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Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency

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Abstract

In view of the importance of wheat, less available and costly P fertilizer and shortage of water a field study was conducted under farmer's field conditions to see the effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. Fertilizer P doses 0, 47, 81 and 111 kg P_2O_5 ha^{-1} were calculated by using adsorption isotherms and applied by broadcast and band placement. Four irrigations i.e. 0, 2, 3, 4 were applied at critical stages of wheat. Basal N:K=130:65 kg ha^{-1} were applied. Wheat grain yield increased from 1.58 Mg ha^{-1} to 3.94 Mg ha^{-1} with the use of P @ 81 kg P_2O_5 ha^{-1}. Band placement of P proved better over broadcast, whilst three irrigations at crown roots, booting, and grain development stages were sufficient to get maximum yield and improve phosphorus use efficiency.

Keyword: Wheat; Phosphorus use efficiency; Irrigation; Freundlich adsorption isotherms

Introduction

Wheat is staple diet of communities living in Pakistan. In order to continue its adequate supply, it is mandatory to improve per acre yield of the crop. Among the plant nutrients, P is critical to improve the yield of wheat as over 90 % soils in Pakistan are low in available P (Ahmed *et al.*, 1992). Moreover, with the passage of time, the adsorption of P gets firmer thus creating difficulties in release to soil solutions. Consequently, efficiency of fertilizer P in calcareous soils remains comparatively low (Delgado *et al.*, 2002).

The agronomic practices that influence the efficiency of applied fertilizer, time and method of application are of significant importance. There is need to make P fertilizer recommendations site specific as well as crop specific on scientific basis (Ahmed *et al.*, 1992). Wheat roots absorb P only from the soil solution (Johnston *et al.*, 1999). Once the optimum soil solution P level for plant growth is identified, P adsorption isotherms can be utilized to predict fertilizer P rates required to adjust soil solution P at the desired level necessary for maximum plant growth. An adsorption isotherm could successfully relate P concentration in soil solution to the P adsorbed onto soil surface and takes into account both intensity as well as capacity factors of P (Samadi, 2003; Rashid *et al.*, 2007).

The recommended method of application in Pakistan is to broadcast fertilizer on the surface of the soil, followed by incorporation, before seeding of the crop. This practice enhances the conversion of soluble P to insoluble forms because of wider contact between soil particles and P (Malik *et al.*, 1992; Shah *et al.*, 2006). Ahmad *et al.* (1992) concluded that the soil moisture affects every aspect of plant growth, modifying their anatomy, morphology, physiology, and biochemistry. Hence, adequate and timely irrigation is one of the most important cultural practices that should be considered necessary for successful crop husbandry.

Irrigated agriculture is facing acute shortage and competition for low cost and high quality irrigation water (Howell, 2001). The irrigation water supply, at farmer level is quite inadequate and the water requirement of crop is not met fully to obtain the optimum yield. For wheat crop too, the soil moisture levels are rarely optimal during its growing season, because the irrigation water is often in short supply. The ground water is, generally not fit for irrigation purposes. It is, therefore, essential to find out the crucial plant growth stages, where the irrigation must be applied to avoid moisture stress and get normal yield (Iqbal *et al.*, 1999).

Keeping in view the above said points a field experiment was conducted to examine the interaction of rate and method of P application, and irrigation scheduling on wheat yield and phosphorus use efficiency (PUE). The results of present investigation are of significant importance for the farmers in order to improve the grain yield by using appropriate phosphorus rates.

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Material and Methods

A farmer's field in district Toba Tek Singh was selected for the conduction of present research. Composite soil sample from 0-30 cm depth was collected with the help of 5 cm diameter auger. These samples were analyzed for physical and chemical characteristics by following standard methods of analysis.

Phosphorous adsorption isotherms and application of model

Phosphorus (P) adsorption capacity of the soil was determined by shaking 2.5g soil sample with 25 mL 0.01 M $CaCl_2$ containing P (as KH_2PO_4) at 0, 5, 20, 40, 60, 80, 100, 200, 300, 400 and 500 µg P mL^{-1} for 24 hours at 25 ^oC (Fox and Kamprath, 1970). Sorption isotherms were constructed according to the methods described by Rowell (1994). The amount of P adsorbed was calculated from 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) as shown below.

Modified Freundlich model

The modified Freundlich model is as follows:

$$\mathbf{P = a\,C^{b/a}}$$

The main advantage of this equation is that **a** and **b** are the amount and the buffer capacities, respectively, at the same point on the curve, where C= 1 µg mL^{-1}. The parameters **a** and **b** were estimated by regression of the logarithmic form of the data obtained from adsorption isotherms. In the present study, derived form Freundlich model was used that is as follow

Derived form: x /m = Kf (EPC)1/n

Linear form: Log x/m = Log Kf + 1/n (Log EPC)

EPC: Equilibrium phosphorus concentration

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.

Field experiment

A field experiment was conducted on sandy loam soil in split-split plot design and the treatments were replicated three times. The treatments included: four P rates (0, 47, 81 and 111 kg P_2O_5 ha^{-1}) that were applied in sub-sub plots two methods of P application band placement and broadcasting and four irrigation schedules applied in sub-plots and main plots, respectively. The irrigation schedules were: No irrigation, two irrigations at crown root and booting stages, three irrigations at crown root, booting and grain development stages, four irrigations at crown root, booting, anthesis and grain development stages. The plot size was 18 m^2.

Wheat crop cv. Inqulab-91 was sown @ 125 kg seed ha^{-1} by *Rabi* drill during 2nd week of November. Seeds were treated with *Benlate* @ 100 g per 40 kg of wheat seed prior to sowing. Computed four levels of P along with 130 kg N and 65 kg K ha^{-1} were applied in their respective plots; DAP, urea, and SOP were used to meet the requirements. Half of N and whole of K were applied during seedbed preparation and other half of N with first irrigation. The data regarding total number of tillers m^{-2}, number of grains per spike, 1000-grain weight and grain yield were recorded. The grain sample was ground, passed through 0.5 mm sieve and then dried at 70 ^oC for three days. The samples were digested using diacid mixture (concentrated HNO_3 and $HC1O_4$, with 9:4) and phosphorus concentrations were measured from digested samples using ammonium molybdate vanadate method (Method 54a, US Salinity Lab. Staff, 1954). Soil samples collected after harvesting of wheat were analyzed for Olsen P (Olsen *et al.*, 1954).

P use efficiency

Phosphorus use efficiency was calculated using the formulae as described by Fageria *et al.* (1997).

PUE % =

$$\frac{\text{Total P uptake (kg ha}^{-1}\text{) in fertilized plot} - \text{Total P uptake (kg ha}^{-1}\text{) in control plot}}{\text{P dose applied (kg ha}^{-1}\text{)}} \times 100$$

P uptake (kg ha^{-1}) =

P Concentration (%) x yield (Mg ha^{-1}) x 1000 / 100

Total P uptake (kg ha^{-1}) =

Grain P uptake + Straw P uptake

Total protein

Total protein was determined by Chapman and Parker method (1961). The samples were digested with concentrated sulfuric acid in the presence of digestion mixture containing K_2SO_4, $CuSO_4$ and $FeSO_4$ (90: 10: 1). The resultant mixture was further diluted and distilled with NaOH using steam in micro Kjeldahl distillation apparatus. The ammonia produced was collected in 2% boric acid solution and nitrogen contents were determined by titrating against 0.1 N sulphuric acid. Protein contents were tabulated by multiplying nitrogen with a factor of 6.25.

Statistical analysis

Analysis of variance (ANOVA) and Duncan's Multiple Range (DMR) tests were used to determine the significance of difference among treatments (Steel and Torrie, 1980; Duncan, 1955).

Results and Discussion

The soil of the experimental field was sandy loam in texture, calcareous ($CaCO_3$ > 5 %), non-saline, and non-sodic but alkaline in reaction and deficient in available P and organic matter (Table 1).

Table 1: Physical and chemical properties of soil

Properties	Value
EC_e (dS m^{-1})	1.81
pH_s	8.2
$CaCO_3$ (%)	5.0
O. M (%)	1.13
Olsen P (mg kg^{-1})	8.0
Extractable K (mg kg^{-1})*	90
Sand (%)	69
Silt (%)	17
Clay (%)	14
Texture	Sandy loam

* Extracted with ammonium acetate

Phosphorus adsorption by the soil

The amount of P adsorbed (x/m) increased with every increment in amount of added P but the percent adsorption proportion of added phosphorus followed the reverse trend (Table 2). Similar results were also reported by Kumar and Singh (1998), Samadi (2003) and, Zhou and Li, (2001).

Table 2: P adsorption by soil

P added (mg L^{-1})	Adsorbed P (mg kg^{-1})
20	75.10
40	83.05
60	83.55
80	81.21
100	78.91
200	74.33
300	71.07
400	68.59
500	54.05

Phosphorus adsorption data was used to develop the Freundlich equation [Log x/m vs. Log EPC] that gave a linear fit (Figure 1) and analogous linear relationship was observed. The empirically derived (Table 3) Freundlich adsorption equation (Pant and Reddy 2001) used in this study is:

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

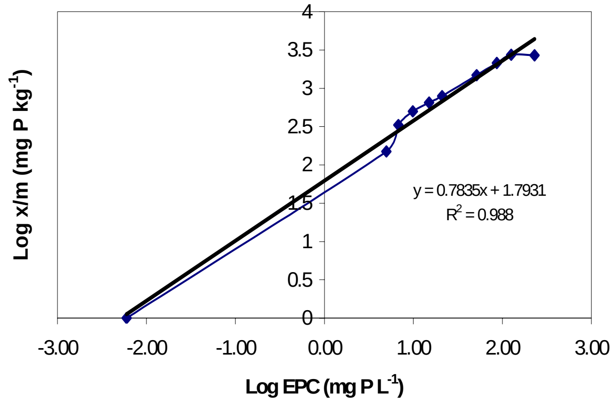

Figure 1: Freundlich adsorption isotherm

Table 3: Derived Freundlich adsorption equations

Soil	Derived Freundlich adsorption equations	
	Derived form x /m = Kf (EPC)1/n	Linear forms Log x/m = Log Kf + 1/n (Log EPC)
Sandy loam	x /m = 62.10 $(EPC)^{0.164}$	Y= 0.164 (Log EPC) + 1.7931

Computation of fertilizer P doses for wheat by using Freundlich equation

The sandy loam soil under this study showed high P adsorption capacities (>3.0% $CaCO_3$) possibly due to high calcareous nature (Zhou and Li, 2001). Therefore, linear form of derived Freundlich adsorption equation [Log x/m = Log K_f + 1/n (Log EPC)] was used for computing P fertilizer doses to adjust the soil solution P level of, 0.00, 0.10, 0.20 and 0.30 mg L^{-1} (Table 4). The regression equation can be solved for any desired solution P level 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 amounts of P (kg ha^{-1}) were converted to P_2O_5 (kg ha^{-1}) by multiplying P with 2.29.

Table 4: Computed P doses for sandy loam soil

Adjusted Soil solution P levels	P	P_2O_5
mg L^{-1}	kg ha^{-1}	
0.00	0	0
0.10	20	47
0.20	35	81
0.30	48	111

Number of tillers m^{-2}

Tillering increased significantly with the increase of P rate (Table 5). It is the most important yield component of wheat crop. The highest number of tillers m^{-2} (307.38) was obtained with 81 kg P_2O_5 ha^{-1} thus recommending higher rate (111 kg P_2O_5 ha^{-1}) was not judicious. Tillering in wheat increased significantly with the increase in number of irrigations from zero to three. Fourth irrigation could not help to further improve number of tillers m^{-2}. Thus, the optimum numbers of irrigations were three i.e. at crown root, booting and grain development stages. Khan *et al.* (2002) reported significantly maximum number of fertile tillers with three irrigation levels. These results are also in confirmity with those of Ghazal *et al.* (1998). Band application of P also significantly affected the number of tillers m^{-2} as compared to broadcast application. These results are in conformity with those of Turk and Tawaha (2001) who reported that the number of tillers m^{-2} were significantly greater with band placement than with broadcast method of P application.

1000–Grain weight (g)

Results regarding 1000–grain weight are presented in Table 5. It was observed that 1000–grain weight increased significantly with increase in P rate. Relatively heavier grains were produced with 81 kg P_2O_5 ha^{-1}. Grain weight increased significantly with the increase in number of irrigations from zero to three. Thus, the optimum numbers of irrigations were three. These results are in line with those of Maqsood *et al.* (2002), who concluded that three irrigations at critical growth stages gave the maximum number of productive tillers, number of grains per spike, 1000 grain weight and grain yield. Band placement of P proved better over broadcast for producing heavier grains. Similar results were obtained by Turk and Tawaha (2001) who reported that the 1000-grain weight was significantly higher with band placement than with broadcast method of P application.

Table 5: Effect of number of irrigation, rate and method of P application on tillers m^{-2}, grains $spike^{-1}$, 1000-grain weight and grain yield

Treatment	P rate (kg ha^{-1})	Tillers m^{-2}	Grains $spike^{-1}$	1000-grain weight (g)	Grain yield (Mg ha^{-1})
T1	0	229.33d	26.21c	26.28d	1.58d
T2	47	271.71c	31.11b	31.92c	3.33c
T3	81	307.38a	39.01a	36.25a	3.94a
T4	111	295.00b	37.29a	34.48b	3.67b
LSD (P=0.05)		**7.648**	**1.88**	**1.047**	**0.107**
Treatment	**No. of irrigation**				
T1	0	259.04c	30.61c	28.63d	2.32c
T2	2	272.79b	32.13bc	30.63c	2.98b
T3	3	290.67a	34.53a	35.60a	3.65a
T4	4	287.92a	33.35ab	34.07b	3.57a
LSD (P=0.05)		**7.648**	**1.88**	**1.047**	**0.107**
Treatment	**Method**				
T1	Band placement	280.58a	33.37a	32.75a	3.17a
T2	Broadcast	271.13b	31.95b	31.72b	3.10a
LSD (P=0.05)		**5.408**	**1.33**	**0.74**	**0.076**

Grains $spike^{-1}$

The number of grains $spike^{-1}$ increased significantly with increase in P rates (Table 5). The highest number (39) of grains $spike^{-1}$ was obtained with 81 kg P_2O_5 ha^{-1}, and higher rate could not further increase grains $spike^{-1}$. Grains $spike^{-1}$ increased significantly with the increase in number of irrigation from zero to three. Fourth irrigation was at par with third one. Similar results were obtained by Qadir *et al.* (1999) who reported that water stress during the reproductive growth, reduced number of tillers m^{-2}, grains $spike^{-1}$ and 1000-grain weight and thus reduction in grain yield of wheat. Band placement of P had significant positiveeffect on grains $spike^{-1}$ as compared to broadcasting.

Grain yield

It was observed that grain yield (Table 5) increased significantly as a function of P application rate. Highest grain yield was obtained with 81 kg P_2O_5 ha^{-1} and further increasing the rate of P could not increase grain yield. Wheat grain yield increased from 1.58 Mg ha^{-1} in control to 3.96 Mg ha^{-1} obtained with 81 kg P_2O_5 ha^{-1} calculated against adjusted soil solution P level of 0.20 mg L^{-1} on sandy loam soil. Maximum P rate (111 kg P_2O_5 ha^{-1}) could not further improve the yield. It might be due to the reason that 81 kg P_2O_5 ha^{-1} is sufficient under the experimental condition. The soil solution P level for obtaining maximum wheat grain yield was found to be 0.20 mg L^{-1} as reported earlier by Rehman *et al.* (2004). Grain yield increased significantly upto three irrigations, whilst fourth irrigation could not help to further improve wheat grain yield. Thus, the optimum number of irrigations may be three i.e. at crown root, booting and grain development stages. Without irrigation, yield of 2.32 Mg ha^{-1} was obtained, while maximum yield was obtained with three irrigations (3.65 Mg ha^{-1}). There was non significant effect of method of P application on grain yield.

Reddi and Reddi (1995) and Sharif (1999) also reported higher grain yield of wheat as a result of increased irrigation levels. Similar results were obtained by Turk and Tawaha (2001) who reported that grain yield, straw yield, total biomass and total number of tillers m^{-2} were significantly higher with band placement than with broadcast method of P application. The superiority of band placement was probably due to better fertilizer efficiency as developing roots were in intimate contact with P-enriched soil adjacent to fertilizer granules.

Olsen P status in soil after wheat harvest

Olsen P status after wheat harvest was computed and presented in Table 6. At harvesting, available P status of soil significantly increased over control. The highest Olsen P of 10.57 mg kg^{-1} was found in plots treated with 111 kg P_2O_5 ha^{-1} and the lowest of 3.22 mg kg^{-1} was found in control plots. The results are in line with those of Sharma (2006) who described that the continuous application of recommended levels of P significantly increased the soils available P status. It was further observed that Olsen P decreased significantly with increasing the number of irrigations possibly due to increased plant growth. The maximum of 7.56 mg kg^{-1} Olsen P was noted in plots with zero irrigation and it decreased gradually at each increasing irrigation number and the minimum of 5.65 mg kg^{-1} was observed in plots where four irrigations were applied. It was concluded that lower water content reduces P diffusion through soil to the root surface and similar results were obtained by Hira and Singh (1977). Methods of P application also significantly affected Olsen P status; higher Olsen P content of 6.97 mg kg^{-1} was noted in broadcasting as compared to band placement. It is also reported that the availability of readily soluble P fertilizer is influenced by the volume of soil that is exposed to the applied P and the time of contact between soil and the fertilizer P (Soon, 1997).

P concentration (%) in wheat grain and straw

The data presented in Table 6 indicated that P concentration in wheat grain increased significantly as a function of increasing P rate. Higher P concentration of 0.201 % in wheat grain was obtained with 111 kg P_2O_5 ha^{-1} as compared to 0.113 % in control. Furthermore, P concentration increased significantly from 0.116 % (zero irrigation) to 0.195 % (four irrigations).

Likewise, P concentration in wheat straw increased significantly with increase of P application rate; maximum (0.135 %) was obtained with 111 kg P_2O_5 ha^{-1} (Table 6). P concentration increased significantly as a function of increasing number of irrigations. The lowest P concentration (0.077 %) was recorded in straw at zero irrigation as compared to maximum (0.113 %) with four irrigations. Among methods of P application, band placement gave better performance as compared to broadcasting in improving the P concentration in wheat grain and straw.

P uptake by wheat crop (kg ha^{-1})

The data regarding P uptake are given in Table 6, which showed that P uptake increased at each increment of fertilizer P. The maximum P uptake (15.23 kg ha^{-1}) was recorded with 111 kg P_2O_5 ha^{-1} application, whilst minimum (4.06 kg ha^{-1}) P was up taken by wheat crop in control. Additionally, P uptake increased significantly owing to increase in number of irrigations. The results revealed linear tendency in P uptake; the minimum (5.78 kg ha^{-1}) in plots with zero irrigation and the maximum (14.59 kg ha^{-1}) was observed with four irrigations. Total P uptake was improved by water regimes. Similar results have also been reported by Power *et al.* (1961) and Sharma *et al.* (1972). Among methods of P application, band placement improved P uptake significantly as compared to broad casting. Phosphorus uptake was 10.98 kg ha^{-1} with band placement of P and 9.72 kg ha^{-1} with broadcast.

The decreased soil and total P uptake by wheat with decrease in irrigation number may be due to restricted root growth in the top soil and less chemically available soil P at the root absorption site. These results are in confirmity with those of Garg and Welch (1967) and Singh (1962) who concluded that placement of P fertilizer to a small portion of soil volume, rather than mixing it with whole soil, decreased P fixation and increased P uptake by plants

P use efficiency in wheat

Data of P use efficiency (PUE) of wheat are given in Table 6. PUE was calculated in terms of P uptake per unit of fertilizer P application. The results revealed that lower PUE was seen at higher P rates. The maximum PUE of 14.68 % was observed at 47 kg P_2O_5 ha^{-1} and it decreased significantly at higher P rates. Similarly, irrigation numbers significantly affected the PUE and the minimum of 3.45 % was obtained with zero irrigation and it increased with each irrigation number, the maximum PUE (14.36 %) was noted with four irrigations. Results are in confirmity with those of

Hira and Singh (1977) who concluded that lower water content reduced P diffusion through soil to the root surface. However, it is clear from Table 6 that P application through band placement significantly enhanced the PUE with that of broad casting.

In the present study, grain protein percentage was improved with three irrigations. Increased grain protein with limited irrigation might be the results of reduction and synthesis of carbohydrates under water deficit, allowing more nitrogen accumulation in the grain per unit of starch.

Table 6: Effect of number of irrigation, rate and method of P application on Olsen P, P % in grain and straw, total P uptake, P use efficiency and protein in grain

Treatment	P rate (kg ha^{-1})	Olsen P (mg kg^{-1})	P % in grain	P % in straw	Total P uptake kg ha^{-1}	P use efficiency (%)	Protein in grain (%)
T1	0	3.22d	0.113d	0.075d	4.06d	0.000	8.01d
T2	47	5.57c	0.130c	0.099c	9.89c	14.68a	9.66c
T3	81	6.53b	0.147b	0.107b	12.24b	11.42b	11.29b
T4	111	10.57a	0.201a	0.135a	15.23a	11.02c	12.35a
LSD (P=0.05)		0.016	0.0042	0.0034	0.257	0.307	0.083
Treatment	**No. of irrigation**						
T1	0	7.56a	0.116d	0.077d	5.78d	3.45d	10.16b
T2	2	6.70b	0.128c	0.095c	8.70c	7.35c	9.70c
T3	3	5.97c	0.152b	0.111b	12.35b	11.97b	11.33a
T4	4	5.65d	0.195a	0.113a	14.59a	14.36a	10.11b
LSD (P=0.05)		0.016	0.0042	0.0034	0.257	0.307	0.083
Treatment	**Method**						
T1	Band placement	5.98b	0.156a	0.108a	10.98a	10.09a	10.73a
T2	Broadcast	6.97a	0.140b	0.100b	9.72b	8.47b	9.93b
LSD (P=0.05)		0.011	0.0030	0.0024	0.182	0.217	0.059

These results are in confirmity with Alam *et al.* (2005) and Latif *et al.* (1997) who concluded that P placement methods improved PUE significantly as compared to broadcast and incorporation at sowing. Similarly, they found that rate and method of P application positively influenced the PUE by wheat. It can be explained that more frequent irrigations increase labile P, enhance P diffusion as cross sectional area for diffusion increases and tortuosity of path is decreased. Hence wetter soil moisture regimes increased uptake and utilization of applied and native P.

Protein content in wheat grain

The data regarding protein content in wheat grain are given in Table 6. Protein contents in wheat grains increased at each increment of fertilizer P. The maximum protein content of 12.35 % was noted in grains with 111 kg P_2O_5 ha^{-1}, whilst the minimum protein content (8.01 %) was observed in control. Grain protein content was also influenced by irrigation treatments; the highest grain protein content (13.65 %) was recorded with three irrigations. The lowest grain protein content (9.70 %) was noted in plots where two irrigations were given. Band placement of P caused significantly more (10.73 %) protein content over broad casting (9.93 %).

Similar results were reported by Clark *et al.* (1990) and Panozzo and Eagles (2000) who observed positive effect of water stress applied at different stages of growth on grain protein contents in wheat.

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 the present study, wheat yield increased significantly with the use of P and the optimum rate for sandy loam soil is 81 kg P_2O_5 ha^{-1}. Band placement is preferable method for fertilizer P application to improve PUE. Moreover, three irrigations each at crown root, booting and grain development stages may help to save water but it should be site specific. Further studies are urgently needed to assess the significance of improving phosphorous use efficiency for other grain crops in Pakistan.

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