



### Full Length Article

# Band Placement of Phosphorus Improves the Phosphorus Use Efficiency and Wheat Productivity under Different Irrigation Regimes

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## ABSTRACT

This study was conducted to evaluate the phosphorus (P) application methods under different irrigation levels to maximize wheat yield and phosphorus use efficiency (PUE). P was applied at 0, 61, 104 and 142 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> as band placement or by broadcasting in wheat irrigated at four irrigation regimes (0, 2, 3 & 4 irrigations). Phosphorus levels were determined to adjusted soil solution P levels (0.0, 0.1, 0.2 & 0.3 mg P L<sup>-1</sup>) in soil solution by Freundlich Model. Increasing P rate up to 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (0.2 mg P L<sup>-1</sup> in soil solution) improved the grain yield, yield related traits, grain and straw P contents, total P uptake, net income and benefit-cost ratio (BCR) of wheat. However, P application at 61 and 142 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (0.1 & 0.6 mg P L<sup>-1</sup> in soil solution) caused higher PUE and Olsen P, respectively. Band placement was more effective and economical than broadcasting. Three irrigations at crown root initiation, booting and grain development stages were more economical to achieve higher grain yield and net income of wheat. In crux, band placement of P at 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (0.2 mg P L<sup>-1</sup> in soil solution) with 3 irrigations (at crown rooting, booting & grain development stages) is the best option to harvest maximum wheat productivity, PUE and net economic returns in sandy clay loam soils. © 2012 Friends Science Publishers

**Key Words:** Grain yield; P uptake; Irrigation; Freundlich adsorption isotherms; P application

## INTRODUCTION

Enhancement in the productivity of bread wheat (*Triticum aestivum* L.) on sustained basis is obligatory to feed the increasing population the world over. In Indo-Gangetic plains, wheat occupies a major area during winter season but its yield is far below than the potential of existing wheat genotypes (Mann *et al.*, 2004). Water shortage at critical growth stages, traditional method of seedbed preparation for preceding crop (e.g., rice), delayed planting, poor weeds management, and non-judicious and imbalance use of fertilizers along with several other conflicts reduce the wheat productivity (El-Gizawy, 2009).

The unavailability and inadequate supply of essential plant nutrients is another factor responsible for low yield in the region. For instance, 90% soils are deficient in nitrogen (N) and phosphorus (P) and 40% in potassium in Pakistan (Ahmad & Rashid, 2004). Among all the nutrient elements required by a plant, P has prime importance for crop production and emphasis is being given on the efficient use of P fertilizers for sustainable crop production (Ryan, 2002). In Pakistan, over 90% soils are low in available P, suffering from moderate to severe P deficiency due to alkaline

calcareous nature of soil (Iqbal *et al.*, 2003); as P fixation is a severe dilemma in alkaline (pH>7) and calcareous (CaCO<sub>3</sub>>3%) soils (Sharif *et al.*, 2000). Major portion (over 80%) of added P gets fixed and only a minute portion of it goes to soil solution which may be either taken up by crops or precipitates (Leytem & Mikkelsen, 2005). Additionally, the adsorbed P becomes firm to release in soil solutions, resulting in decline in efficiency of P fertilizer with time (Delgado *et al.*, 2002). This P deficiency is further aggravated due to 60% lesser use of recommended P (Hussain *et al.*, 2008). To grasp the full yield potential of modern wheat cultivars, optimum P supply is vital (Clark, 1990); as it plays a crucial role in energy storage and transfer within the cells, speeds up root development, facilitates greater N uptake and results in higher grain protein.

As P is less mobile, less soluble and highly prone to soil fixation; effectiveness of applied P depends on the properties of soil being fertilized, fertilizer itself and time and method of its application (Iqbal *et al.*, 2003). Therefore, it is important to make site specific and crop specific P application on scientific basis (Rahim *et al.*, 2010). Phosphorus adsorption isotherms can be efficiently utilized

to predict the P rates required to adjust soil solution P at the desired level after identifying optimum soil solution P level for wheat (Rahim *et al.*, 2010).

To enhance phosphorus use efficiency (PUE) of applied P fertilizer, time and method of its application are critically important, because different P application methods differ in PUE. In Indo-Gangetic plains, P is generally broadcasted on soil surface followed soil incorporation before sowing of the crop, which results in the conversion of soluble P to insoluble forms and thus reduces its use efficiency (Shah *et al.*, 2006). Fixation of broadcasted P is much greater than the fertilizer applied in bands because of less contact with P fixing ingredients (Rehman *et al.*, 2006). P application in dilute solution (less than 5%) with irrigation water proved better to enhance PUE (Zafar *et al.*, 2003). Recently, Rahim *et al.* (2010) reported better PUE from band placement of P than its broadcasting. However, split application of P by top dressing or by fertigation is better option to harvest better grain yield and PUE than soil incorporation at sowing under some circumstances (Latif *et al.*, 2001).

For successful crop production in present-day agriculture, adequate and ample supply of irrigation water from either source is pre-requisite. However, irrigated agriculture is facing an acute shortage and competition for low cost and high quality irrigation water (Howell, 2001). In this prospect, water wise cultivation is the need of time and it is therefore, essential to find out the most crucial plant growth stages, where the irrigation must be applied to avoid moisture stress and get normal yield (Farooq *et al.*, 2009; Hussain *et al.*, 2009).

This study was conducted to find out optimum P level, determined according to adjusted soil solution P levels by using Freundlich Model, application method and judicious irrigation scheduling for maximizing wheat productivity, PUE and net economic return.

## MATERIALS AND METHODS

**Experimental site description:** This study was conducted at Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad, Pakistan (31.25° N, 73.06° E & 183 m a.s.l.) during winter season 2006-07. The experimental area was quite uniform and calcareous ( $\text{CaCO}_3 > 5\%$ ) in nature. Experimental soil was sandy clay loam with  $\text{ECe}$  2.3  $\text{dS m}^{-1}$ , pH 7.8, organic matter 0.8%, Olsen P 7.7  $\text{mg g}^{-1}$  and Extractable K 140  $\text{mg g}^{-1}$ . Weather data during the experimental period is given in Table I.

**Experimental details:** Wheat seed (*Triticum aestivum* L. cv. Inqulab-91) was obtained from Wheat Research Institute, Ayub Agricultural Research Institute, Faisalabad, Pakistan having 11.5% moisture contents with above 96% germination percentage. The experiment was laid out in randomized complete block design (RCBD) with split-split plot arrangement having three replications and net plot size of 1.8 m × 4 m. Irrigation levels, P application methods and

**Table I: Mean monthly weather data during the course of study**

Month	Temperature (°C)	Relative humidity (%)	Total monthly rainfall (mm)
November	20.9	47.0	12.8
December	15.5	57.4	46.2
January	12.5	67.4	0.0
February	15.5	67.1	55.9
March	19.4	47.0	41.3
April	28.9	35.1	0.0

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan

P levels were randomized in main, sub and sub-sub plots, respectively. Phosphorus was applied at 0, 61, 104 and 142  $\text{kg P}_2\text{O}_5 \text{ ha}^{-1}$  (according to adjusted soil solution P levels i.e., 0.0, 0.1, 0.2 & 0.3  $\text{mg P L}^{-1}$  in soil solution by Freundlich Model) by band placement and broadcasting at four irrigation levels viz. 0 (no irrigation), 2 (each at crown root initiation & booting stages), 3 (each at initiation crown root, booting & grain development stages) and 4 (each at crown root initiation, booting, anthesis & grain development stages).

**Phosphorous adsorption isotherms and application of model:** Phosphorus (P) adsorption capacities of the soils were determined by shaking 2.5 g soil sample with 25 mL 0.01 M  $\text{CaCl}_2$  containing 0, 5, 20, 40, 60, 80, 100, 200, 300, 400 and 500  $\mu\text{g P mL}^{-1}$  as  $\text{KH}_2\text{PO}_4$  for 24 h at 25°C. Sorption isotherms were constructed according to the methods described by Rowell (1994). The amount of P adsorbed was estimated by the difference of P added and P remaining in the solution after P equilibrium was established. The adsorption data were fitted to the modified Freundlich equation (Samadi, 2003).

**Modified Freundlich model:** The simple form of the Freundlich model used in the present study was proposed by Le Mare (1982) as follows:

$$P = a C^b$$

Where a is the amount of P adsorbed ( $\mu\text{g g}^{-1}$ ), when the concentration C is 1  $\mu\text{g mL}^{-1}$  and b ( $\text{mL g}^{-1}$ ), is the buffer power defined by the slope of the sorption curve at the point where  $P/C = 1$  ( $\text{mL g}^{-1}$ ). The modified Freundlich model used to describe the soils in this work is as follows:

$$P = a C^{b/a}$$

The parameters 'a' and 'b' were counted by regression of the logarithmic form of the data derived from adsorption isotherms. Theoretical doses of P and phosphatic fertilizers required to develop P levels in soil solutions under field conditions were calculated from this equation and applied in the field experiment.

**P adsorption by the soils:** Adsorbed P (x/m) showed progressive increase as amount of added P was increased (Fig. 1) in the soil but the increase was not linear.

**Freundlich adsorption isotherm:** The constructed adsorption isotherm was tested according to the linear shape

of the Freundlich equation [Log  $x/m$  vs. Log EPC] that gave a linear fit (Fig. 2) and an analogous linear relationship was observed. The empirically derived Freundlich adsorption equation (Pant & Reddy 2001) used in this study is:

$$x/m = K_f (\text{EPC})^{1/n}$$

The values of exponent  $1/n$  were found less than one (0.171) in Freundlich adsorption equation, which indicates higher P equilibrium concentration in soil. If  $1/n$  value is more than one it indicates low equilibrium P concentration in soil solution. In this study P concentration in soil solution increased with increasing level of added P and the value of  $1/n$  observed in this study was  $0.171 \text{ L kg}^{-1}$ . The  $K_f$  value indicates the capacity factor; soil with larger  $K_f$  value has larger adsorbing capacity than a soil having smaller  $K_f$  value. The  $K_f$  calculated value may be used to distinguish soils having different P adsorption capacities. Zhou and Li (2001) stated that low  $K_f$  values indicate low P adsorption capacities at low P concentrations ( $\leq 1 \text{ mg P L}^{-1}$ ); moreover, a large amount of P may be retained by the process of precipitation at high p concentration. Thus,  $K_f$  value only indicates the amount of adsorbed P at low P concentration and not the precipitation. The linear transformation of the data indicated that all the lines on the graphs are linear. By using these P adsorption values, the Freundlich plot equation for sandy clay loam soil was constructed as:

$$x/m = 78.22 (\text{EPC})^{0.171}$$

**Computation of fertilizer P doses for wheat by Freundlich equation:** Linear form of derived Freundlich adsorption equation [Log  $x/m = \text{Log } K_f + 1/n (\text{Log EPC})$ ] was used for calculating fertilizer doses to adjust the soil solution P level of, 0.10, 0.20 and  $0.30 \text{ mg L}^{-1}$  for sandy clay loam soil. The regression equations can be solved for any desired solution P level ( $0.0, 0.1, 0.2 \text{ \& } 0.3 \text{ mg L}^{-1}$ ) by putting the value of Log EPC on x-axes and Log  $x/m$  on y-axes from the equation obtained, for required solution P level. The calculated amount of P ( $0, 26, 45 \text{ \& } 61 \text{ kg ha}^{-1}$ ) was converted to  $\text{P}_2\text{O}_5$  ( $0, 61, 104 \text{ \& } 142 \text{ kg ha}^{-1}$ ) by multiplying it with 2.29.

**Crop husbandry:** Ten cm pre-soaking irrigation was applied prior to seedbed preparation and seedbed was crafted by cultivating the field twice with tractor-mounted cultivator each followed by planking when the soil reached to feasible moisture level. Wheat (Inqulab-91) was sown on November 10, 2006 with single row cotton drill using seed rate of  $125 \text{ kg ha}^{-1}$  and maintaining row to row distance of 22.5 cm. Seed was treated with benlate at  $2.5 \text{ g kg}^{-1}$  wheat seed before sowing. Computed levels of P along with 130 kg N and  $65 \text{ kg K ha}^{-1}$  were applied using triple super phosphate (TSP), urea and sulphate of potash (SOP), respectively as sources. Half N and whole P and K were applied at sowing as basal application, while remaining half N was applied with 1<sup>st</sup> irrigation; whereas whole N was applied at sowing time in treatment receiving no irrigation. All other agronomic practices were kept uniform to all the

treatment combinations to keep crop free from weeds, insect pests and diseases. The mature crop was harvested on April 15, 2007.

**Observations recorded:** At final harvest, number of tillers, grains in a spike and 1000-grains was counted from a sample harvested randomly from unit area at four different locations in each plot. Two central rows were harvested and sun dried for three days, threshed manually, grains were separated and weighed on an electric balance to calculate the grain yield and then converted into  $\text{kg ha}^{-1}$ . Grain yield was then adjusted to 10% moisture contents.

One gram oven dried straw and grain sample was digested in 10 mL of di-acid mixture (concentrated  $\text{HNO}_3$  & 72%  $\text{HClO}_4$ , with 9:4 ratio) cooled the digest, transferred to 100 mL volumetric flask and made volume (US Salinity Laboratory, 1954). Five mL of the digested aliquot was taken in 50 mL volumetric flask, added 5 mL of ammonium vanadate (0.25%) and ammonium molybdate (5%), made volume and allowed to stand for 15-30 min. Reading was recorded on spectrophotometer. Then from the standard curve, P concentration (%) in grain and straw was calculated. Soil samples collected after harvesting of wheat were analyzed for Olsen P (Olsen *et al.*, 1954). Total P uptake by straw and grains was calculated using the following formulae:

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

Phosphorus use efficiency (PUE) was recorded according the formulae given by Fageria *et al.* (1997) as under:

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

Grain protein contents were determined according to Chapman and Parker (1961). The samples were digested with concentrated sulfuric acid in the presence of digestion mixture containing  $\text{K}_2\text{SO}_4$ ,  $\text{CuSO}_4$  and  $\text{FeSO}_4$  (90: 10: 1). The resultant mixture was further diluted with NaOH using steam in micro Kjeldahl distillation apparatus. The ammonia produced was collected in 2% boric acid solution and N contents were determined by titrating against  $0.1 \text{ N H}_2\text{SO}_4$ . Protein contents were calculated by multiplying nitrogen with a factor of 6.25.

**Economic analysis:** A benefit–cost analysis was conducted to estimate the economic feasibility of different rates and methods of P application, and irrigation regimes to enhance wheat productivity and net economic returns. The cost of  $\text{P}_2\text{O}_5$  was PKR  $140 \text{ kg}^{-1}$  ( $1 \text{ PKR} = 0.012 \text{ US\$}$ ). The production costs of wheat included field preparation, seed, sowing, fertilizing, weeding, crop protection measures and harvesting. The gross income was estimated using the prevailing average market price of wheat grain in Pakistan, PKR  $23.75 \text{ kg}^{-1}$ .

**Statistical analysis:** Collected data were statistically analyzed by using the Fisher's analysis of variance

technique and least significant difference test was used for comparing the treatment's means at 0.05 probability level (Steel *et al.*, 1997).

## RESULTS

Different phosphorus (P) rates, irrigation regimes and P application methods significantly ( $p=0.01$ ) affected the wheat yield related traits except the non-significant effect of P application methods on grains per spike and grain yield of wheat ( $p=0.05$ ). Interactive effect of P rates and irrigation levels significantly affected number of tillers and grain yield while the affect was non-significant on grains per spike and 1000-grain weight ( $p=0.05$ ). Likewise, the interactive effect of P rates and application method with irrigation levels on grain yield and related traits was not significant ( $p=0.05$ ).

Greater number of tillers, 1000-grain weight and grain yield were recorded from P application at 104 kg ha<sup>-1</sup> through band placement with three irrigations at crown root, booting and grain development stages (Table II). However, minimum grain yield, number of tillers and grains per spike and grain protein contents were recorded from wheat grown without P application and irrigation (Table II). However, maximum grain protein contents were recorded from P application at 104 kg ha<sup>-1</sup> through band placement with three irrigations (Table II).

Different phosphorus levels and application methods, irrigation regimes, and interaction between P levels and application methods, and P rates and irrigation regimes had significant effect on grain and straw P contents, Olsen P and PUE of wheat ( $p<0.01$ ). Interaction between P application methods and irrigation levels was not significant for grain and straw P contents and significant for Olsen P and PUE of wheat ( $p<0.01$ ). However, the interactive effect of P rates and application methods with irrigation levels had non-significant effect on grain and straw P contents, and PUE while significant effect on Olsen P ( $p<0.05$ ).

P application progressively enhanced the grain and straw P contents, P uptake and Olsen P with every increment of P and maximum grain and straw P contents along with higher P uptake and Olsen P were recorded at higher rate of P application (142 kg ha<sup>-1</sup>), while maximum PUE was recorded at 61 P<sub>2</sub>O<sub>5</sub> kg ha<sup>-1</sup> (Table III). Likewise, wheat grown with four irrigations at crown root, booting, anthesis and grain development stages exhibited higher grain and straw P contents with higher P uptake and PUE, while minimum PUE, P uptake and higher Olsen P were recorded from wheat sown without irrigation (Table III). Likewise, P application through band placement resulted in improved grain and straw P contents with higher P uptake and PUE, whereas P broadcasting resulted in more Olsen P (Table III).

Wheat sown with three irrigations at crown root, booting and grain formation stages of crop exhibited higher net income with higher benefit-cost ratio (BCR; Table IV). Whereas maximum net income and BCR P were recorded

from P application at 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> followed by 61 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (Table IV). Likewise, band application of P proved superior with enhanced net income and BCR of wheat compared with broadcasting (Table IV).

## DISCUSSION

This study indicated that wheat yield, PUE and net returns can be increased if P is applied wisely with band placement even with less water application. In this experiment maximum yield was harvested by P application at 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> however yield was decreased beyond this rate (Table II). This indicated that P may also be toxic, if applied in excess. Optimum P supply improved the yield related traits including number of tillers, grains per spike and grain size, resulting in better yield harvest (Table II). Phosphorus not only regulates the energy storage and transfers within the cells, is structural part of several vital compounds but also triggers the meristematic activities in the developing roots and facilitates the uptake of N and other mineral nutrients. However, P deficiency altered the normal pattern of tiller emergence, root development and plant growth (Daniel *et al.*, 1998) thus impairing the harvest of better yields (Table II).

Band placement of P performed well compared with broadcasting; as developing roots were in close contact with P-enriched soil adjacent to fertilizer granules in case of band application. In addition, there was a little contact of applied P, through band placement, with alkaline earth carbonates and soil colloids, which are partially responsible for precipitation, fixation and retention of phosphorus fertilizer resultantly P availability to plants was improved (Shah *et al.*, 2006; Rahim *et al.*, 2010). Likewise, wheat grain yield progressively increased with increasing irrigation regimes up to three; after which no further increase in grain yield was observed (Table II). Therefore, three irrigations at crown root, booting and grain development stages of wheat are enough to harvest better wheat yield. Crop grown without irrigation did not perform well with minimum grain yield due to devastating effect of all yield related traits on all yield contributing components. As water is the medium of nutrient mobility in soil, its deficiency strongly influences the nutrient dynamics in the soil and its uptake resulting in impairment of crop growth, rate of photoassimilation and thus the grain yield (Farooq *et al.*, 2009). Increase in P application substantially increased the grain protein contents (Table II). This was probably due to better nitrogen uptake with increase in P rate.

Improvement in grain and straw P contents with increase in P application rate seems due to higher P contents in soil solution, which were available to plant (Table III). Likewise, at higher P application the adsorption of P increased because the plants readily utilize only 8-33% of applied P in the first growing season and remaining portion remained fixed that consequently resulted in higher Olsen P (Hussein, 2009). Nonetheless, higher PUE at lower P level

**Table II: Influence of phosphorus application methods at varying rates on grain yield, related traits and grain proteins of wheat under different irrigation levels**

Treatment	Number of tillers (m <sup>-2</sup> )	Number of grains per spike	1000-grain weight (g)	Grain yield (t ha <sup>-1</sup> )	Grain protein contents (%)
<b>P levels (P) kg ha<sup>-1</sup></b>					
P <sub>1</sub> = 0.0	214.00 d	25.75 c	28.03 c	2.10 d	7.27 d
P <sub>2</sub> = 61.0	277.00 c	30.34 b	39.28 b	3.27 c	9.29 c
P <sub>3</sub> = 104.0	302.00 a	34.22 a	40.68 a	4.06 a	10.02 b
P <sub>4</sub> = 142.0	290.00 b	32.35 a	40.03 ab	3.80 b	11.37 a
<b>LSD at 5%</b>	<b>8.18</b>	<b>1.93</b>	<b>1.13</b>	<b>0.16</b>	<b>0.09</b>
<b>Irrigation Regimes (I)</b>					
I <sub>1</sub> = 0	249.00 c	28.70 c	34.72 d	2.61 c	9.18 c
I <sub>2</sub> = 2	261.00 b	30.10 bc	36.30 c	3.39 b	8.55 d
I <sub>3</sub> = 3	290.00 a	32.52 a	39.10 a	3.88 a	10.66 a
I <sub>4</sub> = 4	283.00 a	31.33 ab	37.90 b	3.25 b	9.56 b
<b>LSD at 5%</b>	<b>8.18</b>	<b>1.93</b>	<b>1.13</b>	<b>0.16</b>	<b>0.08</b>
<b>P application methods (M)</b>					
M <sub>1</sub> = Band placement	274.00 a	31.06	37.48 a	3.74 a	9.59 a
M <sub>2</sub> = Broad cast	267.00 b	30.26	36.53 b	3.67 a	9.38 b
<b>LSD at 5%</b>	<b>5.78</b>	<b>NS</b>	<b>0.80</b>	<b>0.11</b>	<b>0.06</b>

Means not sharing the same letter in a column, for a factor, differ significantly from each other at 5% level of probability

**Table III: Influence of phosphorus application methods at varying rates on Olsen P, grain and straw P contents, P uptake and PUE of wheat under different irrigation levels**

Treatment	Olsen P(mg kg <sup>-1</sup> )	Grain P contents (%)	Straw P contents (%)	Total P uptake (kg ha <sup>-1</sup> )	P use efficiency (%)
<b>P levels (P) kg ha<sup>-1</sup></b>					
P <sub>1</sub> = 0.0	3.14 d	0.105 d	0.069 d	4.02 d	0.00 c
P <sub>2</sub> = 61.0	5.15 c	0.140 c	0.091 c	8.92 c	10.78 a
P <sub>3</sub> = 104.0	6.35 b	0.162 b	0.120 b	12.97 b	10.22 b
P <sub>4</sub> = 142.0	11.82 a	0.224 a	0.140 a	16.40 a	9.90 b
<b>LSD at 5%</b>	<b>0.012</b>	<b>0.007</b>	<b>0.003</b>	<b>0.41</b>	<b>0.37</b>
<b>Irrigation Regimes (I)</b>					
I <sub>1</sub> = 0	7.85 a	0.112 d	0.065 d	5.29 d	2.71 d
I <sub>2</sub> = 2	6.88 b	0.140 c	0.0979 c	8.85 c	6.29 c
I <sub>3</sub> = 3	6.20 c	0.168 b	0.125 b	12.80 b	9.76 b
I <sub>4</sub> = 4	5.53 d	0.211 a	0.132 a	15.36 a	12.14 a
<b>LSD at 5%</b>	<b>0.012</b>	<b>0.007</b>	<b>0.003</b>	<b>0.41</b>	<b>0.37</b>
<b>P application methods (M)</b>					
M <sub>1</sub> = Band placement	6.20 b	0.168 a	0.109 a	11.29a	8.48 a
M <sub>2</sub> = Broad cast	7.03 a	0.147 b	0.101 b	9.86 b	6.97 b
<b>LSD at 5%</b>	<b>0.008</b>	<b>0.005</b>	<b>0.002</b>	<b>0.29</b>	<b>0.26</b>

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

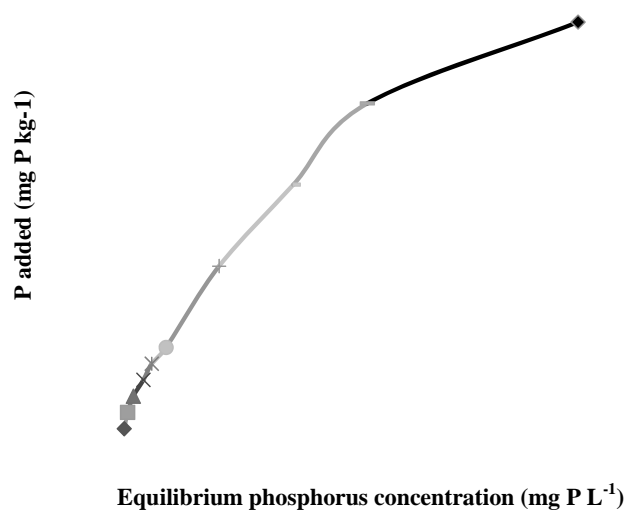
**Table IV: Influence of phosphorus application methods at varying rates on net income and benefit-cost ratio of wheat under different irrigation levels**

Treatment	Total expenditure (Rs.)	Gross income (Rs.)	Net income (Rs.)	Benefit-cost ratio
<b>P levels (P) kg ha<sup>-1</sup></b>				
P <sub>1</sub> = 0.0	44474	49875	5401	1.12
P <sub>2</sub> = 61.0	52964	77663	24699	1.47
P <sub>3</sub> = 104.0	59144	96425	37281	1.63
P <sub>4</sub> = 142.0	64230	90250	26020	1.41
<b>Irrigation Regimes (I)</b>				
I <sub>1</sub> = 0	54144	61988	7844	1.14
I <sub>2</sub> = 2	56644	80513	23869	1.42
I <sub>3</sub> = 3	57894	92150	34256	1.59
I <sub>4</sub> = 4	59144	77188	18044	1.31
<b>P application methods (M)</b>				
M <sub>1</sub> =Band placement	59144	88825	29681	1.50
M <sub>2</sub> = Broad cast	59144	87163	28019	1.47

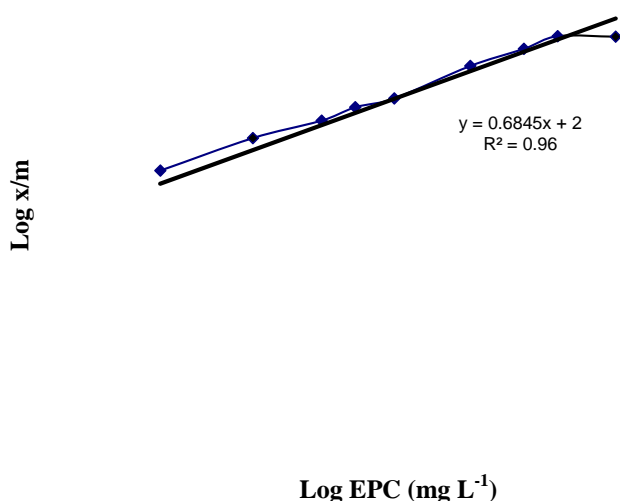
might be the result of intense root competition and thereby an efficient exploitation of applied P. Similarly, at higher P application rates plants used smaller proportion of fertilizer

P that resulted in low PUE (Rahim *et al.*, 2010). Higher Olsen P in broadcasted P compared with band application might be due to fixed and unutilized P left over as more soil

**Fig. 1: Adsorption isotherms of the sandy clay loam soil**  
Equilibrium phosphorus concentration was established after adding phosphorus in the soil solution



**Fig. 2: Freundlich adsorption isotherm (Adsorbed phosphorus against phosphorus in the soil solution)**



to fertilizer contact may arise in broadcasting than band application; causing more adsorption of P (Rehman *et al.*, 2006). Band application of P enhanced the straw and grain P contents that resulted in higher P uptake; as the developing roots were in close contact with P-enriched soil adjacent to fertilizer granules in band placement rather than broadcasted P. Nonetheless, there were low chances for P adsorption in band placement over broadcast because of less contact with soil. Therefore, higher P uptake by band application resulted in higher PUE in wheat in this study.

Maximum grain and straw P contents and P uptake at higher irrigation regimes might be the reason of enhanced root growth and more available P contents due to higher soil moisture contents. Lower irrigation levels significantly decreased the PUE but enhanced the Olsen P in the soil (Table III); as lower soil water contents reduced P diffusion

through soil to the root surface that ultimately resulted in lower P uptake by the crop (Rahim *et al.*, 2010).

Higher net income and BCR from three irrigations viz. at crown root, booting and grain formation stages of crop, P application at 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> and band application method P was the direct result of better grain yield (Table II) due to more efficient utilization of applied fertilizer.

In conclusion, phosphorus use should be based on soil testing and Freundlich Model may be used to assess P requirements for different soils and crops, as it takes care of readily available soil solution P. In this study, wheat yield and its components increased significantly with the use of P and the optimum rate for sandy clay loam soil is 104 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. Band placement is preferable method for fertilizer P application to improve PUE. Furthermore, three irrigations viz. at crown root, booting and grain development stages may help to save water but it should be site specific.

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