Pak. J. Bot., 44(4): 1391-1398, 2012.

PHOSPHORUS USE EFFICIENCY OF *TRITITICUM AESTIVUM* L. AS AFFECTED BY BAND PLACEMENT OF PHOSPHORUS AND FARMYARD MANURE ON CALCAREOUS SOILS

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Abstract

This study was conducted to explore the role of different phosphorus (P) levels and application methods in improving wheat grain yield, P uptake and phosphorus use efficiency (PUE) on calcarious soils. Five P levels viz., 0.0, 27.0, 47.0, 81.0 and 111.0 kg P_2O_5 ha^{-1} (calculated using adsorption isotherms) and three application methods i.e., broad casting, band placement and top dressing was included in the study. The experiment was conducted with and without FYM application. Band placement of P at 81 kg P_2O_5 ha^{-1} improved grain yield and yield components, grain protein contents, P uptake and PUE with and without FYM application. Nonetheless, application of 111.0 kg P_2O_5 ha^{-1} resulted in maximum straw and grain P contents and uptake, grain protein contents, Olsen P and PUE of wheat. Broad casting of P performed poor at all P levels. Application of FYM with P fertilizer improved wheat yield and PUE as compared with fertilizer alone.

Introduction

Wheat (*Triticum aestivum* L.) is not only the most important cereal crop in the world but also the major source of staple food for the inhabitants of Pakistan (Tunio, 2006; Malik, 2006). Despite of being grown on larger area, average yield at farmers' fields is still far below than the potential (Mann *et al.,* 2004). Traditional method of seedbed preparation for preceding crop (e.g., rice), late planting (after rice and cotton), high weeds infestation, water shortage at critical growth stages and non-judicious use of fertilizers reduce the wheat productivity. The major role of mineral fertilizers is to improve crop yields but the main constraint in achieving proven crop potential is low use of fertilizers particularly that of P and K as compared to N (Anon., 2002). As P is an expensive nutrient compared to N, and wheat commonly suffers from P deficiency while grown on alkaline calcareous soils. It is, therefore, imperative to manage it properly to achieve maximum benefits (Malik *et al.,* 1992). Overall 90% of Pakistan soils are low in available P and suffer from moderate to severe P deficiency (Ahmad *et al*., 1992; Nisar *et al.,* 1992). Plants require adequate P from the very early stages of growth for optimum crop production (Grant *et al.,* 2005).

It is generally agreed that higher P supply is a prerequisite for high yield potential of modern wheat cultivars (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. Nutrient efficiency has been widely used as a measure of the capacity of a plant to acquire and utilize nutrient for biological and grain yield but PUE is well below than other nutrients due to alkaline (pH > 7.0) and calcareous ($CaCO_3$ > 3.0%) nature of soils of Pakistan (Saleem, 1992). More than 80% of added P gets fixed and only a part of it goes to soil solution which may be either taken up by crops or precipitates (White, 1982; Leytem & Mikkelsen, 2005). With time, adsorbed P becomes difficult to release into soil solution and consequently efficiency of P fertilizer in calcareous soils remains low (Delgado *et al.,* 2002).

P fixation is of great importance in the interpretation of soil tests and fertilizer recommendations. Therefore, site and crop specific P recommendations on scientific basis are direly needed (Nisar *et al*., 1992). Wheat roots absorb P only from the soil solution (Johnston *et al.,* 1999); thus, external soil solution P requirement may be a plant characteristic (Fox, 1981). Thus information about the quantities of P fertilizer to adjust the soil solution P to a level optimal for targeted crop yield is needed (Samadi, 2003). Once the soil solution P level for optimum plant growth is identified, P adsorption isotherms can be utilized to predict P rates required to adjust soil solution P to the desired level. An adsorption isotherm could successfully relate P concentration in soil solution to the P adsorbed onto soil surface and takes into account the both intensity as well as capacity factors. Moreover, it is a rapid and accurate method for assessing P fertilizer requirements of soils (Samadi, 2003). A little information is available on the use of this technique for calcareous soils.

To enhance PUE of applied P fertilizer, time and method of its application are critically important because different P application methods differ in PUE. In Pakistan, recommended method of P application is to broadcast it on the surface of the soil, followed by incorporation, before sowing of the crop that results in the conversion of soluble P to insoluble forms and thus reduces its use efficiency (Shah *et al*., 2006). Recently, Rehim *et al*., (2010) reported better performance of wheat crop and enhanced PUE due to band placement of P over broadcast. There are many reports which highlight the importance of split application of N and P by top dressing or by fertigation method to attain higher grain yield, P uptake and PUE compared to the incorporation of P at sowing (Alam *et al.,* 1999; 2002; Latif *et al.,* 2001).

Nutrient efficiency has been widely used as a measure of the capacity of a plant to acquire and utilize nutrient for biological and grain yield. P fertilizer when applied to soil after mixing (12 hours before application) with moist and well-decomposed farmyard manure in the ratio of 1:2 resulted in 30% higher P use efficiency (Anon., 2003). The fertilizer efficiency improved significantly, when integrated (organic and inorganic) source of P was used (Yamoah *et al*., 2002). The use of FYM improved soil organic matter, and soil physical, chemical and microbial properties that ultimately affect P nutrition of plants (Belay *et al*., 2001; Karaman *et al*., 2001).

Keeping in view the aforementioned discussion, the present study was designed to explore the role of different P levels and methods of P application with and without FYM application on wheat yield and PUE on calcareous soils.

Materials and Methods

Experimental site description: The present study was conducted at Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad, Pakistan (31.25^o N, 73.06^o E and 183 m a.s.l.) during Rabi Season 2006-07. The soil was quite uniform and calcareous ($CaCO_3$ > 5 %) in nature. The whole physico-chemical analysis of soil is given in Table 1. Weather data during the whole course of study is given in Table 2.

Table 1. Physico-chemical properties of soils.

	Units	Value
Properties	0-30 (cm)	
EC	(dS m^{-1})	1.81
pH_5		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
Textural class		Sandy loam

Table 2. Weather data during the course of the study.

Month	Mean monthly temperature (^{o}C)	Mean monthly relative humidity (%)	Total monthly rainfall (mm)
Nov. 2006	20.9	47.0	12.8
Dec. 2006	15.5	57.4	46.2
Jan. 2007	12.5	67.4	0.0
Feb. 2007	15.5	67.1	55.9
Mar. 2007	19.4	47.0	41.3
Apr. 2007	28.9	35.1	0.0

Source: Agricultural Meteorology Cell, Department of Crop Physiology, University of Agriculture, Faisalabad-38040, Pakistan

Experimental details: Wheat seed (*Triticum aestivum* L. cv. Inqulab-91) was obtained from Ayub Agricultural Research Institute (AARI), Faisalabad Pakistan having 11.5% moisture contents and 98% germination percentage. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications and net plot size of 1.8 m x 4 m. Phosphorus application methods and P levels were randomized in main and subplots, respectively. Phosphorus application methods were broad casting, band application and top dressing. P levels included in the study were 0.0, 27.0, 47.0, 81.0 and 111.0 kg P_2O_5 ha^{-1}. These levels were determined according to adjusted soil solution P levels i.e., 0.0, 0.05, 0.1, 0.2 and 0.3 mg P L^{-1} in soil solution that was determined according to Freundlich Model (Samadi, 2003). The study was conducted in two portions. In first, all P application methods and P levels were employed without farmyard manure (FYM) application while in 2nd portion 300 kg ha^{-1} well rotten FYM was applied along with aforementioned P application methods and P levels.

Crop husbandry: Pre-soaking irrigation of about 10 cm was applied at both sites prior to seedbed preparation. When soil reached to workable moisture level, seedbed was prepared by cultivating the field two times with tractor-mounted cultivator each followed by planking. Wheat (Inqulab-91) was sown on 10th of November during 2006 and sowing was done with the help of single row cotton drill using seed rate of 125 kg ha^{-1} maintaining row to row distance of 22.5 cm. Seed was treated with benlate @100 g per 40 kg of wheat seed before sowing in order to keep the crop free from soil and seed born diseases. Computed levels of P along with 130 kg N and 65 kg K ha^{-1} in the form of urea, sulphate of potash (SOP) and diammonium phosphate (DAP) were used. Half of nitrogen and whole of potash were applied at sowing, while remaining nitrogen was applied with 1st irrigation. Plant protection measures were adopted to keep crop free of insects and diseases. Overall four irrigations were applied to save the crop from moisture stress. The mature crop was harvested on 15th April 2007.

Observations recorded: To calculate total number of tillers (m^{-2}), total number of tillers (either spike bearing or not) was counted from a randomly selected unit area of (0.5 m^2) at four different locations in each plot, averaged and then converted into square meter area. Ten randomly selected spikes were threshed manually and their total number of grains were counted and averaged to record number of grains per spike. Three random samples of 1000 grains were counted from each seed lot, weighed on electrical balance and averaged to record 1000-grain weight. At harvest maturity, two central rows were harvested, sun dried for three days, tied into bundles and weighed by using spring balance to record biological yield and then converted into kg ha^{-1} by unitary method. After that wheat was threshed manually, grains were separated and weighed on an electric balance to calculate the grain yield and then converted into kg ha^{-1} by unitary method. Grain yield was then adjusted to 10% moisture contents. To record straw yield, grain yield was subtracted from biological yield. Harvest index (HI) was computed by using following formula:

$$\text{Harvest index (\%)} = \frac{\text{Grain Yield}}{\text{Biological Yield}} \times 100$$

To calculate straw and grain P contents, one gram oven dried straw and grain was digested in 10 mL of di-acid mixture (Concentrated HNO_3 and 72% $HC1O_4$, with 9:4 ratio) cooled the digest, transferred to 100 mL volumetric flask and made volume (Method 54a, US Salinity Lab. Staff, 1954). Five mL of the digested aliquot was taken in 50mL volumetric flask, added 5 mL of ammonium vanadate (0.25%) and ammonium molybdate (5%), made volume and allowed to stand for 15-30 minutes. Reading was recorded on spectrophotometer. Then from the standard curve, P concentration (%) in grain 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:

$$\text{Puptake (kg ha}^{-1}) = \frac{\text{Pcontents (\%) in plant part (dry matter) x Yield (kg ha}^{-1})}{100}$$

Phosphorus use efficiency (PUE) on the basis of formulae as described by Fageria *et al*., (1997).

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

Grain protein contents (%): Total protein was determined by Chapman & 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 sulfuric acid. Protein contents were tabulated by multiplying nitrogen with a factor of 6.25.

Statistical analysis: The data collected was analyzed by using the Fisher's analysis of variance technique under Randomized Complete Block Design (RCBD) and the treatments means were compared by Least Significant Difference (LSD) test at 0.05 probability levels (Steel *et al*., 1997).

Results

Different P levels (P), application methods (M) and their interaction had significant effect on grain yield and yield components of wheat (Table 3). Band placement of P resulted in maximum number of tillers, 1000-grain weight and grain yield compared with both other P application methods (broad casting and top dressing) under both conditions i.e. farmyard manure (FYM) application and without its application (Table 3). But number of grains per spike remained unchanged in all P application method where no FYM was applied. Likewise, P application methods also had non-significant effect on 1000-grain weight under FYM application (Table 3). Similarly, 81 kg P_2O_5 ha^{-1} resulted in maximum number of tillers, grains per spike, 1000-grain weight and grain yield but it was at par with 111 kg P_2O_5 ha^{-1} for all yield components except grain yield in case of no FYM application, and only for number of tillers with FYM application (Table 3). While, 0.0 kg P_2O_5 ha^{-1} (control) resulted in minimum number of tillers, grains per spike, 1000-grain weight and grain yield with and without FYM application but it was at par with 27 kg P_2O_5 ha^{-1} for number of grains per spike and grain yield where FYM was applied (Table 3). In case of interactions between M x P, band placement of P at 81 and 111 kg P_2O_5 ha^{-1} resulted in maximum number of tillers, grains per spike and 1000-grain weight with and without FYM application but maximum grain yield was recorded where band placement of P was done at 81 kg P_2O_5 ha^{-1} (Table 3). Minimum number of tillers, grains per spike, 1000-grain weight and grain yield of wheat was recorded in control (0.0 kg P_2O_5 ha^{-1}) with and without FYM application (Table 3).

Maximum straw yield, biological yield, harvest index and grain protein contents were recorded in band placement of P with and without FYM application. While with broadcasting P minimum straw yield, biological yield, harvest index and grain protein contents were recorded but it was at par with top dressing of P for straw yield, biological yield and harvest index under both FYM application and without application (Table 4). Broadcasted P resulted in maximum Olsen P against band application of P that resulted in minimum Olsen P under both conditions but it was at par with top dressing of P where no FYM was applied (Table 4). Likewise, 81 kg P_2O_5 ha^{-1} resulted in maximum straw and biological yield compared with control (0 kg P_2O_5 ha^{-1}) that resulted in minimum straw and biological yield of wheat under both FYM application and without application (Table 4). In case of FYM application, maximum HI was recorded at 81 kg P_2O_5 ha^{-1} against 0 and 111 kg P_2O_5 ha^{-1}, but in case of FYM application, maximum HI was recorded at 0, 81 and 111 kg P_2O_5 ha^{-1} against minimum HI that was recorded at 47 kg P_2O_5 ha^{-1} (Table 4). While, maximum Olsen P and grain protein contents were recorded at 111 kg P_2O_5 ha^{-1}. The control treatment resulted in minimum Olsen P and grain protein contents under both FYM application and without application (Table 4). Regarding interactive effects of M x P, band application of P at 81 and 111 kg P_2O_5 ha^{-1} level resulted in maximum straw and biological yield, and HI of wheat compared with the control plots (0 kg P_2O_5 ha^{-1}) under both situations (Table 4). Maximum Olsen P was recorded in broadcasted P at 111 kg P_2O_5 ha^{-1} against the minimum Olsen P without P application under both FYM application and without application (Table 4). Maximum grain protein contents were obtained at 81 and 111 kg P_2O_5 ha^{-1} level in band application of P and band placement and top dressing of P under without FYM application and with FYM application, respectively (Table 4).

Table 3. Effect of different rate and methods of P application on yield and yield components of wheat

Treatments	Number of tillers (m^{-2})		Number of grains per spike		1000-grain weight (g)		Grain yield (Mg ha^{-1})	
	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM
	Methods of P application (M)							
M_1 = Broad casting	257.67 b	268.40 c	29.66	29.72 b	36.61 b	38.20	3.03 c	3.37 b
M_2 = Band placement	266.87 a	277.53 a	30.62	31.96 a	38.62 a	39.84	3.36 a	3.64 a
M_3 = Top dressing	260.86 b	272.53 b	29.81	30.99 ab	37.65 ab	38.23	3.16 b	3.43 b
LSD at 5%	3.82	3.79	NS	1.97	1.71	NS	0.11	0.14
	P levels (kg P_2O_5 ha^{-1})							
P_0 = 0.00	231.0 d	240.33 d	26.69 c	28.00 d	33.47 c	35.13 c	2.40 e	2.82 d
P_1 = 27.00	240.9 c	259.78 c	29.58 b	28.32 cd	35.82 b	37.54 b	2.60 d	2.96 d
P_2 = 47.00	268.2 b	271.89 b	30.21 ab	30.41bc	37.47b	39.01 b	3.35 c	3.56 c
P_3 = 81.00	286.7 a	298.44 a	32.67 a	35.69 a	41.10 a	42.42 a	3.96a	4.18 a
P_4 = 111.00	282.0 a	293.67 a	31.00 ab	32.18 b	40.31a	39.68 b	3.62 b	3.88 b
LSD at 5%	4.93	4.89	2.49	2.54	2.21	2.40	0.14	0.18
	Interaction between M x P							
M_1P_0	231 h	240.33 h	26.7 c	27.84 d	33.5 e	35.1 e	2.40 g	2.82 g
M_1P_1	238 gh	258.33 g	29.5 abc	27.79 d	35.2 de	37.7 cde	2.58 fg	2.87 fg
M_1P_2	265 f	265.00 fg	30.1 abc	28.53 d	37.3 cd	38.6 bcde	3.18 e	3.49 e
M_1P_3	278 cd	291.33 cd	31.8 ab	33.76 abc	38.7 bcd	40.9 abc	3.65 c	3.92 bcd
M_1P_4	276 de	287.00 d	30.3 abc	30.68 cd	38.4 bcd	38.7 bcde	3.35 de	3.75 de
M_2P_0	231 h	240.33 h	26.7 c	27.84 d	33.5 e	35.1 e	2.40 g	2.82 g
M_2P_1	244 g	262.67 g	30.5 abc	29.04 d	37.2 cde	39.0 bcde	2.68 f	3.14 f
M_2P_2	272 def	277.33 e	30.7 abc	31.73 cd	38.0 cd	39.5 bcd	3.54 cd	3.64 de
M_2P_3	297 a	307.33 a	33.3 a	37.15 a	42.8 a	44.0 a	4.25 a	4.51 a
M_2P_4	290 ab	300.00 ab	31.9 ab	34.02 abc	42.0 ab	42.0 abc	3.90 b	4.10 bc
M_3P_0	231 h	240.33 h	26.7 c	27.84 d	33.5 e	35.1 e	2.40 g	2.82 g
M_3P_1	240 g	258.33 g	28.7 bc	28.14 d	35.1 de	35.9 de	2.52 fg	2.88 fg
M_3P_2	268 ef	273.33 ef	29.9 abc	30.97 cd	37.5 cd	39.0 bcde	3.32 de	3.53 e
M_3P_3	285 bc	296.67 bc	32.9 ab	36.15 ab	41.7 ab	42.4 ab	3.97 b	4.11 b
M_3P_4	280 cd	294.00 bcd	30.8 abc	31.85 bcd	41.0 abc	38.8 bcde	3.60 c	3.80 cde
LSD at 5%	8.53	8.47	4.31	4.40	3.82	4.15	0.25	0.31

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

Maximum grain and straw P contents, and grain and straw P uptake and phosphorus use efficiency (PUE) was recorded in band placement of P under both FYM application and without application (Table 5). Likewise, minimum grain and straw P contents, grain and straw P uptake and PUE was recorded in broadcasted P but it was at par with top dressing of P for straw P contents and uptake under both FYM application and without application (Table 5). Nonetheless, maximum grain and straw P contents and grain and straw P uptake was recorded at 111 kg P_2O_5 ha^{-1} against the minimum values that were recorded in control both under FYM application and without application. Maximum PUE was recorded at 47 and 111 kg P_2O_5 ha^{-1}, and 47 kg P_2O_5 ha^{-1} under without FYM application and FYM application, respectively while control (no application of P) resulted in minimum PUE (Table 5). Regarding interactive effects of M x P, band application of P at 111 kg P_2O_5 ha^{-1} resulted in maximum grain and straw P contents, grain and straw P uptake while control (0 kg P_2O_5 ha^{-1}) resulted in minimum grain and straw P contents, and grain and straw P uptake under both situations (Table 5). Likewise, band placement of P enhanced PUE at 47 and 111 kg P_2O_5 ha^{-1} and 47 kg P_2O_5 ha^{-1} without and with FYM application, respectively while control resulted in low PUE without and with FYM application (Table 5).

Table 4. Effect of different rate and methods of P application on straw and biological yield, HI, Olsen P and protein contents of wheat.

Treatments	Straw yield ($Mg\ ha^{-1}$)		Biological yield ($Mg\ ha^{-1}$)		Harvest index (%)		Olsen P ($mg\ L^{-1}$)		Grain protein contents (%)	
	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM
	Methods of P application (M)									
M_1 = Broad casting	4.55 b	5.00 b	7.58 c	8.37 b	39.95 b	40.27 b	9.0 a	8.80 a	10.60 c	11.65 c
M_2 = Band placement	4.71 a	5.10 a	8.07 a	8.74 a	41.33 a	41.60 a	8.3 b	7.72 c	11.21 a	12.52 a
M_3 = Top dressing	4.62 b	5.02 b	7.79 b	8.45 b	40.46 b	40.53 b	8.3 b	8.08 b	10.80 b	12.20 b
LSD at 5%	0.72	0.07	0.14	0.14	0.87	1.00	0.03	0.02	0.12	0.12
	Adjusted soil solution P levels ($mg\ L^{-1}$) (P)									
P_0 = 0.00	3.70 d	4.05 d	6.10 e	6.87 e	39.36 c	41.07 ab	4.1 e	4.22 e	8.51 d	9.14 e
P_1 = 0.05	4.20 c	4.33 c	6.80 d	7.29 d	38.19 d	40.64 b	6.6 d	5.88 d	8.93 c	11.43 d
P_2 = 0.10	4.37 b	5.56 b	7.72 c	9.11 c	43.38 a	38.97 c	7.7 c	7.16 c	11.00 b	12.77 c
P_3 = 0.20	5.46 a	5.70 a	9.41 a	9.89 a	41.97 b	42.28 a	10.7 b	10.02 b	12.93 a	13.53 b
P_4 = 0.30	5.42 a	5.57 b	9.04 b	9.45 b	40.00 c	41.04 ab	13.7 a	13.72 a	12.97 a	13.76 a
LSD at 5%	0.11	0.08	0.18	0.19	1.12	1.30	0.03	0.03	0.15	0.15
	Interaction between M x P									
M_1P_0	3.70 g	4.05 d	6.10 i	6.87 f	39.36 fgh	41.07 bc	4.1 m	4.22 m	8.5 g	9.14 j
M_1P_1	4.10 f	4.26 c	6.68 h	7.13 f	38.61 gh	40.20 bcd	6.7 k	6.67 j	8.5 g	10.40 i
M_1P_2	4.30 e	5.54 b	7.49 f	9.03 d	42.54 abc	38.61 d	8.3 g	7.65 g	10.4 e	12.05 g
M_1P_3	5.34 bc	5.61 b	8.99 c	9.53 bc	40.58 def	41.14 bc	11.1 d	10.31 d	12.7 b	13.28 e
M_1P_4	5.30 c	5.55 b	8.66 d	9.30 cd	38.65 fgh	40.34 bcd	14.8 a	15.17 a	12.7 b	13.40 de
M_2P_0	3.70 g	4.05 d	6.10 i	6.87 f	39.36 fgh	41.07 bc	4.1 m	4.22 m	8.5 g	9.14 j
M_2P_1	4.30 e	4.40 c	6.99 g	7.55 e	38.42 gh	41.64 abc	6.4 l	5.25 l	9.5 f	12.24 g
M_2P_2	4.50 d	5.58 b	8.04 e	9.22 cd	44.04 a	39.49 cd	7.2 i	6.74 i	11.5 c	13.47 cde
M_2P_3	5.60 a	5.83 a	9.40 b	10.35 a	43.32 abc	43.61 a	10.9 e	9.71 f	13.3 a	13.70 bc
M_2P_4	5.50 ab	5.61 b	9.80 a	9.70 b	41.51 cde	42.17 ab	13.2 b	12.68 c	13.2 a	14.04 a
M_3P_0	3.70 g	4.05 d	6.10 i	6.87 f	39.36 fgh	41.07 bc	4.1 m	4.22 m	8.5 g	9.14 j
M_3P_1	4.20 ef	4.31 c	6.71 gh	7.19 f	37.51 h	40.07 bcd	6.8 j	5.73 k	8.8 g	11.65 h
M_3P_2	4.30 de	5.55 b	7.64 f	9.08 d	43.56 ab	38.80 d	7.6 h	7.09 h	11.0 d	12.78 f
M_3P_3	5.47 abc	5.66 b	9.44 b	9.78 b	42.02 bcd	42.08 ab	10.1 f	10.03 e	12.9 b	13.60 bcd
M_3P_4	5.44 abc	5.55 b	9.05 c	9.34 cd	39.83 efg	40.62 bcd	13.1 c	13.32 b	12.8 b	13.83 ab
LSD at 5%	0.19	0.15	0.31	0.32	1.94	2.25	0.06	0.05	0.26	0.27

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

Discussion

P application and application methods improved the yield and yield components of wheat at both sites (Tables 3 & 4). Maximum number of tiller (m^{-2}) with band placement of P might be due to the more root growth because of near and readily access of P during early growing season. Earlier, Turk & Tawaha (2001) recorded maximum number of tillers with band placement of P than broadcast in wheat. Maximum 1000-grain weight due to band placement of P might be due to higher uptake of P with band application (Table 5) because of its involvement in grain development. Likewise, enhanced grain yield with band application of P was the direct result of improved yield components due to band application of P (Table 3) at both sites. The superiority of band placement of P was probably due to better fertilizer efficiency as developing roots were in intimate contact with P-enriched soil adjacent to fertilizer granules. Most recently, Rehim *et al*., (2010) reported enhanced grain yield along with yield components by band placement of P over broadcast.

Likewise, 81 kg P_2O_5 ha^{-1} resulted in enhanced grain yield due to improvement in all yield components like total number of tillers, number of grains per spike and 1000-grain weight (Table 3). Improvement in total number of tillers with P application might be due to the role of P in emerging radicle and seminal roots during seedling establishment in wheat (Cook & Veseth, 1991). Similarly, Daniel *et al*., (1999) also reported enhanced number of tillers in wheat with increased P application. Minimum number of tillers in control (0.0 kg P_2O_5 ha^{-1}) was due to the deficiency of P that directly altered the normal pattern of tiller emergence by inhibiting the emergence of leaves on the main stem and reducing the rate of tiller emergence (Daniel *et al*., 1999). Readily availability of P during early season which saved the plants from early stresses and its higher uptake (Table 5) at higher levels resulted into enhanced number of grains per spike and 1000-grain weight due to its involvement in grain formation and development. Enhanced yield due to higher level of P application was the direct result of improved yield components (Table 3). There are several reports that signify the role of P application in the enhancement of yield and yield components of wheat (Imtiaz *et al*., 2003; Alam *et al*., 2003; Rehman *et al*., 2005; Rehim *et al*., 2010). Nonetheless, enhanced grain yield along with yield components with band application of P at 81 kg P_2O_5 ha^{-1} might be due the interactive effect of improved method of application and application rate. Band application created favorable conditions by increasing readily accessible P to roots and higher levels resulted in more P availability in soil solution that resulted in more P uptake (Table 5). Similarly, Rehim *et al*., (2010) reported that P application with band placement resulted in enhanced total number of tillers, number of grains per spike, 1000-grain weight and wheat yield.

Table 5. Effect of different rate and methods of P application P concentration and uptake of grain and straw and PUE of wheat.

Treatments	P concentration in grain (%)		P concentration in straw (%)		P uptake in grain (kg ha^{-1})		P uptake in straw (kg ha^{-1})		PUE	
	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM	Without FYM	With FYM
	Methods of P application (M)									
M_1 = Broad casting	0.15 c	0.19 c	0.09 b	0.10 b	4.64 c	6.58 c	4.27 b	5.22 c	5.37 c	8.39 c
M_2 = Band placement	0.20 a	0.22 a	0.10 a	0.12 a	6.93 a	8.61 a	4.75 a	6.11 a	9.37 a	13.62 a
M_3 = Top dressing	0.18 b	0.21 b	0.09 ab	0.11 a	5.81 b	7.49 b	4.44 b	5.83 b	7.16 b	11.52 b
LSD at 5%	0.01	0.01	0.01	0.01	0.33	0.45	0.21	0.21	0.67	0.88
	Adjusted soil solution P levels (mg L^{-1}) (P)									
P_0 = 0.00	0.09 e	0.08 e	0.07 c	0.07 d	2.26 e	2.36 e	2.75 e	2.97 e	0.00 d	0.00 d
P_1 = 0.05	0.12 d	0.13 d	0.08 c	0.07 d	3.19 d	3.74 d	3.27 d	3.29 d	5.24 c	6.80 c
P_2 = 0.10	0.17 c	0.20 c	0.10 b	0.11 c	5.72 c	7.22 c	4.42 c	6.27 c	10.84 a	17.65 a
P_3 = 0.20	0.18 b	0.25 b	0.10 b	0.13 b	7.20 b	10.61 b	5.72 b	7.47 b	9.72 b	15.90 b
P_4 = 0.30	0.29 a	0.36 a	0.12 a	0.15 a	10.61 a	13.86 a	6.30 a	8.58 a	10.69 a	15.53 b
LSD at 5%	0.01	0.01	0.01	0.01	0.43	0.58	0.27	0.27	0.86	1.13
	Interaction between M x P									
M_1P_0	0.09 g	0.08 f	0.07 e	0.07 fg	2.26 g	2.36 i	2.75 h	2.97 gh	0.00 g	0.00 h
M_1P_1	0.10 g	0.12 e	0.08 ed	0.06 g	2.54 g	3.47 h	3.22 g	2.77 h	2.69 f	3.85 g
M_1P_2	0.16 de	0.14 e	0.09 d	0.09 e	5.22 e	4.79 g	3.95 f	4.95 e	8.77 c	9.66 e
M_1P_3	0.18 d	0.25 d	0.10 cd	0.13 cd	6.36 d	9.74 de	5.52 d	7.09 d	8.44 cd	14.35 d
M_1P_4	0.20 c	0.34 b	0.11 bc	0.15 b	6.82 d	12.54 bc	5.93 bcd	8.30 b	6.94 e	14.09 d
M_2P_0	0.09 g	0.08 f	0.07 e	0.07 fg	2.26 g	2.36 i	2.75 h	2.97 gh	0.00 g	0.00 h
M_2P_1	0.14 f	0.13 e	0.08 ed	0.08 ef	3.67 f	4.11 gh	3.30 g	3.73 f	7.18 de	9.76 e
M_2P_2	0.20 c	0.24 d	0.11 bc	0.13 cd	6.84 d	8.75 ef	4.93 e	7.10 d	14.33 a	22.66 a
M_2P_3	0.20 c	0.27 c	0.11 bc	0.13 cd	8.54 c	12.26 c	6.02 bc	7.68 c	11.75 b	18.19 c
M_2P_4	0.34 a	0.39 a	0.13 a	0.16 a	13.36 a	15.55 a	6.77 a	9.07 a	13.59 a	17.49 c
M_3P_0	0.09 g	0.08 f	0.07 e	0.07 fg	2.26 g	2.36 i	2.75 h	2.97 gh	0.00 g	0.00 h
M_3P_1	0.13 f	0.13 e	0.08 e	0.08 f	3.35 f	3.64 h	3.27 g	3.39 fg	5.88 e	6.79 f
M_3P_2	0.15 e	0.23 d	0.10 cd	0.12 d	5.09 e	8.13 f	4.37 f	6.77 d	9.41 c	20.62 b
M_3P_3	0.17 d	0.24 d	0.10 cd	0.14 bc	6.69 d	9.84 d	5.61 cd	7.65 c	8.97 c	15.16 d
M_3P_4	0.31 b	0.36 b	0.11 bc	0.15 ab	11.64 b	13.49 b	6.19 b	8.37 b	11.52 b	15.01 d
LSD at 5%	0. 02	0.02	0.01	0.01	0.74	1.00	0.48	0.47	1.50	1.96

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

More Olsen P in broadcasting of P compared with other methods of P application might be due to fixed and unutilized P left over as more soil to fertilizer contact may arise in broadcasting than band application causing more adsorption of P (Rehman *et al*., (2006). Likewise with increasing P rate, 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 (Tandon, 1987; Sharma, 2006). Higher protein contents at higher P levels with band application were due to more P uptake (Table 5); as P is an important structural component of DNA and RNA. The phosphate group in nucleic acids bridges the RNA or DNA, respectively. (Mengel & Kirkby, 2001). Similarly, Hussain (1991) reported that crude protein contents were increased with P application.

Band application of P at 111 kg P_2O_5 ha^{-1} enhanced the straw and grain P contents that ultimately resulted in higher straw and grain P uptake. The superiority of band placement of P at higher P levels might be due to the reason that developing roots were in intimate contact with P-enriched soil adjacent to fertilizer granules in band placement rather than broadcasted P and lower P levels. Nonetheless, there were low chances for P adsorption in band placement over broadcast because of minimum contact with soil. Earlier many researchers quoted the same findings (Singh *et al*., 2000; Delong *et al*., 2001; Imtiaz *et al*., 2003; Alam *et al*., 2003; Rehim *et al*., 2010). Elevated PUE due to band placement of P compared to broad casting and top dressing might be due to the greater fixation of broadcast P than the applied in bands because of narrow soil to fertilizer ratio in the later situation, since P sorption maxima depends on the ratio of soil to applied P (Sultani *et al*., 2004; Alam *et al*., 2005). Likewise, higher PUE at lower P level was probably a consequence of intense root competition and thereby an efficient exploitation of applied P. At higher P application rates plants used smaller proportion of fertilizer P that resulted in low PUE.

Although P application improved grain yield and PUE of wheat both with and without FYM application but with FYM application P application had more pronounced effects rather than without FYM application. The use of FYM improved soil organic matter, and soil physical, chemical and microbial properties that ultimately affect P nutrition of plants (Belay *et al*., 2001; Karaman *et al*., 2001). P fertilizer when applied to soil after mixing (12 hours before application) with moist and well-decomposed farmyard manure in the ratio of 1:2 resulted in 30% higher P use efficiency (Anonymous, 2003). The fertilizer efficiency improved significantly, when integrated (organic and inorganic) source of P was used (Yamoah *et al*., 2002).

In crux, band placement of P 81 kg P_2O_5 ha^{-1} improved the total number of tillers (m^{-2}), 1000-grain weight, grain yield, straw yield, biological yield, HI, straw and grain P contents, grain and straw P uptake, grain protein contents and PUE with and without FYM application. Nonetheless, P application at 111 kg P_2O_5 ha^{-1} resulted in maximum straw and grain P contents, grain and straw P uptake, grain protein contents, Olsen P and PUE of wheat with and without FYM application. Application of FYM with P fertilizer improved wheat yield and PUE as compared with fertilizer alone.

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(Received for publication 6 February 2011)