Journal of
Agriculture and Biology
ISSN: 3007-1755 (Print), 3007-1763 (Online)

Check for updates

ROOTS PRESS

Research Article

Optimizing Phosphorous Rates for Different Sowing Methods of Maize to Enhance Productivity and Profitability

Arshad Hussain[1], Sana Munawar[2], Fida Hussain[1], Sanober Gul Khan[3], Ali Sher[4], Akash Zafar[5], Naeem Arshad Maan[5], Basharat Ali[1], Syed Asad Manzoor[5*], Zahid Aslam[6]
[1] *Agronomic Research Station, Bahawalpur, Pakistan.*
[2] *The Islamia university of Bahawalpur, Pakistan.*
[3] *Department of plant breeding and genetics, Ghazi University, D.G Khan.*
[4] *Cotton research Sub Station, Jhang.*
[5] *Regional Agricultural research institute, Bahawalpur.*
[6] *Cotton research Station, Bahawalpur.*

ABSTRACT

Phosphorous use efficiency under alkaline calcareous soil conditions of Pakistan is less than 25%. Higher phosphorus fixation aggravates yield gaps and cost of production in maize. An experiment was laid out with the objectives to enhance maize yield and profitability through various soil manipulation methods. Experiment was conducted using randomized complete block design with split plot arrangement. The experimental treatments comprised of sowing methods in main plots viz; S_1 = flat sowing; S_2 = ridge sowing and S_3 = bed sowing while phosphorous rates in split plots viz. P_1 = 100; P_2 = 125 and P_3 = 150 kg ha^{-1}. The results revealed the substantially higher cob length, diameter and 1000-grain weight observed in ridge sowing and 125 kg ha^{-1} phosphorous. Under flat sowing conditions, 150 kg ha^{-1} P depicted more plant height, grain rows per cob, grains per cob, biological, grain yield and harvest index. Ridge and bed sowing depicted higher values of all attributes with 125 kg ha^{-1} phosphorous. Significantly more yield was produced with 125 kg ha^{-1} phosphorous under both ridge (6160 kg ha^{-1}) and bed planting (5600 kg ha^{-1}) systems. Significantly lower values of all parameters were recorded in flat sowing with 100 kg ha^{-1} phosphorous. In addition, highest marginal rate of return was recorded for ridge sowing with 125 kg ha^{-1} phosphorous. In conclusion, ridge planting system produced more grain yield and economic benefits using less phosphorous than flat and bed sowing using 125 kg ha^{-1} phosphorous.

Keywords: Benefit cost ratio, Cost of production, Sustainability, Soil manipulation, Marginal returns, Phosphorous fixation

OPEN ACCESS

Correspondence
Syed Asad Manzoor
syedasadmanzoor53@gmail.com

Article History
Received: May 04, 2025
Accepted: October 03, 2025
Published: October 16, 2025

Copyright: *© 2024 by the authors.* ***Licensee:*** *Roots Press, Rawalpindi, Pakistan.*

This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license: *https://creativecommons.org/licenses/by/4.0*

INTRODUCTION

Maize (*Zea mays* L.) is an annual, cross pollinated, C_4 carbon fixer and short-day plant (Shahi, 2021; Ahmad et al., 2016). It is increasingly acquiring substantial position in crop husbandry owing to its shorter duration and higher yield potential (Liu et al., 2017). In Pakistan, maize accounts for 0.6 % contribution in GDP and 2.9% in value addition in agriculture. It is cultivated on an area of 1.41 million hectares with annual production of 7.236 million tons (GOP, 2020) Yield potential of maize is lagging far below world's leading maize producing nations (Islam et al., 2016). Numerous factors that decline maize yield below its potential is the poor availability of quality seed, fertilizers, irrigation, climatic skepticism, energy crises and poor marketing system (Liu et al., 2014). Improper sowing methods, imbalanced nutrition and water scarcity are primary aspects to attain potential yield (Badr et al., 2016). Fertilizer placement affects crop P utilization, soil P dynamics, residual P concentration in different soil depths, and soil-plant interactions (Coelho et al., 2019). but some version of band application such as single band, double band, surface and deep bands, is often more beneficial than broadcast P (Alam et al., 2018). Applying fertilizer in moist soil also helps increase nutrient mobility and availability for plant uptake.

Phosphorous use efficiency (PUE) in Pakistan is less than 25% owing to higher pH, whereas, P requirement of plants is 0.2-0.8% (Rehim et al., 2016). Phosphorous (P) availability is shambled under alkaline calcareous soil conditions of Pakistan (Abbas et al., 2024; Mahmood et al., 2013). Among innumerable processes responsible for low PUE, precipitation and adsorption are vital (Kumar et al., 2022; Shah et al., 2013). However, it is always difficult task to disentangle adsorption and precipitation. Usually, smaller addition consequence into adsorption while larger addition causes precipitation (Shi et al., 2015). Adding P in soil promoted precipitation to synthesize poorly soluble calcium phosphate (Rafiue et al., 2015). Consequently, calcite minerals fix P strongly and decline solution P (Ali et al., 2016). Calcite minerals that develop as consequence of adsorption are hydroxy apatite, dibasic Ca phosphate dehydrate and octa calcium phosphate (Bajwa and Khan, 2015). Likewise, higher lime and Fe-dithionite contents react with solution P to form non-soluble compounds and thus exacerbate P deficiency (Mouazen and Kuang, 2016). Henceforward, these reactions bound P so tightly even flooding of water would not enhance solution P concentration remarkably (Elahi et al., 2015). Ultimately, desired solution P contents can be brought out using management strategies that retain water for longer duration, facilitate deeper root penetration to intercept P and water and application of adequate P in soil to reduce adsorption and precipitation (Saleem et al., 2015).

Ultimately, adverse implications of reduced P availability negatively regulate biosynthesis of sugar phosphates (Li et al., 2016). Hence, photosynthesis limits yield by reducing starch and sucrose availability for grain filling (Xing and Wu, 2014). Phosphorous deficiency triggered down regulation of sucrose signaling reduced cell division (Khavari-Nejad et al., 2013). Predominantly, impaired biosynthesis of ribulose 1,5-bis phosphate is a typical indicator of P deficiency regarding photosynthesis (Aparicio-Fabre, 2013). Henceforward, expansion of epidermal cell is impaired and thus leaf area declines (Habibzadeh, nd). Similarly, declined activity of photosystem-II alters chlorophyll fluorescence negatively. Besides, inadequacy of P also declines soluble and insoluble protein contents (Shinano et al., 2013).

Soil manipulation strategies to augment fertilizer use efficiency must be aimed at enhancing water use efficiency and diminishment in evapotranspiration losses (Qin et al., 2014). Flat sowing of maize entails more seed rate, uneven seed germination, evapotranspiration losses of water, lodging, phosphorous fixation and consequently higher cost of production (Eldoma et al., 2016). Additionally, flat sowing triggered soil compaction declines root interception of phosphorous and hence yield (Liu et al., 2016). Furthermore, Soil compaction mediated disruption in hormonal signaling diminish aerial growth, root density, nutrient and water availability (Guan et al., 2014). Furthermore, lower emergence, higher seed rate and fertilizer costs can be accredited to uneven dispersal of water and nutrients in flat sowing (Mo *et al*., 2017). Likewise, spatial variations in moisture, seed germination and nutrient allocation further exacerbate yield gaps (Cid et al., 2013). Contrarily, ridge and bed planting saves 30-40% irrigation, enhances root growth, fertilizer, water use efficiency and decreases lodging (Tanwar et al., 2014). Deep infiltration ensures moisture retention for longer duration and hence nutrient availability enhances (Zhao et al., 2014). Additionally, upper soil layers in beds and ridges buffer soil temperature and allows P root interception (Wang et al., 2015).

Little facts are prevailing regarding phosphorous utilization under different planting geometry and their comparative effects on yield components, growth and yield of maize. Moreover, economic feasibility concerning different planting geometry is predominantly lacking in previous studies. There is no expedient approach to dispense phosphatic fertilizer and other inputs homogenously except manipulation of soil. Eventually, declined phosphorous fixation and water losses might enhance yield of corn on sustainable basis. Therefore, objectives of experiment were to Examine the effect of flat, ridge and bed planting on yield and yield components of maize, to Elucidate the optimum rate of phosphorous application in different planting geometry and to Boost the phosphorus use efficiency and ultimately profit on sustainable basis.

MATERIALS AND METHODS

Site Selection

The experiment was conducted at Research Farm, Agronomic Research Station Bahawalpur during summer 2022. The study site is located at 29.3544° N, 71.6911° E and214 m above sea level. It experiences an average annual temperature of 26.1℃ with an annual rainfall of 223 mm. The location experiences a semi-arid climate and relative humidity is 88%.

https://doi.org/10.55627/agribiol.003.02.1477

Soil Analysis

Pre-sowing soil analysis was performed collecting soil samples up to the depth of 30 cm. is presented below

Table 1. Analysis of soil

pH	Electrical conductivity dS m^{-}	Available P ppm	Potassium Ppm	Textural class	Saturation percentage %
7.9	1.8	15.4	180	loam	34.6

Meteorological Data

The metrological data recorded during crop period were collected from Agro-meteorological Observatory, Regional Agricultural Research Institute Bahawalpur is depicted in Figure 1.

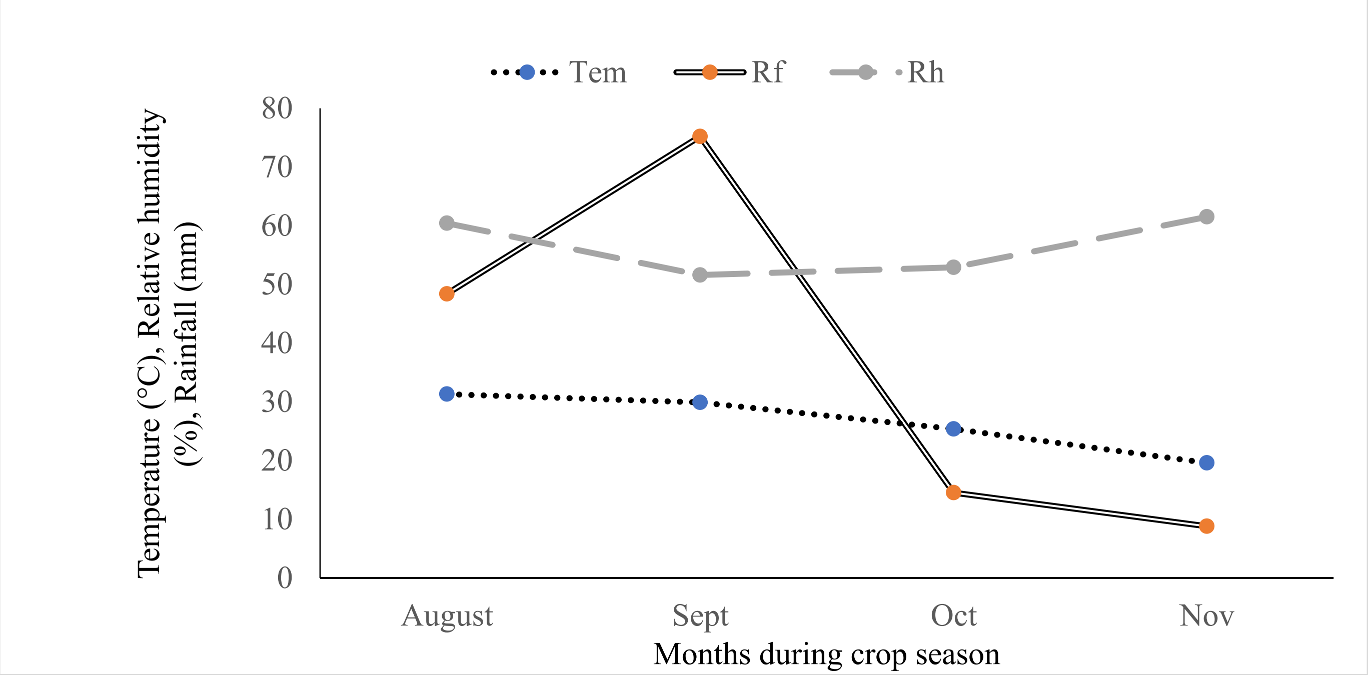

Figure 1. Weather parameters during crop season.

Treatments

The experiment was laid out in randomized complete block design (RCBD) with split plot arrangement having three replications. The net plot size was 5.0 m × 3.0 m. Each plot consisted of 4 rows having row to row distance of 75 cm and plant to plant distance of 20 cm. Sowing methods were randomized in main plots viz. S_1 = flat sowing; S_2 = ridge sowing and S_3 = bed sowing. Whereas, the phosphorous rates were randomized in split plots viz. P_1 = 100, P_2 = 125 and P_3 = 150 kg ha^{-1}. Single super phosphate was employed as source of phosphorous.

Crop Husbandry

Maize single cross hybrid was sown on a well-prepared seedbed on August 10, 2018. The crop was sown with hand drill by maintaining row × row distance of 75 cm. Seed rate used was 25 kg ha^{-1}. Nitrogen and potassium fertilizers were applied at the rate of 250: 125 kg ha^{-1} respectively. Urea and SOP (sulfate of potash) were applied as a source of nitrogen and potassium. Sowing was done manually with the help of hand drill, by maintaining a row to row distance of 75 cm. Carbofuran (Furadan 3-G) was applied after thinning of crop, to shelter the crop from weeds. After soaking irrigation, first irrigation to maize crop was applied at 15 days after sowing whereas subsequent irrigations were applied according to the need of the crop. Total 8 irrigations were provided. The crop was harvested on November 24, 2018. After harvesting the plants were left in field for four days to sun dry. The crop was tied into bundles and stoked for four weeks. Then cobs were separated from the stalks and allowed drying in sunshine for five days before shelling. Shelling was conducted to separate grains from the cob pith, using a mechanical maize sheller available at farm.

Data Collection

Height of five randomly selected plants at maturity from each plot was measured from the ground surface up to base of tassel with the help of measuring tape. Cob length of five randomly selected cobs from each plot was taken at harvesting and their length was measured with the help of measuring tape and then averaged. Cob girth of five cobs was taken from each plot with the help of Vernier caliper and then mean was taken. It was measured in centimeters (cm). Five cobs were selected at random from treatment plot and the total numbers of rows per cob were counted and average number of rows per cob was calculated. Five cobs were selected at random from each plot and total grains were counted and then averaged. For 1000-grains weight, 100 grain were taken using weighing balance and converted to 1000-grains weight through unitary method. The crop was harvested at maturity, tied up into small bundles and left in their respective plot for sun drying. The sun-dried bundles were weighed with the help of spring balance. Biological yield of each experimental unit was taken and then converted to t ha^{-1}. The cobs were sun dried and shelled to record grain yield for each experimental unit which was later converted into t ha^{-1}. The harvest index was calculated in percentage according to the formula (Gardner et al., 1985)

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

All the expenses occurred during the research were recorded and cost of production involved in growing the crop was calculated. The economic parts of the crop were measured and sold at the prevailing market rate. All the income was summed up to calculate the gross income.

Gross benefits were calculated as

$$\text{Net field benefits} = \text{Gross income} - \text{Variable cost}$$

Benefit cost ratio for each treatment was calculated by using the following formula

$$\text{Benefit cost rtio} = \frac{\text{Gross income}}{\text{Gross expenditure}}$$

Marginal rate of return was calculated by using the following formula (CIMMYT, 1988).

$$\text{Marginal rate of return} = \frac{\text{Marginal net benefits}}{\text{Marginal cost}}$$

Statistical Analysis

All statistical analyses of the data were analyzed using Statistic version 8.1 and subjected to analysis of variance (ANOVA). Least significant difference at 5% probability level was used for mean separation (Steel et al., 1997).

RESULTS AND DISCUSSION

On the whole, application of P positively influenced yield and yield components of maize. However, varying P nutrition augmented different traits distinctly under different soil environments. Although, varying P rates manifested dissimilar response under unalike sowing methods at numerous instances and consequence in significant sowing methods × phosphorous rates effect (Table 2).

Table 2. Analysis of variance for effect of sowing methods and phosphorous rates on wheat maize yield components and yield (A) Mean sum of squares

SOV	DF	Parameters								
		PH	CL	CD	GRPC	GPC	TGW	BY	GY	HI
Blocks	2	2.81	0.93	0.003	0.38	812.0	185.59	3.89	1.47	30.54
Sowing methods (S)	2	333.76*	2.06*	0.154**	14.09*	10572.7**	370.70**	57.63**	5.72**	2.59^{NS}
Error 1	4	23.53	1.76	0.007	0.41	1384.4	15.15	0.50	0.06	15.26
Phosphorous rates (P)	2	615.64**	2.00*	0.011*	9.20**	25806.9**	4.04**	33.43**	9.25**	85.38**
S × P	4	397.80**	0.09^{NS}	0.002^{NS}	3.25**	20411.1**	21.25^{NS}	4.14**	3.24**	440.57**
Error 2	12	16.11	0.68	0.002	0.32	1087.7	7.09	0.52	0.11	11.43

Significantly more cob length (21.77 cm), diameter (4.42 cm) and 1000-grain weight (140.44 g) was observed in ridge sowing. Whereas, cob length (21.16 cm), diameter (4.16 cm) and 1000-grain weight (127.67 g) was significantly reduced under flat sowing. Application of P at the rate of 125 kg ha^{-1} significantly enhanced cob length (21.61 cm), diameter (4.34 cm) and 1000-grain weight (135.11 g). While, significantly less cob length (21.61 cm), diameter and 1000-grain weight was recorded for 100 kg ha^{-1} P. Besides, medial cob length, diameter and 1000-grian weight was manifested under bed sowing and 150 kg ha^{-1} P (Table 3).

Table 3. Effect of sowing methods and phosphorous rates on yield components of maize

A	**Parameters**		
	CL	**CD**	**TGW**
Sowing methods (S)			
Flat sowing (S_1)	21.16 C	4.16 C	127.67 C
Ridge sowing (S_2)	21.77 A	4.42 A	140.44 A
Bed sowing (S_3)	20.83 B	4.32 B	135.11 B
LSD ($p \leq 0.05$)	0.090	4.340	5.090
Phosphorous levels (P)			
P_{100}	20.72 C	4.26 C	133.78 C
P_{125}	21.61 A	4.34 A	135.11 A
P_{150}	21.44 B	4.30 B	134.33 B
LSD ($p \leq 0.05$)	0.130	0.030	0.390

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$; SOV= Source of variation; DF= Degree of freedom; *= Significant; **= Highly significant; NS= Non-significant; P_{100} = 100 kg ha^{-1} P; P_{125} = 125 kg ha^{-1} P; P_{150} = 150 kg ha^{-1} P; PH = Plant height (cm); CL = Cob length (cm); CD = Cob diameter (cm); GRPC = Number of grain rows per cob; GPC = Number of grains per cob; TGW = 1000-grain weight (g); BY = Biological yield (t ha^{-1}); GY = Grain yield (t ha^{-1}); HI = Harvest index (%)

Enhancement of cob length and diameter under ridge and bed sowing over flat sowing can be ascribed to P and in biological yield and plant height (DEY, 2022). Increasing P might have boosted signaling for phloem sucrose translocation. Consequently, higher sucrose availability improved cell division in cob. Furthermore, bed and ridge planting might have enhanced root growth and ultimately improved root P interception (Chen et al., 2022). Henceforth, incline in P uptake augmented biosynthesis of sugar phosphates. Thus, improved availability of sugar phosphates promoted carbohydrate partitioning to cob. Furthermore, upsurge of grain rows per cob and grains per cob under ridge and bed planting established the role of enhanced P availability in improving yield attributes. Likewise, bed and ridge mediated increment in cob length and diameter can also disclosed in terms of diminished P adsorption and fixation. Bed and ridge sowing might have declined P fixation and adsorption and thus ultimately embellished cob length and diameter. Application of P in ridges and beds declined O fixation and adsorption. Additionally, consequences of improved root growth exalted yield components of maize (Kruse et al., 2015). Likewise, phosphorous application in bed and ridge sowing negatively influenced calcium phosphate synthesis. Elevated P uptake ultimately improved yield components of maize (Chen et al., 2022; Norris et al., 2016).

Improvement in 1000-grain weight under bed and ridge soil systems over flat sowing conditions can be defined in context ridge and bed mediated improvement in biological yield and plant height. Beds and ridges mediated raise in P availability might aggravated activity of ribulose- 1,5- bisphosphate and carbonic anhydrase. Hence, boost in enzymatic activity might have uplifted carbon fixation. Consequently, upsurge of green leaf area caused higher carbohydrates towards reproductive organs. Likewise, P embellishment in beds and ridges over flat sowing might have enhanced capability of chlorophyll to utilize high intensity to reduce carbon in photosynthesis. Therefore, sucrose translocation might have inclined under P triggered signaling and hence number of grain rows per cob, grains per cob and 1000-grain weight was exalted. Declined P availability could cause reduced green photosynthetic area and ultimately carbohydrates partitioning towards reproductive parts. Moreover, role of beds and ridges mediated uplift in P availability was accomplished from enhancement of cob length and diameter. Phosphorous application improved green leaf area and net photosynthesis. Consequently, yield and growth was improved over control. Growth improvement was an outcome of upsurge in enzymatic activities and quantum yield of photosystem-II (Xing and Wu, 2014). Nutrient use efficiency was augmented in beds over flat sowing conditions. Uplift in nutrient uptake enhanced water use efficiency, photosynthetic area and yield (Badr et al., 2016). Ridge planting decreases P fixation and adsorption with lime and calcium as a result of improvement in root P interception (Li et al., 2017).

Application of 100 and 125 kg ha^{-1} P under flat sowing conditions revealed more and statistically similar plant height. However, 125 and 150 kg ha^{-1} P produced significantly higher and statistically alike plant height under ridge and bed sowing. Whereas, significantly less plant height was recorded where 100 kg ha^{-1} P was applied under ridge and planting system. Regarding harvest index, application of 125 kg ha^{-1} P manifested significantly higher harvest index under flat and ridge sowing. Where, statistically analogous harvest index was observed with 100 and 125 kg ha^{-1} P under bed sowing (Table 4).

Table 4. Effect of heat stress on antioxidant activity and grain yield of maize varieties

Treatments	PH	GRPC	GPC	BY	GY	HI
Flat sowing (S_1)						
P_{100}	167.47 a	13.26 b	439.67 c	7.01 b	2.20 b	21.68 b
P_{125}	198.20 a	14.00 b	503.67 b	8.19 ab	3.44 b	41.70 a
P_{150}	200.77 b	15.86 a	610.00 a	9.24 a	3.88 a	39.36 b
Ridge sowing (S_2)						
P_{100}	191.63 b	15.06 c	580.00 b	14.10 b	3.04 c	31.45 c
P_{125}	206.17 a	18.66 a	711.00 a	15.73 a	6.16 a	50.99 a
P_{150}	203.00 a	16.66 b	654.00 a	9.74 c	4.98 b	41.91 b
Bed sowing (S_3)						
P_{100}	188.77 b	14.73 a	536.67 a	9.67 b	2.77 c	42.76 a
P_{125}	204.54 a	15.53 a	589.00 a	13.01 a	5.60 a	43.11 a
P_{150}	201.50 a	14.86 a	554.67 a	10.39 b	4.42 b	28.60 b
LSD ($p \leq 0.05$)	7.140	1.000	58.670	1.290	0.590	6.01

Any two means not sharing a letter in common differ significantly at $p \leq 0.05$; P_{100} = 100 kg ha^{-1} P; P_{125} = 125 kg ha^{-1} P; P_{150} = 150 kg ha^{-1} P; PH = Plant height (cm); GRPC = Number of grain rows per cob; GPC = Number of grains per cob; BY = Biological yield (t ha^{-1}); GY = Grain yield (t ha^{-1}); HI = Harvest index (%)

Application of P at the rate of 150 kg ha^{-1} produced significantly more number of grain rows per cob (15.86) and grains per cob (610.00) in flat sowing method. Whereas, 125 kg ha^{-1} P depicted significantly higher number of grain rows per cob (18.66) and grains per cob (711.00) under ridge sowing conditions. Though, statistically comparable number of grain rows per cob and grains per cob were detected. Likewise, application of 150 kg ha^{-1} P displayed remarkably higher biological (9.24 t ha^{-1}) and grain yield (3.88 t ha^{-1}) under flat sowing. Contrarily, statistically more biological and grain yield was conspicuous under ridge and bed planting. Application of 100 kg ha^{-1} manifested either significantly lower or statistically analogous biological and grain yield over 125 kg ha^{-1} P under all sowing techniques.

Increment in grain yield and harvest index under beds and ridges planting system over flat system can be adjudicated to soil manipulation mediated upsurge in P availability under beds and ridges. Uplift in P availability might have boosted energy rich sugar phosphates biosynthesis in photosynthesis. Henceforth, elevated P might upregulate adenosine phosphate synthase. Eventually, rapidly metabolized sugar phosphates boosted carbohydrate partitioning towards grains.

Likewise, enhanced P availability might have provoked hydrolytic phosphorylation of protein that ultimately transduced signal for carbohydrate partitioning towards grains. Besides, elevated P availability under bed and ridge planting techniques might boost ADP-glucose pyro-phosphatase (ADPG-PPase) activity. Consequently, ADPG-PPase might upsurge triose phosphates availability for sucrose biosynthesis and ultimately grain yield was elevated. Furthermore, ridges and beds mediated enhancement in P availability was also confirmed from soil manipulation triggered grain rows per cob and grains per cob. Likewise, increment of grain yield and harvest index under beds and ridges over flat sowing might be due to upregulation of regeneration of ribulose- 1,5- bisphosphate. Ultimately, aggravated resurgence of CO_2 acceptor augmented photosynthesis and hence grain yield. Furthermore, enhanced P mediated upregulation of ribulose- 1,5- bisphosphate regeneration was accomplished from beds and ridges provoked improvement of biological yield, cob length and diameter. Additionally, boost in P availability might have enhanced ATPs for Sucrose-

H$^+$ cotransporter. Ultimately, phloem sucrose unloading was triggered and thus sucrose partitioning towards grains was enhanced. Bed planting improved grain yield, 1000-grain weight, P uptake, average grain weight and soil properties (Cid et al., 2014). Similarly, bed planting augmented total nitrogen, available P, K and organic matter contents. Consequently, number of grains per spike, spikelet, spike length, 1000-grian weight, harvest index and yield of wheat was higher over control. Improvement in yield components was attributed to enhanced nutrient uptake in bed s over flat sowing conditions (Ma et al., 2016). Additionally, ridge planting of maize boosted nutrient uptake and yield of maize (Mo *et al*., 2017). Phosphorous mediated increment in plant height and biological yield might be due to P triggered cell division and elongation. Higher cell division ultimately promoted epidermal cells division and hence biological yield was higher under increased P in external environment. Application of P provoked cell division of epidermal cells. Consequently, leaf area and biological yield was augmented (Alam et al., 2016).

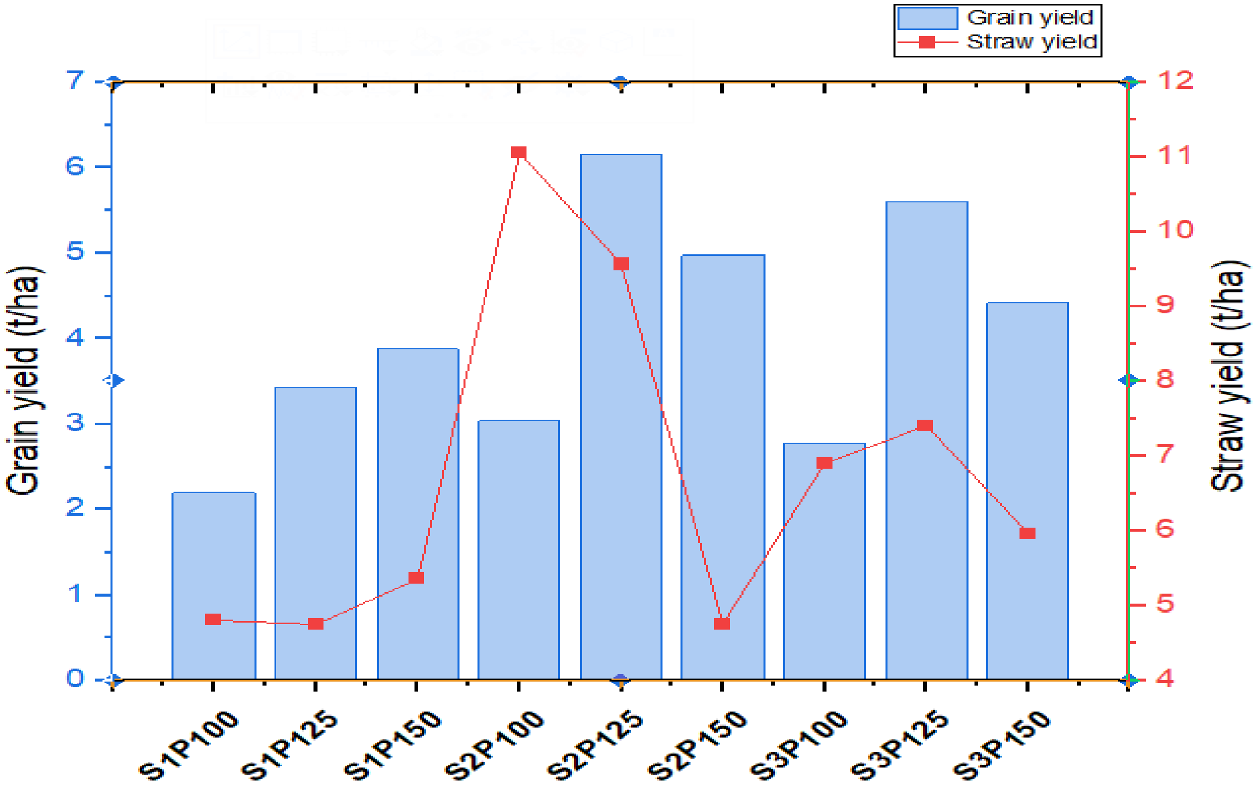

Figure 2. Grain yield and Straw yield of Mazie under various methods of sowing and phosphorus application rates.

Economic analysis indicted that application of 125 kg ha^{-1} P using ridge sowing and bed planting was relatively more advantageous than other P rates. In this regard, BCR of 1.59 and 1.41 was ostentatious employing 125 kg ha^{-1} under ridge and bed sowing, respectively. Although, higher BCR (1.00) was enunciating under 150 kg ha^{-1} P under flat sowing conditions (Table 5). Whereas, marginal and dominance analysis bespoke applying 150 kg ha^{-1} P caused wastage of P fertilizer and evidenced enhanced cost of production and diminished marginal returns (MRR = 257%). Henceforth, ridge (MRR = 2171%) and bed planning (MRR = 848) substantiated more beneficial than flat sowing applying 125 kg ha^{-1} P (Table 6).

Table 5. Effect of sowing methods and phosphorous rates on the economic analysis of maize

Treatments	**Grain Yield (t ha^{-1})**	**Value (Rs. ha^{-1})**	**Straw yield (t ha^{-1})**	**Value (Rs. ha^{-1})**	**Gross Income (Rs. ha^{-1})**	**Variable cost (Rs. ha^{-1})**	**Total cost (Rs. ha^{-1})**	**Net Return (Rs. ha^{-1})**	**Benefit cost ratio**
S$_1$P$_{100}$	2.20	44495	4.81	5772	50267	15750	87136	- 36869	- 0.58
S$_1$P$_{125}$	3.44	69574	4.75	5700	75274	10800	82186	- 6912	- 0.92
S$_1$P$_{150}$	3.88	78473	5.36	6432	84905	13500	84886	19	1.00

S_2P_{100}	3.04	61484	11.06	13272	74756	11700	83086	- 8330	- 0.90
S_2P_{125}	6.16	124586	9.57	11484	136070	14400	85786	50284	1.59
S_2P_{150}	4.98	100720	4.76	5712	106432	16650	88036	18396	1.21
S_3P_{100}	2.77	56023	6.90	8280	64303	17250	88636	-24333	- 0.73
S_3P_{125}	5.60	113260	7.41	8892	122152	15000	86386	35766	1.41
S_3P_{150}	4.42	89394	5.97	7164	96558	12300	83686	12872	1.15

Table 6. Effect of sowing methods and phosphorous rates on marginal analysis

Treatments	Gross income (Rs. ha^{-1})	Variable cost (Rs. ha^{-1})	Marginal cost (Rs. ha^{-1})	Net field benefits (Rs. ha^{-1})	Marginal net benefit (Rs. ha^{-1})	MRR (%)
S_1P_{125}	75274	10800	-	64474	-	-
S_1P_{150}	84905	13500	2700	71405	6931	257
S_1P_{100}	50267	15750	D	34517	D	D
S_2P_{100}	74756	11700	-	63056	-	-
S_2P_{125}	136070	14400	2700	121670	58614	2171
S_2P_{150}	106432	16650	D	89782	D	D
S_3P_{150}	96558	12300	-	84258	-	-
S_3P_{125}	122152	15000	2700	107152	22894	848
S_3P_{100}	64303	17250	D	47053	D	D

S_1 = Flat sowing; S_2 = Ridge sowing; S_3 = Bed sowing; P_{100} = 100 kg ha^{-1} P; P_{125} = 125 kg ha^{-1} P; P_{150} = 150 kg ha^{-1} P

Higher MRR under bed and ridges with 125 kg ha^{-1} can be defined in terms declined fixation of P with calcium under alkaline calcareous soil conditions. Contrarily, P fixation might have aggravated under flat sowing conditions. Hence, higher profit was obtained in flat sowing using 150 kg ha^{-1} P while125 kg ha^{-1} might have fixed and was not available for uptake. Therefore, marginal returns were negative. Lower MRR in flat sowing conditions can also be attributed to reduced root growth. Henceforth, root interception of P might be a consequence of lesser P interception that ultimately worsen economic feasibility of flat sowing conditions. Moreover, applying 150 kg ha^{-1} did not produce negative returns, although its returns were lagging far behind beds and ridges. Besides, extra P fertilizer in flat sowing might also contribute in enhanced cost of production and made it non-feasible to grow maize in flat sowing conditions. Whereas, lower benefits using 100 kg ha^{-1} under all sowing conditions can be attributed to adsorption of P. Lesser amount of P might have aggravated adsorption of P and ultimately exacerbate P availability. Thus, cost was enhanced and margin return was lesser. Larger amount P added in soil is fixed through synthesis of calcium phosphate while lesser amount of added P undergoes adsorption reaction and ultimately plant available P was declined (Gathala *et al*., 2016). Moreover, P adsorption was enhanced in flat sowing as a result of reaction of carbonates and bicarbonates of Ca and Mg at surface of soil (Qin et al., 2014).

CONCLUSIONS

In crux, both bed and ridge planting techniques not only declined the use of phosphorous fertilizer and cost of production but also produced more benefits than flat sowing. Significantly more grain yield was obtained sowing maize in ridges (6.16 t ha^{-1}) and beds (5.60 t ha^{-1}) applying 125 kg ha^{-1} phosphorous. More benefits were achieved in ridge sowing and applying 125 kg ha^{-1} phosphorous. Ridge planting system was followed by bed sowing. Some benefits were realized in flat sowing conditions also applying 150 kg ha^{-1} phosphorous. However, marginal analysis depicted that applying 150 kg ha^{-1} phosphorous under flat sowing declines marginal returns and also enhances use of phosphorous fertilizer. The study is beneficial for the farmers and agricultural industry in decision making of phosphorus placement methods and how to reduce economic burden on farmers of Pakistan. The calculated amount of phosphorus fertilizers will reduce its quantity in contrast to broadcast method ultimately leading to higher yields in effective phosphorus uptake.

ACKNOWLEDGEMENTS

Not applicable.

AUTHOR CONTRIBUTIONS

All the authors contributed equally to this research.

COMPETING OF INTEREST

No conflicts of interest have been disclosed by the authors.

REFERENCES

Abbas, M., Irfan, M., Shah, J.A., et al 2024. Enhancing phosphorus use efficiency in wheat grown on alkaline calcareous soils. *Eurasian J. Soil Sci.* 13: 79-88.

Ahmad, Z., Khan, S.M., Abd_Allah, E.F., et al 2016. Weed species composition and distribution pattern in the maize crop under the influence of edaphic factors and farming practices: A case study from Mardan, Pakistan. *Saudi J. Biol. Sci.* 23: 741-748.

Alam, H., Razaq, M., Khan, J. 2016. Effect of organic and inorganic phosphorous on growth of roselle (Hibiscus sabdariffa L.). *J. Northeast Agric. Univ. (Engl. Ed.)* 23: 23-30.

Alam, M.K., Bell, R.W., Salahin, N., et al 2018. Banding of fertilizer improves phosphorus acquisition and yield of zero tillage maize by concentrating phosphorus in surface soil. *Sustainability.* 10: 3234.

Ali, S., Raza, S.A., Butt, S.J., et al 2016. Effect of foliar boron application on rice (Oryza sativa L.) growth and final crop harvest. *Agric. Food Sci. Res.* 3: 49-52.

Aparicio-Fabre, R., Guillén, G., Loredo, M., et al 2013. Common bean (Phaseolus vulgaris L.) PvTIFY orchestrates global changes in transcript profile response to jasmonate and phosphorus deficiency. *BMC Plant Biol.* 13: 26.

Badr, M.A., Abou-Hussein, S.D., El-Tohamy, W.A. 2016. Tomato yield, nitrogen uptake and water use efficiency as affected by planting geometry and level of nitrogen in an arid region. *Agric. Water Manag.* 169: 90-97.

Bajwa, G.A., Khan, M.A. 2015. Management of macro- and micro nutrients in soil and mulberry foliage in Peshawar, Pakistan. *Sarhad J. Agric.* 31: 151-158.

Chen, X., Liu, P., Zhao, B., et al 2022. Root physiological adaptations that enhance the grain yield and nutrient use efficiency of maize (Zea mays L.) and their dependency on phosphorus placement depth. *Field Crops Res.* 276: 108378.

Cid, P., Carmona, I., Murillo, J.M., et al 2014. No-tillage permanent bed planting and controlled traffic in a maize-cotton irrigated system under Mediterranean conditions: Effects on soil compaction, crop performance and carbon sequestration. *Eur. J. Agron.* 61: 24-34.

Cid, P., Perez-Priego, O., Orgaz, F., et al 2013. Short- and mid-term tillage-induced soil CO2 efflux on irrigated permanent- and conventional-bed planting systems with controlled traffic in southern Spain. *Soil Res.* 51: 447-458.

CIMMYT, M. 1988. From agronomic data to farmer recommendations: An economics training manual. Completely revised edition. CIMMYT, D.F. pp. 31-33.

Coelho, M.J.A. 2019. Legacy phosphorus under long-term soil and fertilizer management in crop production. Doctoral dissertation, Universidade de São Paulo.

Dey, P.C. 2022. Growth and yield of white maize as influenced by earthing up practices and application methods of nitrogen fertilizer.

Ehsan Elahi, E.E., Asif Wali, A.W., Nasrullah, N., et al 2015. Response of cauliflower (Brassica oleracea L. botrytis) cultivars to phosphorus levels. *Pure Appl. Biol.* 4: 187-194.

Eldoma, I.M., Li, M., Zhang, F., et al 2016. Alternate or equal ridge–furrow pattern: Which is better for maize production in the rain-fed semi-arid Loess Plateau of China? *Field Crops Res.* 191: 131-138.

Gardner, F.P., Pearce, R.B., Mitchell, R.L. 2017. Physiology of crop plants. 2nd Ed. pp. 327.

Gathala, M.K., Timsina, J., Islam, M.S., et al 2016. Productivity, profitability, and energetics: A multi-criteria assessment of farmers' tillage and crop establishment options for maize in intensively cultivated environments of South Asia. *Field Crops Res.* 186: 32-46.

Govt. of Pakistan. 2020. Economic survey of Pakistan 2015-16. Ministry of Food and Agriculture, Islamabad, Pakistan. Chap. 2 pp. 23-44.

Guan, D., Al-Kaisi, M.M., Zhang, Y., et al 2014. Tillage practices affect biomass and grain yield through regulating root growth, root-bleeding sap and nutrients uptake in summer maize. *Field Crops Res.* 157: 89-97.

Habibzadeh, Y. 2015. The effects of arbuscular mycorrhizal fungi and phosphorus levels on dry matter production and root traits in cucumber (Cucumis sativus L.). *Afr. J. Environ. Sci. Technol.* 9: 65-70.

Islam, F., Yasmeen, T., Arif, M.S., et al 2016. Combined ability of chromium (Cr) tolerant plant growth promoting bacteria (PGPB) and salicylic acid (SA) in attenuation of chromium stress in maize plants. *Plant Physiol. Biochem.* 108: 456-467.

Khavari-Nejad, R.A., Najafi, F., Tofighi, C. 2013. The effects of nitrate and phosphate deficiencies on certain biochemical metabolites in tomato (Lycopersicon esculentum Mill. cv Urbana VF) plant. *J. Stress Physiol. Biochem.* 9: 64-73.

Kruse, J., Abraham, M., Amelung, W., et al 2015. Innovative methods in soil phosphorus research: A review. *J. Plant Nutr. Soil Sci.* 178: 43-88.

Kumar, K., Yadava, P., Gupta, M., et al 2022. Narrowing down molecular targets for improving phosphorus-use efficiency in maize (Zea mays L.). *Mol. Biol. Rep.* 49: 12091-12107.

Li, M., Shi, X., Guo, C., et al 2016. Phosphorus deficiency inhibits cell division but not growth in the dinoflagellate Amphidinium carterae. *Front. Microbiol.* 7: 826.

Li, X., Kang, Y., Wan, S., et al 2017. Effect of ridge planting on reclamation of coastal saline soil using drip-irrigation with saline water. *Catena.* 150: 24-31.

Liu, H., Liang, R., Antoniou, J., et al 2014. The effect of high moisture heat-acid treatment on the structure and digestion property of normal maize starch. *Food Chem.* 159: 222-229.

Liu, Q., Chen, Y., Liu, Y., et al 2016. Coupling effects of plastic film mulching and urea types on water use efficiency and grain yield of maize in the Loess Plateau, China. *Soil Tillage Res.* 157: 1-10.

Liu, R., Xu, C., Cong, X., et al 2017. Effects of oligomeric procyanidins on the retrogradation properties of maize starch with different amylose/amylopectin ratios. *Food Chem.* 221: 2010-2017.

Ma, Z., Chen, J., Lyu, X., et al 2016. Distribution of soil carbon and grain yield of spring wheat under a permanent raised bed planting system in an arid area of northwest China. *Soil Tillage Res.* 163: 274-281.

Mahmood, I.A., Arshad Ali, A.A., Muhammad Aslam, M.A., et al 2013. Phosphorus availability in different salt-affected soils as influenced by crop residue incorporation. *Int. J. Agric. Biol.* 15: 472-478.

Mo, Y., Li, G., Wang, D. 2017. A sowing method for subsurface drip irrigation that increases the emergence rate, yield, and water use efficiency in spring corn. *Agric. Water Manag.* 179: 288-295.

Mouazen, A.M., Kuang, B. 2016. On-line visible and near infrared spectroscopy for in-field phosphorous management. *Soil Tillage Res.* 155: 471-477.

Norris, S.L., Blackshaw, R.P., Dunn, R.M., et al 2016. Improving above and below-ground arthropod biodiversity in maize cultivation systems. *Appl. Soil Ecol.* 108: 25-46.

Qin, S., Zhang, J., Dai, H., et al 2014. Effect of ridge–furrow and plastic-mulching planting patterns on yield formation and water movement of potato in a semi-arid area. *Agric. Water Manag.* 131: 87-94.

Rafique, A.B., Baloch, S.U., Baloch, S.K., et al 2015. Effect of zinc and boron in combination with NPK on sunflower (Helianthus annuus L.) growth and yield. *J. Biol. Agric. Healthc.* 5: 101-107.

Rehim, A., Hussain, M., Hussain, S., et al 2016. Band-application of phosphorus with farm manure improves phosphorus use efficiency, productivity, and net returns of wheat on sandy clay loam soil. *Turk. J. Agric. For.* 40: 319-326.

Saleem, R., Ahmad, Z.I., Anees, M.A., et al 2015. Productivity and land use efficiency of maize mungbean intercropping under different fertility treatments. *Sarhad J. Agric.* 31: 37-44.

Shah, M.A., Manaf, A., Hussain, M., et al 2013. Sulphur fertilization improves the sesame productivity and economic returns under rainfed conditions. *Int. J. Agric. Biol.* 15: 1301-1306.

Shahi, J. 2021. Assessment of genetic diversity in maize [Zea mays (L.)] inbred lines. Doctoral dissertation, Banaras Hindu University, Varanasi.

Shi, L.L., Shen, M.X., Lu, C.Y., et al 2015. Soil phosphorus dynamic, balance and critical P values in long-term fertilization experiment in Taihu Lake region, China. *J. Integr. Agric.* 14: 2446-2455.

Shinano, T., Yoshimura, T., Watanabe, T., et al 2013. Effect of phosphorus levels on the protein profiles of secreted protein and root surface protein of rice. *J. Proteome Res.* 12: 4748-4756.

Steel, R.G.D., Torrie, J.H. 1981. Principles and procedures of statistics, a biometrical approach. 2nd Ed. p. 633.

Tanwar, S.P.S., Rao, S.S., Regar, P.L., et al 2014. Improving water and land use efficiency of fallow-wheat system in shallow Lithic Calciorthid soils of arid region: Introduction of bed planting and rainy season sorghum–legume intercropping. *Soil Tillage Res.* 138: 44-55.

Wang, Q., Song, X., Li, F., et al 2015. Optimum ridge–furrow ratio and suitable ridge-mulching material for alfalfa production in rainwater harvesting in semi-arid regions of China. *Field Crops Res.* 180: 186-196.

Xing, D., Wu, Y. 2014. Effect of phosphorus deficiency on photosynthetic inorganic carbon assimilation of three climber plant species. *Bot. Stud.* 55: 60.

Zhao, H., Wang, R.Y., Ma, B.L., et al 2014. Ridge-furrow with full plastic film mulching improves water use efficiency and tuber yields of potato in a semiarid rainfed ecosystem. *Field Crops Res.* 161: 137-148.