Research Article

Envisaging the Response of Wheat (*Triticum aestivum* L) under Different Phosphorus Doses and Methods of Application

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Abstract | Nutrient deficit soils pose serious threats to healthy wheat crop growth. Among the major nutrients, Phosphorus (P) stands at a significant position for providing aid in seed and fruit formation, energy provision, photosynthesis, and continuation of metabolic function in plants. However, it is not readily available to the crop because of its immobile nature. In order to ensure its efficient uptake by crop, an experiment was conducted to appraise the effect of various P placement methods and fertilizer rates on wheat. The fertilizer treatments were F1=150-00-60 NPK kilogram/hectare, F2=150-30-60 NPK kilogram/hectare, F3=150-60-60 NPK kilogram/hectare, F4=150-90-60 NPK kilogram/hectare, F5=150-120-60 NPK kilogram/hectare. While the placement methods were M1=Line sowing + Band application of phosphorus, M2=Line sowing +Broadcast application of Phosphorus at sowing, M3=Line sowing + Broadcast application of P at first irrigation. Yield and yield determining parameters were measured along with phosphorus stress factor, agronomic P use efficiency, and economic analysis. The results revealed that the band placement method gave the highest yield in comparison to the broadcast at sowing and broadcast at first irrigation. The best P fertilizer rate was identified as 150-120-60 NPK kg/ha. It has been recommended that wheat, when sown under band placement @ 120 kg/ha, gave maximum grain yield.

Received | January 14, 2020; **Accepted** | March 21, 2020; **Published** | June 23, 2020
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Citation | Anum, W., L. Ali, U. Riaz, A. Ali, N. Manzoor, L.H. Akhter, A.U Rahman, N. Maan and I. Ahmad. 2020. Envisaging the response of wheat (*Triticum aestivum* L) under different phosphorus doses and methods of application. *Pakistan Journal of Agricultural Research,* 33(2): 395-405.
DOI | http://dx.doi.org/10.17582/journal.pjar/2020/33.2.395.405
Keywords | PUE, Phosphorus, *Triticum aestivum*, Band placement, Agronomic use efficiency, Economic analysis

Introduction

Wheat (*Triticum Aestivum* L.) belongs to the family Gramineae /Poaceae. It is one of the first domesticated food crops, specifically in Asia (Barton and An, 2014), Europe and South Africa (Buxo, 2016), and Currently, wheat covers more arable land area than any other commercial crop and is ranked as the most critical food grain source for humans (Atchison et al., 2010). Its production surpasses all significant crops- including rice, maize, and potatoes. Pakistan Bureau of Statistics listed that in Pakistan, wheat is the most consumed grain than all other gains, and its production is 25979.4 million tones in area of 9199.3 million hectares. For a healthy crop, fertilizers must be provided in adequate quantity so that the deficient soils can produce optimum yields (Roberts, 2019).

Phosphorus is an essential nutrient for plant growth and plays a leading role in the metabolism of plants (Fabianska et al., 2019). It is involved in cellular energy transmission, respiration, and photosynthesis (Gupta et al., 2014). It is stated that P is also a structural component of the nucleic acids of genes and chromosomes (Adams, 2012). It is the building block of many coenzymes, phosphoproteins, and phospholipids (Hunter, 2012). At the earliest stages of plant growth, P supply in an adequate amount is the mandatory step for a good yield (Grant et al., 2001; Bindraban et al., 2020). If the deficiency of P is followed at the start of the growing season, then the plant cannot recover from its nutrient deficiency, and eventually, the overall yield is affected.

In acutely P-stressed plants, leaf senescence, phasic improvement, and anthesis are hindered. The deficiency of P restricts tiller development (Fioreze et al., 2012) the rate of appearance and the number of leaves per plant and yield of the plant. The persistent deficiency of P depressed the grain yield predominantly by reducing the number of fertile tillers. P can be applied in the field through different ways, i.e. at the time of seed planting, stabbed into the soil by using equipment such as field cultivators, or, broad sweeps with ammonia (dual applied band) or without ammonia through broadcasted preceding to planting. Numerous Researches demonstrate that phosphorus if applied through seed application or knifed bands, gives higher profitability than the broadcast application (Abdur et al., 2012). The adeptness of band applications (seed or knifed bands) upturns as accessible soil phosphorus declines. If wheat is grown on low phosphorus soils, the broadcasting of phosphorus is an effective method of application than others which will usually result in increased wheat yields and useful applications, But the overall seed or knifed band applications are much superior to broadcast in terms of profitability.

The objective of this experiment is to evaluate the effects of P fertilizer on the wheat yield and to evaluate the proper placement methods as well as fertilizer dose. This study could be significant for the farmers of arid regions and phosphorus deficient soils.

Materials and Methods

A two-year experiment was conducted at Regional Agricultural Research Institute, Bahawalpur, Pakistan, during 2015- 2016 to 2016-2017. The research area is situated at 29° 20' latitude, 73° 51' longitude, and has an elevation of 161 meters. It has a scorching and dry climate in summer and a dry and cold climate in winter. The maximum temperature rises to a (41°C while the minimum temperature falls to 12 °C. The average annual rainfall in the district is (143 mm). The weather data was recorded during the experimental period as depicted in Table 1. The soil analysis was performed before sowing (Table 2) The experiment was conducted during the wheat-growing seasons (Rabbi) from November 2015 to April 2017. The wheat variety, used for this experiment was Johar-16 (Locally developed variety at Regional agricultural research institute, Bahawalpur). The experiment was laid out in Randomized Complete Block Design (Split Plot) with 3 replications, and a plot size of (7Lx1.8W). The main plots comprised P placement methods while sub-plots consisted of the various phosphorus amounts. The treatments for methods of application were M1=Line sowing + Band application of phosphorus, M2=Line sowing + Broadcast application of Phosphorus at sowing, M3=Line sowing + Broadcast application of phosphorus at 1st irrigation. And the treatments for rate of phosphorus were F1=150-00-60 NPK kilogram/hectare, F2=150-30-60 NPK kilogram/hectare, F3=150-60-60 NPK kilogram/hectare, F4=150-90-60 NPK kilogram/hectare, F5=150-120-60 NPK kilogram/hectare. During the first year of study, the trial was sown on 29-11-2015 while in the second year it was 26-11-2016. Diammonium phosphate was used as the P source while potassium was applied in SOP sulfate of potash. Sop was added @ 9.3 kg/experiment. Urea was the nitrogen source applied @ 4kg at first irrigation and 4 kg at second irrigation. The irrigation was applied as of 1st 2nd and 3rd on 23-12-2015, 24-1-2016 and 26-2-2016 respectively.

During the second year (2016-2017), all the practices were kept the same. The 1st, 2nd and 3rd irrigation was applied on 17-12-16, 8-1-17 and 22-2-17, respectively. Data regarding yield parameters like Plant height (cm), Number of productive tillers, Spike length (cm), Number of grains per spike, 1000-grain weight, and Grain yield were collected.

Table 1: *Meteorological data collected during the*

experimental years.

October	2014		2015	
	Average	Range	Average	Range
Temp. (Max. ^{0}C)	33	29-36	30	25-36
Temp. (Min. ^{0}C)	22	19-25	20	16-25
Humidity (%)	76	68-80	70	60-78
Rainfall (mm)	04		02	
Cloudy Days	02		02	
November	**2014**		**2015**	
Temp. (Max. ^{0}C)	27	24-30	26	23-30
(Min. ^{0}C)	13	10-19	15	12-20
Humidity (%)	74	65-82	70	60-78
Rainfall (mm)	-		-	
Cloudy Days	-		-	
December	**2014**		**2015**	
Temp. (Max. ^{0}C)	22	11-28	20	16-25
Temp. (Min. ^{0}C)	09	04-14	09	07-13
Humidity (%)	70	68-85	68	64-82
Rainfall (mm)	-		-	
Cloudy Days	-		-	
January	**2015**		**2016**	
Temp. (Max. ^{0}C)	20	16-25	18	15-24
Temp. (Min. ^{0}C)	09	07-13	07	05-12
Humidity (%)	68	64-82	69	64-83
Rainfall (mm)	-		Light shower	
Cloudy Days	-		03	
February	**2015**		**2016**	
Temp. (Max. ^{0}C)	21	20-25	25	21-30
Temp. (Min. ^{0}C)	10	07-15	10	09-13
Humidity (%)	68	68-81	68	60-79
Rainfall (mm)	06		02	
Cloudy Days	04		03	
March	**2015**		**2016**	
Temp. (Max. ^{0}C)	25	16-32	28	20-37
Temp. (Min. ^{0}C)	17	10-23	14	12-18
Humidity (%)	75	68-81	76	68-84
Rainfall (mm)	22		32	
Cloudy Days	03		04	
April	**2015**		**2016**	
Temp. (Max. ^{0}C)	34	31-41	35	31-43
Temp. (Min. ^{0}C)	23	19-29	21	17-22
Humidity (%)	70	62-80	65	61-82
Rainfall (mm)	10		04	
Cloudy Days	07		09	
October	**2015**		**2016**	
Temp. (Max. ^{0}C)	31	25-36	37	34-40
Temp. (Min. ^{0}C)	19	14-24	23	19-28
Humidity (%)	70	60-78	63	57-74
Rainfall (mm)	02		0	
Cloudy Days	02		01	
November	**2015**		**2016**	
Temp. (Max. ^{0}C)	26	23-30	33	29-37
Temp. (Min. ^{0}C)	15	12-20	17	13-22
Humidity (%)	70	60-78	63	49-73
Rainfall (mm)	-			
Cloudy Days	-			
December	**2015**		**2016**	
Temp. (Max. ^{0}C)	20	16-25	27	25-33
Temp. (Min. ^{0}C)	09	07-13	11	08-15
Humidity (%)	68	64-82	73	64-88
Rainfall (mm)	-		-	
Cloudy Days	-		03	
January	**2016**		**2017**	
Temp. (Max. ^{0}C)	19	15-24	18	15-21
Temp. (Min. ^{0}C)	08	05-12	07	04-09
Humidity (%)	73	64-83	89	83-95
Rainfall (mm)	Light shower		08	
Cloudy Days	03		02	
February	**2016**		**2017**	
Temp. (Max. ^{0}C)	25	21-30	28	23-32
Temp. (Min. ^{0}C)	10	09-13	11	08-15
Humidity (%)	68	60-79	73	59-86
Rainfall (mm)	02		05	
Cloudy Days	03		03	
March	**2016**		**2017**	
Temp. (Max. ^{0}C)	28	20-37	34	26-42
Temp. (Min. ^{0}C)	14	12-18	18	12-24
Humidity (%)	76	68-84	74	56-90
Rainfall (mm)	32		Nil	
Cloudy Days	04		02	
April	**2016**		**2017**	
Temp. (Max. ^{0}C)	35	31-42	37	34-43
Temp. (Min. ^{0}C)	21	17-24	25	18-33
Humidity (%)	70	61-82	71	63-82
Rainfall (mm)	04		Traces	
Cloudy Days	09		03	
May	**2016**		**2017**	
Temp. (Max. ^{0}C)	42	36-47	45	42-48
Temp. (Min. ^{0}C)	27	22-31	27	22-32
Humidity (%)	60	51-70	76	60-91
Rainfall (mm)	02		15	
Cloudy Days	02		03	

Table 2: *Soil analysis before experiment.*

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Year	Depth (cm)	EC (d Sm^{-1})	pH	OM (%)	Available K (ppm)	Available P (ppm)	Tex-ture
First	0-6	2.6	8.1	0.64	116	8.0	Loam
	6-12	2.4	8.0	0.54	110	7.6	
Second	0-6	2.2	8.1	0.74	110	8.2	
	6-12	2.0	7.9	0.64	108	8.0	

To record the plant height and spike length, ten tillers from each plot were measured separately by using the metering rod. The number of productive tillers, spike bearing tillers were counted by using quadrate method. To record the number of grains per spike, ten spikes were taken randomly from each plot were threshed manually, their grains were counted, and the average was worked out. The 1000-Grain weight was obtained by counting 1000 seeds and weighted.

Phosphorus stress factor was calculated as: (Siddiqi and Glass, 1981).

$$PSF\ (\%) = \frac{Yield\ adequate - yeild\ control}{Yield\ adequate} \times 100 \quad ...(1)$$

Where; yield adequate and yield controls are the grain yield kg/ha in fertilized and control (without P application) per plots, respectively.

Agronomic phosphorus efficiency was calculated by using the formula outlined by Alam et al. (2003).

$$APE = \frac{yield\ in\ fertilized\ plot\ kg\ ha - yield\ in\ control\ (kg\ ha)}{quantity\ of\ phosphorus\ applied\ in\ kg\ ha} \quad ...(2)$$

Economic analysis

Economic analysis was done by implementing the following equations:

$$Net\ income = value\ of\ increased\ yield - cost\ of\ fertilizer \quad ...(3)$$

$$Benefit\ cost\ ratio = \frac{Net\ income}{Cost\ of\ fertilizer} \quad ...(4)$$

Statistical analysis

The observed parameters were statistically evaluated by using the package Statisticx version 8.1. Fisher analysis of variance was implemented and Two-way ANOVAs were produced in order to know the significance of the results (Steel, 1997). The comparison of means was made, and significant results were separated @ 0.05 LSD.

Results and Discussion

The average height of tiller (cm)

The data analysis showed that plant height was not significantly affected under the different placement methods; however, a variation was observed in obtained Values. During the first year, the band placement method gave the highest plant height. However, during the second year, it was obtained in line sowing with the broadcast method. Overall it was clear that plant height was not affected significantly under the applied treatments. The overall results are depicted in Table 3.

No. of spikelet per spike

The statistical analysis of number of spikelets per spike explained that the number of spikelets was affected by different levels and placement methods of phosphorus. During first year the highest spikelets were observed in-band placement methods (17 spikelets) as in the case of fertilizer levels, 120 kg/ha of P gave maximum spikelets (17). The same trend in the results were present during the second year. However, the values were different. The detailed results are depicted in Table 4.

Average tiller per m^2

The statistical data analysis of number of tillers per m^2 shows different behavior at different levels and placement methods. The tillers were affected at the different fertilizer doses. Maximum tillers were noted under 120 kg/ha of P applied (268) in the first year while during the second year the trend was similar the maximum number of noted tillers were (256) Moreover, the control shows a minimum number of tillers per m^2, i.e., 242 and 233 in a first and second year respectively. And in context of placement method of P, the maximum number of tillers per m^2 251 was observed by broadcasting (at sowing time) placement followed by band application, i.e., 238 and the least no of tillers per m^2 (230) was shown in broadcasting (at 1st irrigation) during the second year, the detail results are represented in Table 5.

If we talk about the interaction between the P levels and placement method, the maximum no of tillers per m^2 are seen by the broadcasting (at sowing time) at the level of 120 kg/ha and the minimum no of tillers per $m^2$was observed under broadcasting at the control level.

Table 3: *Effect of phosphorus placement methods and quantities on plant height (cm) of wheat crop.*

	First Year					Second Year			
	M1	M2	M3	Mean		M1	M2	M3	Mean
F1	92	90	85	89A	F1	95.6	91.6	90.0	92.6A
F2	94	98	87	93A	F2	92.3	91.6	92.6	92.2A
F3	92	95	90	92.3A	F3	94.0	90.6	92.6	92.5A
F4	89	92	92	91A	F4	95.6	90.6	96.3	94.2A
F5	94	91	93	92.6A	F5	95.6	88.6	93.6	92.6A
Mean	92.4A	93.2A	89.4A		Mean	94.66A	90.66A	93.26A	

Means with the same letter are not significantly different from each other @ P>0.05 probability level. LSD for methods: 7.39; LSD for methods: 5.6; LSD for fertilizer: 4.36; LSD for fertilizer: 3.2; F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing band application of phosphorus; M2: Line sowing broadcast application of Phosphorus at sowing; M3: Line sowing broadcast application of phosphorus at first irrigation.

Table 4: *Effect of phosphorus placement methods and quantities on number of spikelet's per spike of wheat.*

	First Year					Second Year			
	M1	M2	M3	Mean		M1	M2	M3	Mean
F1	14	13	13	13.3C	F1	19.9	19.9	18.1	19.2B
F2	19	15	14	16B	F2	19.9	20.1	19.3	19.7AB
F3	18	16	14	16B	F3	19.7	19.6	20.1	19.8A
F4	17	16	16	16.3B	F4	20.0	20.2	19.6	19.9A
F5	19	17	16	17.3A	F5	19.6	20.2	19.9	19.9A
Mean	17A	15B	14.6B		Mean	19.8AB	19.9A	19.4B	

Means with the same letter are not significantly different from each other @ P>0.05 probability level. LSD for methods: 1.3; LSD for methods: 0.53; LSD for fertilizer: 0.69; LSD for fertilizer: 0.59; F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

Table 5: *Effect of phosphorus placement methods and quantities No of tillers per square meter.*

First Year					Second Year				
	M1	M2	M3	Mean	Treatments	M1	M2	M3	Mean
F1	229	249	249	242.3B	F1	220	251.6	199	233.5C
F2	270	263	247	260A	F2	261.7	276.6	220	252.7A
F3	266	271	256	264.3A	F3	240	250.0	222	237.3B
F4	265	286	251	267.3A	F4	240.3	221.6	235	232.3BC
F5	270	283	252	268.3A	F5	230	259.3	278.7	256A
Means	260AB	270.4A	251B		Means	238.4AB	251.8A	230.9B	

Means with the same letter are not significantly different from each other @ P>0.05 probability level. LSD for methods: 11.86; LSD for methods: 15.9; LSD for fertilizer: 13.28; LSD for fertilizer: 12.86; F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

Table 6: *Effect of phosphorus placement methods and quantities on 1000 grain weight (g).*

	First Year					Second Year			
	M1	M2	M3	Mean		M1	M2	M3	Mean
F1	32	30.9	29.2	30.7C	F1	32.3	30.9	29.2	30.8C
F2	39.0	36.9	33.4	36.4B	F2	39.0	38.9	33.4	37.1B
F3	40.7	38.8	35.9	38.4B	F3	39.7	39.1	36.1	38.3AB
F4	41.8	39.4	35.2	38.4AB	F4	39.2	39.7	36.2	38.3AB
F5	45	40	38.9	41.3A	F5	41.8	41.6	38.2	40.5A
Mean	39.7A	37.2AB	34.5B		Mean	38.4A	38.04A	34.6A	

Means with the same letter are not significantly different from each other @ P>0.05 probability level. LSD for methods: 2.94; LSD for methods: 4.07; LSD for fertilizer: 2.73; LSD for fertilizer: 3.30; F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

1000 grain weight (gm)

The 1000-grain weight showed that P level at 120 kg/ha shows more excellent higher value of thousand-grain weight, i.e. 40.9 (average of two years) followed by the level 90 kg/ha while under control, the value is 30.7. In case of application method, while the band placement shows the most significant value 39 followed by the Broadcast (at sowing time). The overall results of both years are depicted in Table 6.

Yield per hectare (Kg)

The data analysis of yield per hectare reveals that the values of yield per hectare are significantly different at fertilizer levels as well as placement methods. The maximum yield per hectare 4959 kg/ha was shown at a level of 120 kg/ha, followed by 4681 kg/ha at a level of 90 kg/ha. While in case of P placement method, the highest yield per hectare was observed in 1st (Band placement i.e. 4784 kg/ha and the least one is seen under 3rd method (Broadcasting at 1st irrigation), i.e., 3879 kg/ha during the first year of study while the same significance trend was seen in the second year however the values differ in both years Table 7.

Table 7: *Effect of phosphorus placement methods and quantities on Wheat yield kg/ha.*

First Year					Second Year				
	M1	M2	M3	Means		M1	M2	M3	Means
F1	3927	3499	3331	3586 d	F1	3213	2937	2911	3021d
F2	4403	4046	3451	3967 c	F2	3809	3741	3482	3678c
F3	4998	4522	4046	4522 b	F3	4461	4238	3762	4174b
F4	5236	4641	4165	4681 b	F4	4736	4391	3995	4374ab
F5	5355	5117	4403	4959 a	F5	4798	4472	4014	4428a
Means	4784a	4365b	3879c			4204a	3956b	3633c	

Means with the same letter are not significantly different from each other @ P>0.05 probability level. F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3:150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

Effect of treatments on the phosphorus stress factor

The experiment showed that application of the varying doses of P fertilizer, the yield was affected significantly. A general trend was observed that with increasing the quantity, the stress factor value was increased which indicated that without the concerned treatment, the wheat can come across severe grain yield deficiency. During the first-year band, placement gave a 34% of yield reduction under stressed conditions while during the second year under the application of 120 kg/ha a value of 33 and 34 were observed in-band placement and broadcast at sowing respectively under stress conditions the yield was reduced up to 33 and 34 %. (Table 8).

Table 8: *Effect of phosphorus placement methods and quantities on phosphorus stress factor.*

Treatment	Year	Yield adequate	Yield control	ya-yc	PSF (%)
M1F1	First Year	3927	3927	0	0
M2F1		3499	3499	0	0
M3F1		3331	3331	0	0
M1F2		4403	3927	476	10.81081
M2F2		4046	3499	547	13.51953
M3F2		3451	3331	120	3.477253
M1F3		4998	3927	1071	21.42857
M2F3		4522	3499	1023	22.62273
M3F3		4046	3331	715	17.67177
M1F4		5236	3927	1309	25
M2F4		4641	3499	1142	24.60677
M3F4		4165	3331	834	20.02401
M1F5		5355	3927	1428	34.28571
M2F5		5117	3499	1618	31.62009
M3F5		4403	3331	1072	24.34704
M1F1	Second Year	3213	3213	0	0
M2F1		2937	2937	0	0
M3F1		2911	2911	0	0
M1F2		3809	3213	596	15.64715
M2F2		3741	2937	804	21.49158
M3F2		3482	2911	571	16.39862
M1F3		4461	3213	1248	27.97579
M2F3		4238	2937	1301	30.69844
M3F3		3762	2911	851	22.62095
M1F4		4736	3213	1523	32.15794
M2F4		4391	2937	1454	33.11319
M3F4		3995	2911	1084	27.13392
M1F5		4798	3213	1585	33.0346
M2F5		4472	2937	1535	34.32469
M3F5		4014	2911	1103	27.47882

F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

Effect of treatments on agronomic phosphorus use efficiency

Agronomic P use efficiency plays an important role in determining how efficiently the plant has utilized P, and the output is seen in terms of grain weight.

During the first and second year, the maximum value was obtained as 18.2 and 26.8 under broadcast at sowing at 30kg/ha of P applied respectively. The overall values for the treatments are depicted in Table 9.

Table 9: *Effect of phosphorus placement methods and quantities on PUE.*

Treat-ment	Year	Yield (fertilized plot)	Yield (control)	P applied (kg)	Apu
M1F1	First year	3927	3927	0	0
M2F1		3499	3499	0	0
M3F1		3331	3331	0	0
M1F2		4403	3927	30	15.86667
M2F2		4046	3499	30	18.23333
M3F2		3451	3331	30	4
M1F3		4998	3927	60	17.85
M2F3		4522	3499	60	17.05
M3F3		4046	3331	60	11.91667
M1F4		5236	3927	90	14.54444
M2F4		4641	3499	90	12.68889
M3F4		4165	3331	90	9.266667
M1F5		5355	3927	120	11.9
M2F5		5117	3499	120	13.48333
M3F5		4403	3331	120	8.933333
M1F1	Second Year	3213	3213	0	0
M2F1		2937	2937	0	0
M3F1		2911	2911	0	0
M1F2		3809	3213	30	19.86667
M2F2		3741	2937	30	26.8
M3F2		3482	2911	30	19.03333
M1F3		4461	3213	60	20.8
M2F3		4238	2937	60	21.68333
M3F3		3762	2911	60	14.18333
M1F4		4736	3213	90	16.92222
M2F4		4391	2937	90	16.15556
M3F4		3995	2911	90	12.04444
M1F5		4798	3213	120	13.20833
M2F5		4472	2937	120	12.79167
M3F5		4014	2911	120	9.191667

F1: 150-00-60 NPK kg ha^{-1}; F2: 150-30-60 NPK kg ha^{-1}; F3: 150-60-60 NPK kg ha^{-1}; F4: 150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

Effect of treatments on Cost-benefit ratio

A detail economic analysis revealed that without P, there was no profit in the crop. With the increasing doses, the net income increased during the first year, a net return of Rs. 27692 was seen under band placement at 90 kg of p applied. This value decreases by 1000 Rs. when 120 kg/ha of p is applied under the same sowing method. These results differed with the grain yield obtained in our experiment. The crop performed best less than 120 kg/ha applied P, but a net profit was less than 90 kg of p applied. The trend was similar during the second year of the experiment. The overall values are depicted in Table 10.

From our results, it is clear that P fertilizer plays a vital role in the establishment of a healthy crop. Fertilizer placement is important consideration that can affect the yield drastically. The reason behind this phenomenon is well understood through many studies. Kaleem et al. (2009) and Khan et al. (2010) stated that wheat grain yield is affected by the P application and without the adequate amounts the plant cannot retain its proper development. Similarly, the amount of application is significant in determining the yield (Rasul, 2016). The agronomic parameters are affected by both, P application method and fertilizer rates. A study indicated that 100 kg of P applied through double band placement enhanced all the yield determining parameters like plant height, productive tillers, grains/spike, 100-grain weight, biological yield, grain yield, and harvest index. Phosphatic fertilizer application methods are also critical (Hopkins and Hansen, 2019). It is revealed that fertilizer that right amount of fertilizer along with application at right place improves fertilizer use efficiency. These strategies also reduce the negative environmental concerns related to synthetic fertilizer use (Panhwar et al., 2019).

Moreover, in addition to PUE in *Triticum aestivum*, it reduced the non-productive tillers compared to other treatments (Bashir et al., 2015).

Plant height is also influenced by p application methods. Rahim et al., 2010 revealed that under the band application method, plant height was significantly increased in comparison to the broadcast method. A similar trend is observed in our study. Similarly, Alam et al. (2003) stated that plant height was proportional to the P amounts in soils. The same trend was followed in this experiment up to 90 kg/ha p application. However, the plant height decreased with further increased in P quantity i.e. 120 kg/ha.

Table 10: *Effect of phosphorus placement methods and treatments on Cost benefit ratio.*

Treatment	Year	Yield	Increase over control	Value of increased yield	Fertilizer cost	Net income	Benefit cost ratio
M1F1	First Year	3927	0	0	0	0	0
M2F1		3499	0	0	0	0	0
M3F1		3331	0	0	0	0	0
M1F2		4403	476	15470	4950	10520	2.125253
M2F2		4046	547	17777.5	4950	12827.5	2.591414
M3F2		3451	120	3900	4950	-1050	-0.21212
M1F3		4998	1071	34807.5	9900	24907.5	2.515909
M2F3		4522	1023	33247.5	9900	23347.5	2.358333
M3F3		4046	715	23237.5	9900	13337.5	1.347222
M1F4		5236	1309	42542.5	14850	27692.5	1.864815
M2F4		4641	1142	37115	14850	22265	1.499327
M3F4		4165	834	27105	14850	12255	0.825253
M1F5		5355	1428	46410	19800	26610	1.343939
M2F5		5117	1618	52585	19800	32785	1.655808
M3F5		4403	1072	34840	19800	15040	0.759596
M1F1	Second Year	3213	0	0	0	0	0
M2F1		2937	0	0	0	0	0
M3F1		2911	0	0	0	0	0
M1F2		3809	596	19370	4950	14420	2.913131
M2F2		3741	804	26130	4950	21180	4.278788
M3F2		3482	571	18557.5	4950	13607.5	2.74899
M1F3		4461	1248	40560	9900	30660	3.09697
M2F3		4238	1301	42282.5	9900	32382.5	3.27096
M3F3		3762	851	27657.5	9900	17757.5	1.793687
M1F4		4736	1523	49497.5	14850	34647.5	2.333165
M2F4		4391	1454	47255	14850	32405	2.182155
M3F4		3995	1084	35230	14850	20380	1.372391
M1F5		4798	1585	51512.5	19800	31712.5	1.601641
M2F5		4472	1535	49887.5	19800	30087.5	1.519571
M3F5		4014	1103	35847.5	19800	16047.5	0.81048

F1:150-00-60 NPK kg ha^{-1}; F2:150-30-60 NPK kg ha^{-1}; F3:150-60-60 NPK kg ha^{-1}; F4:150-90-60 NPK kg ha^{-1}; F5: 150-120-60 NPK kg ha^{-1}; M1: Line sowing+band application of phosphorus; M2: Line sowing+broadcast application of Phosphorus at sowing; M3: Line sowing+broadcast application of phosphorus at first irrigation.

In our study significantly different ($P<0.05$) results were found in the final grain yield (kg/ha).

Band placement was superior to the other treatments. These results are in lines with, Rehim et al. (2010) who reported better performance of wheat crop and enhanced PUE due to band placement of P over broadcast. Turk and Tawaha (2001) also quantified that band application was superior for grain yield as compared to the broadcast method. P fertilizer was banded with wheat seeds and gave superior results in relation to the broadcast method. Banding is beneficial because it is available to the emerging radicle and helps in seminal roots and results in the good seedling establishment (Cook and Veseth, 1991).

According to Camargo et al. (2000), Phosphatic fertilizers can only move to 3-5 cm in the soil which makes only 15 to 20% of the applied fertilizer available to the plants. It was more beneficial at the early stages of crop growth (Matar and Brown, 1989). Banding is effective in many crops including pastures (McLachlan, 2019). The primary factor contributing to the more P uptake lies in the fact that the soil which is more enriched with p allows plant roots to make superior contact with it and increase its availability to the plant. Hence root to fertilizer contact ratio is the basis of fertilizer use efficiency (Barber, 1974; Yao and Barber, 1986). Similarly, the application rates are also critical in determining the wheat yield. As in our experiment, the five rates affect yield e significantly ($P<0.05$). The maximum yield was obtained under 90 kg/ha p applied plots; however, 120 kg/h dose. Hence our results are similar to Ali et al. (2004), who revealed that 114 kg/ha of P is capable of improving wheat yield up to maximum level. When applied through the intra row drilling method. The data further revealed that the maximum P uptake by wheat grain (11.70) kg/ha was recorded from T4 while the minimum (3.30 kg/ ha) in control. However, the lower P use efficiency (PUE) was seen at higher P application rates (Rasul, 2016).

Conclusions and Recommendations

Phosphorus fertilization is crucial for enhancing plant performance. Under nutrient (P) deficit soils, it is impossible to obtain healthy and bumper crops with the addition of P fertilizer. However, in certain conditions, the farmers lack the knowledge of exact quantities of fertilizers that need to be added in their soils. By applying 120 kg/ha, a farmer can obtain high yields. In the same way, by merely altering the P application method, a significant difference can occur in grain yield. A slight difference was observed between the net income under 90 and 120 kg of P; however, the addition of P in 120 kg quantity will ensure the soil fertility with time. As with the passing time, the soils of Pakistan are becoming exhausted with undue exploitation, hence this research is important as it will pave ways for the scientists to further derive methods influencing the P uptake. Other factors affecting the fertilizer uptake and efficiency use need to be further tested under the different soil series of Pakistan. So that an effective management practice can be formed for judicious use of fertilizers in wheat crops.

Author's Contribution

Wajiha Anum, Liaquat Ali and Abid Ali designed and conducted the research study, Laal Hussain Akhter dealt with data analysis, interpretation and supervision, Umair Riaz gave technical input regarding soil analysis and application doses, Nadia Manzoor, Asad ur Rahman gave technical input at all stages. Naeem Maan and Ijaz Mhmed keenly revised and upgraded the overall manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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