37b
T6	42.5	Broadcast	Sowing	17.43±1.92ab	8.97±1.14b	26.41±2.13b
	42.5	Fertigation	1st irrigation			
T7	42.5	Fertigation	1st irrigation	16.63±1.65ab	9.35±0.89ab	25.98±2.13b
	42.5	Fertigation	2nd irrigation			

Means followed by different letters in a column are significantly different at $P < 0.05$

P uptake by grain, straw and their total was lowest in case of control (T1) where no P was applied, i.e. 13.20, 5.22 and 18.43 kg ha^{-1}, respectively. P uptake by grain, straw and their total was highest where P was fertigated at first irrigation (T4), i.e. 20.39, 11.01 and 31.40, respectively. In contrast, where P was applied following farmers' method of broadcasting (T2) the P uptake values for grain, straw and their total were comparatively very low, i.e. 16.6, 9.61 and 26.20, respectively (Table 3). The corresponding increases in P uptake by grain, straw and their total by T4 over T2 were 22.8, 14.6 and 19.8, respectively (Fig.1). The grain accumulated more P than straw and the increase in grain P uptake was also more.

Fertigation of RP at first irrigation (T4) resulted in significantly ($P<0.05$) better PFE (15.3%) as compared to PFE (9.1%) obtained by farmers' practice of broadcasting RP at sowing (T2). The minimum PFE (8.9%) was noted at T7 where P was applied through fertigation in two equal splits at first and second irrigation (Fig.2). T4 increased PFE to 68% as compared to T2 (Fig. 1). Almost similar pattern was observed in case of GNR and VCR. T4 offered maximum values for GNR and VCR (14.2 and 4.3, respectively) as compared to T2 (9.2 and 3.0, respectively) (Fig. 2). Fertigation increased GNR and VCR value to 54.3% and 42.4, respectively (Fig 1).

For almost all the parameters, application of P at lower rates ($2/3^{rd}$ of recommended P, i.e. 64 kg ha^{-1}) through fertigation at first irrigation (T5) produced statistically similar performance compared to that observed where P was applied at full recommended rate (85 kg ha^{-1}) through broadcasting at sowing time (T2) – the conventional P application practice of most of the farmers.

The correlation analysis revealed positive significant relationship of wheat grain yield with all the parameters in order of plant height (0.83*), seed index (0.84*), number of grains $plant^{-1}$ (0.87*), P uptake in straw (0.87*), PFE (0.89*) > spike length (0.89**), total P uptake (0.91**), grain P uptake (0.92**) > number of grains $spike^{-1}$ (0.95***), VCR (0.97***) and GNR (0.98***).

Discussion

Phosphorus is the most unavailable and inaccessible macronutrient in the soil (Vance *et al.*, 2003). Its deficiency has been limiting crop production on >30% of world's arable land. The consistently increasing prices of P fertilizers are due to the alarming depletion of world reserves of rock phosphate along with their notoriously low use efficiency (Shahbaz *et al.*, 2006). Fertilizer use optimization significantly contributes to wheat crop yield. Elevated fertilizer prices and their scarcity at the right time of application mostly accounts for low fertilizer usage (Alam *et al.*, 2005). In Pakistan and elsewhere, the black marketing problem of phosphatic fertilizers at the time of wheat sowing becomes a burning issue, due to general understanding that P must be applied at sowing time. Resultantly, fertilizer use becomes halved to that of recommended and most poor farmers fail to apply P at all (Khan, 2003). However, the maximum advantage of P application starts right after first irrigation to crop (Latif *et al.*, 1994) because rapid P uptake took place only after 3-4 weeks of germination (Alam *et al.*, 1999) in relation to much higher demand for P at this growth stage (Romer & Schilling, 1986). P application at first irrigation instead at sowing is reported to be more beneficial (Nisar *et al.*, 1992), even at low rates in producing equivalent wheat yield coupled with 25-30% increased PFE compared to higher P rates by broadcasting and incorporation at sowing (Alam *et al.*, 1999, 2002). A recent study (Alam *et al.*, 2005) also advocated the feasibility of fertigation technology for P fertilization at first irrigation in case of P fertilizer shortage to avoid late sowing. Our study produced even more encouraging results, clearly indicating the superiority of P fertigation at first irrigation over that of its broadcast application and incorporation to soil at sowing time. The yield and all its attributes, coupled with P uptake, PFE, GNR and VCR were increased due to fertigation over farmers' conventional approach of broadcasting. P Fertigation even at lower rates produced statistically similar results for almost all the parameters compared to P application at full recommended rate through broadcasting at sowing time, as conventionally practiced by the farmers. The most important finding of our study is that fertigation increased PFE up to 68% – offering a successful solution to the major problem faced by Pakistani agriculture and elsewhere in the world. This improved efficiency of P fertilizer increased wheat yield by improving all the growth parameters and hence also improved the profitability of wheat production. Our study concluded that P fertigation at first irrigation is a feasible option of P fertilization for improved yield, PFE and profitability of wheat, and is workable even at lower P rates compared to its recommended application by broadcast at sowing time.

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