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Integrated Use of Phosphorus, Animal Manures and Biofertilizers Improve Maize Productivity under Semiarid Condition

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Additional information is available at the end of the chapter

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Abstract

Phosphorus unavailability and lack of organic matter in the soils under semiarid condition are the major reasons for low crop productivity. Field trial was conducted to investigate the impact of different animal manures (poultry, cattle, and sheep manures) and phosphorus levels (40, 80, 120, and 160 kg P₂O₅ ha⁻¹) on yield and yield components of hybrid maize (CS-200) with (+) and without (-) phosphate-solubilizing bacteria (PSB) seed treatment at the Agronomy Research Farm of The University of Agriculture Peshawar, during summer 2014. Our results confirmed that the application of poultry manure significantly ($P \leq 0.05$) increased yield and yield components of maize. Phosphorus applied at the rate of 120 kg P₂O₅ ha⁻¹ increased ear length, grains ear⁻¹, and shelling percentage, while the highest rate of 160 kg P ha⁻¹ increased grains weight, grain yield, and harvest index. Maize seeds treated with PSB (+) before sowing had produced higher yield and yield components than untreated seeds (-). We concluded from this study that combined application of 160 kg P₂O₅ ha⁻¹ + poultry manure and seed treatment with PSB (+) could improve crop productivity and profitability under semiarid condition.

Keywords: *Zea mays* L., hybrid, yield components, phosphate-solubilizing bacteria, animal manures, phosphorus levels, semiarid climate

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in Pakistan after wheat and rice [1]. In Northwest Pakistan (Khyber Pakhtunkhwa province), maize ranked second after wheat in its importance [2]. Maize average yield in Northwest Pakistan is too low as compared with the

average yield of the country [3, 4]. Maize is a C_4 mode of carbon fixation plant efficiently utilizes inputs, shows rapid growth, producing large quantity of organic matter per unit area [5]. In Pakistan, maize was cultivated on an area of 1059.5 (000 ha) with a total production of 4220.1 (000 tones), while during the same season its area of cultivation and production in the Khyber Pakhtunkhwa Province (semiarid condition) was 463.4 (000 ha) and 858.3 (000 tones), respectively. Its average yield in Pakistan is 3983 kg ha^{-1} , which is much lower than the other corn growing countries of the world (USA, China, Brazil, Argentina, Canada, Italy, Egypt) [6].

The major problems in the way of increasing yield at farmer's fields are the inappropriate nutrients supply [7–9]. Phosphorus unavailability and lack of organic matter under calcareous soils in semiarid climates are some of the major reasons for low crop productivity [10, 11]. Phosphorus is very important for improving crop growth and yield [12–14]. Phosphorus is a macronutrient that plays a number of important roles in plants. Adequate phosphorus results in higher grain production, improved crop quality, greater stalk strength, increased root growth, and earlier crop maturity [3, 4]. Crop phosphorus nutrition depends on the ability of the soil to replenish the soil solution with phosphorus as the crop removes it and on the ability of the plant to produce a healthy and extensive root system that has access to the maximum amount of soil phosphorus. Application of P fertilizers must be done in a way to maximize the P availability to crops and to minimize the risk that P might be lost to the environment by runoff or erosion. According to [15], phosphorus deficiency symptoms appear in the lower part of the plants and results in (1) decreased leaf number, (2) decreased leaf blade length, (3) reduced panicles/ears/spikes per plant, (4) reduced seeds per panicle/ear/spike, and (5) reduced filled seeds per panicle/ear/spike.

Phosphorus is the second most important crop nutrient after nitrogen that increases crop productivity and profitability on P-deficient soils in Khyber Pakhtunkhwa [4, 10, 11]. Phosphorus has been reported to increase the strength of cereal straw, stimulate root development, promote flowering, fruit production, and formation of seeds, and it hastens maturity of the crops [16]. In most of the cropping system especially under semiarid condition, phosphorus is one of the least available mineral nutrient [17] especially in soils high in CaCO_3 [18] and high soil pH [19], which reduces P availability to crops [20, 21]. Because large applied phosphorus application as fertilizer moves in to immobile pools through precipitation reaction with highly reactive Al^{3+} and Fe^{3+} in acidic, and Ca^{2+} in calcareous or normal soil [22]. At least 60% water soluble P fertilizer was more effective in calcareous soils because P uptake by corn plants [23]. Percent utilization fertilizer P and available P content of soil generally decreased with increasing CaCO_3 concentration [24]. The use of microorganisms such as phosphate-solubilizing bacteria (PSB) as inoculants with the seed increases P availability and uptake by the plant [25] by production of organic acid, which reduces the pH of the surroundings rhizosphere [26]. Which either dissolve phosphates as a result of anion exchange or can chelate Ca, Fe, or Al ions associated with the phosphates [22].

Application of organic matter to field crops provides nutrients to the plants, also improves water holding capacity, and helps the soil to maintain better aeration for the seed germination and plant root development [27]. Therefore, the combine use of organic fertilizers along with chemical fertilizers may be utilized as an effective tool to improve growth and increase yields

[28]. Applications of organic manures, such as crop residues, animal manures (AM), chicken manures, green manures, composts, farm yard manure, biochar, and ash, increase the beneficial microbes in the soil and improve soil health and sustainability. Organic fertilizers consisted of farmyard manure, poultry manure, sheep manure, and biofertilizer may be used for crop production as an alternate of inorganic fertilizers [29]. However, most of Pakistani soils comprise <1% organic matter [30], because of lower organic matter added to soils [31, 32]. Pakistan is rich in farm manures with immense livestock population. In Pakistan, about 50% AM is used as fuel and more than 50% is not consumed [33]. Poultry manure mineralizes greater than other manure such as cattle or pig dung: plant absorbed nutrient and utilized rapidly [34]. Basic nutrients required for higher growth and yield of crops contains in poultry manure and increases carbon content, water holding capacity, soil structure, and decreases bulk density [35, 36]. Subsistence farmers should apply organic manure directly to the soil as a natural means of recycling nutrients in order to improve soil fertility and yield of crops [37]. Application of cattle dung increases plant height, leaf area, pod number, pod weight in cowpeas [38] and in maize [39].

Biofertilizers are known to play a number of vital roles in soil fertility; crop productivity and profitability [40]. Biofertilizers are the products containing living cells of different types of beneficial microbes (bacteria, fungi, protozoa, algae, and viruses). Some of the commonly used beneficial microbes in agriculture include *Rhizobia*, *Mycorrhizae*, *Azospirillum*, *Bacillus*, *Pseudomonas*, *Trichoderma*, *Streptomyces* species. According to [40], beneficial microbes are essential for decomposing organic matter in the soil and increase essential macronutrients (nitrogen, phosphorus, potassium, sulfur, calcium, and magnesium) and micronutrients (boron, copper, chlorine, iron, manganese, molybdenum, and zinc) availability to crop plants. Beneficial microbes also play significant role in solid wastes and sewage management. Beneficial microbes increase plants tolerance to different environmental stresses (drought, heat, cold, salinity etc.) and increase plant resistance to insects and diseases attacks. Beneficial microbes not only improve crop growth and productivity by increasing photosynthesis and producing hormones and enzymes but also improve crop quality by controlling different insects and various plant diseases. Beneficial microbes reduce the use of chemical fertilizers and thereby reduce environmental pollution caused by chemical fertilizers. Beneficial microbes reduce cost of production and so increase grower's income and profitability. Beneficial microbes are therefore very important for increasing crop productivity, profitability, and sustainability. PSB increase the growth and yield of different crops as reported in maize [10, 11, 41] and wheat [42]. The use of beneficial microorganisms (biofertilizers) such as PSB as inoculants with the seed increases P availability and uptake by the plants [25], which are important not only for the reduction of the quantity of chemical fertilizers and environment friendly [43] but also increased crop productivity [41].

As phosphorus and organic matter are some of the major limiting factors for crop production under semiarid condition. Therefore, the application of biofertilizer especially PSB and AM could increase phosphorus availability and crop productivity under semiarid condition. However, there is no research to investigate the interactive effects of AM \times PSB \times P under semiarid condition. This research work was therefore designed with the objectives (1) to find

out suitable AM source, (2) to find out proper P level, (3) to find out proper combination of AM \times P, (4) to find out proper combination of AM \times PSB, (5) to find out proper combination of P \times PSB, and (6) to find out proper combination of AM \times PSB \times P for improving yield and yield components of maize hybrid (CS200) under the semiarid condition at Peshawar (Pakistan).

2. Materials and methods

2.1. Site description

Field trial was conducted to investigate effects of AM (poultry, cattle, and sheep manures) and phosphorus levels (40, 80, 120, and 160 kg P_2O_5 ha⁻¹) on growth and yield of maize with (+) and without (–) PSB at the Agronomy Research Farm of The University of Agriculture Peshawar, during summer 2014. The experimental farm is located at 34.01°N latitude, 71.35°E longitude at an altitude of 350 m above sea level. The farm soil is silt clay loam, low in organic matter (0.87%), extractable P (5.6 mg P kg⁻¹), exchangeable, alkaline (pH 8.2), and calcareous in nature [9].

2.2. Experimentation

The experiment was laid out in randomized complete block design with split plot arrangement using three replications. Combinations of three AM and to PSB levels (with and without PSB) were applied to the main plots, whereas four phosphorus (P) levels were applied to subplots. All the AM sources (poultry manure, sheep manure, and cattle manure) were applied at the rate of 5 t ha⁻¹ 2 weeks before seed bed preparation, while P was applied at sowing time. The PSB obtained from NARC, Islamabad, was mixed with the seed just before sowing time. A subplot size of 4 m \times 3.5 m, having five rows, 4 m long, and 70 cm apart was used. A uniform dose of 120 kg N ha⁻¹ as urea in two equal splits, that is, half at sowing, and half at knee height was applied. Maize hybrid “CS-200” was used as a test crop. All other agronomic practices were kept uniform and normal for all the treatments.

2.3. Data recording

Data on ear length (cm) were recorded with the help of meter rod by selecting ten plants randomly from each subplot, and then, the average was worked out. Number of grains ear⁻¹ was calculated on 10 randomly selected ears from each subplot, and then, average was worked out. Thousand grain weights (g) of randomly 1000 grains were taken from seed lot of each subplot and were weighted with the help of electronic balance. For grain yield data, the three central rows of each treatment were harvested, dried, threshed, weighted, and then were converted into grain yield (kg ha⁻¹) using following formula:

$$\text{Grain yield (kg ha}^{-1}\text{)} = \frac{\text{Grains weight in three rows (kg)}}{\text{No. of rows} \times \text{row length} \times \text{R} - \text{R distance}} \times 10,000 \text{ m}^2$$

Harvest index and shelling percentage for each treatment were calculated using the following formulae.

$$\text{Harvest index} = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

$$\text{Shelling \%} = \frac{\text{Grains weight of 10 ears}}{\text{Total weight of 10 ears}} \times 100$$

2.4. Statistical analysis

Data were statistically analyzed according to [44] for randomized complete block design with split plot arrangement, and means among different treatments were compared using least significant differences (LSD) test ($p \leq 0.05$).

3. Results and discussion

3.1. Effect of phosphorus

Phosphorus (P) levels significantly affected ear length, number of grains ear⁻¹, thousand grains weight, grain yield, harvest index, and shelling percentage of maize (**Table 1**). Higher ear length (25 cm) was obtained with the application of P at the rate of 120 kg ha⁻¹, followed by 160 kg P ha⁻¹ (23 cm), whereas lower ear length (20 cm) was produced in plots receiving 40 kg P ha⁻¹. The higher number of grains ear⁻¹ (417) was obtained at 120 kg P ha⁻¹, followed by 160 kg P ha⁻¹ (406), whereas lower number of grains ear⁻¹ (385) was recorded with 40 kg P ha⁻¹. Phosphorus application at the rate of 120 kg P ha⁻¹ produced heavier thousand grains weight (346.5 g) being statistically at par with 160 kg P ha⁻¹ (347.8 g), while the lower thousand grains weight (331.2 g) was recorded with 40 kg P ha⁻¹. The highest grain yield (5245 kg ha⁻¹) was obtained with the highest P level of 160 kg P ha⁻¹ being at par with 120 kg P ha⁻¹ (5164 kg ha⁻¹). The lowest grain yield (4284 kg ha⁻¹) was noted in the plot received the lowest rate of 40 kg P ha⁻¹. Application of 160 kg P ha⁻¹ resulted in the highest harvest index (42.13%) being statistically at par with 120 and 80 kg P ha⁻¹, while plots with 40 kg P ha⁻¹ resulted in the lower harvest index (38.49%). The higher shelling percentage (83.6%) was calculated with 120 kg P ha⁻¹; however, it was statistically at par with 160 kg P ha⁻¹ (82.9%), whereas lowest shelling (80.3%) was recorded with 40 kg P ha⁻¹.

Phosphorus (kg ha ⁻¹)	Ear length (cm)	Grains ear ⁻¹	Thousand grains weight (g)	Grain yield (kg ha ⁻¹)	Harvest index (%)	Shelling percentage (%)
40	20 d	385 d	331.2 c	4284 c	38.49 c	80.3 c
80	21 c	400 c	338.9 b	4754 b	40.28 b	81.5 b
120	25 a	417 a	346.5 a	5164 a	40.55 ab	83.6 a
160	23 b	406 b	347.8 a	5245 a	42.13 a	82.9 a
LSD_{0.05}	0.94	4.43	1.77	159.01	1.63	0.99

Means followed by different letters within each category are significantly different using LSD test ($P \leq 0.05$).

Table 1. Ear length, number of grain ear⁻¹, thousand grains weight, grain yield, harvest index, and shelling percentage of maize hybrid as affected by phosphorus levels.

The increase in the yield components (length, number of grains ear⁻¹, and thousand grains weight), grain yield, harvest index, and shelling percentage with the application of higher P rates (120 and 160 kg P ha⁻¹) over lower rates of P (40 and 80 kg P ha⁻¹) as shown in **Table 1** could be due to the higher requirement of P by maize hybrid. These results are in accordance with those of [32, 33] that number of cobs increased with the increase in the level of organic and inorganic fertilizers. According to [34], ear lengths in maize increased while increasing P level, while [35] reported that the application of P significantly increased the number of grains ear⁻¹ in maize. These results are in agreement with those of [6, 35] that increase in P level increased maize grain yield. According to [41], grain yield in maize increased to maximum level with the application of 90 kg P ha⁻¹. The increase in harvest index with higher P levels might be due to the increase in yield and yield components of maize with higher P rates [6]. The increase shelling percentage with increase in the P level probably may be due to the increase in ear length, number of rows, and number of grains per ear as well as heaviest grain weight [4]. The results published from the same study [11] indicated that maize phenology (tasseling, silking, and physiological maturity) was delayed with lower P levels (40 and 80 kg ha⁻¹) levels. Phenological development enhanced (early development) was observed with the application of higher P levels (120 and 160 kg ha⁻¹). The reason for early phenology with the application of higher P levels might be due to better root development and thus facilitated the plants obtained more P and other nutrient from poultry manure for rapid plant growth and development. These findings are in line with those of [31] who reported that early phenological development with higher P levels. Growth parameters (plant height, mean single leaf area, and leaf area index) were significantly improved with the application of two higher P levels [11]. The biomass yield was significantly increased with the application of 120 or kg P ha⁻¹ and poultry manure. Reduction in biomass yield was observed with the application of 40 kg P ha⁻¹ and cattle manure. The increase in biomass yield reflects the better growth and development of the plants due to balanced and more availability of nutrients, which was associated with increased root growth due to which the plants explore more soil nutrients and moisture throughout the growing period. The increase in biomass yield with integrated use of 120 and 160 kg P ha⁻¹ + poultry manure in our experiment was attributed to the improvement in growth parameters that increased yield and yield components in maize. These results are in line

agreement with [45] who stated that the application of P fertilizer significantly increased the biomass and grain yield of maize.

The results from another research on wheat crop [46] revealed that the increase in P level accumulated more total dry matter (DM) and portioned more DM into leaf, stem, and spike at both anthesis and physiological maturity. A large amount of DM was accumulated in response to the application of the highest rate of (90 kg P ha⁻¹). The increase in total DM accumulation with increase in P probably may be due P being the components of ATP might have contributed to a higher photosynthetic rate, abundant vegetative growth and assimilates formation and partitioning [47]. The results are also in accordance with those of [48] who reported increase in DM partitioning and accumulation while increasing rate of P. The increase in number of spikes m⁻² and grains per spike with increase in P level probably may be the major cause for increasing total DM accumulation and greater amount of partitioning into various plant parts especially the reproductive parts which increased grain yield. Memon et al. [49] and Rahim et al. [50] reported that grains per spike in wheat increased with increase in P level. Recently [10], we found that phosphorus levels had significantly ($P \leq 0.05$) affected number of grains ear⁻¹ and grain srow⁻¹, 1000 grains weight, grain yield, harvest index, and shelling percentage in maize. Phosphorus applied at the two higher rates (75 and 100 kg P ha⁻¹) had increased number of grains ear⁻¹ and grains row⁻¹, 1000 grains weight, grain yield, harvest index, and shelling percentage in local variety "Azam" [10]. Decrease in P level not only decreased yield and yield components of maize "Azam" but also declined the income of maize growers under semiarid climates [4, 10].

3.2. Effect of AM

AM significantly affected ear length, number of grains ear⁻¹, thousand grains weight, grain yield, and harvest index (**Table 2**). Plots applied with poultry manure resulted in higher ear length (24 cm), followed by sheep manure (22 cm), which is statistical at par with cattle manure (21 cm). In case of AM, application poultry manure produced higher number of grains ear⁻¹ (414) lower (391) was observed under cattle manure being at par with the sheep manure (401). In the three AM used, application of poultry manure produced heavier thousand grains weight (348.2 g), followed by sheep manure (341.0 g), while cattle manure resulted in lower thousand grains weight (334 g). The highest grain yield (5216 kg ha⁻¹) was recorded with application of poultry manure, followed by sheep manure (4786 kg ha⁻¹), whereas the lowest grain yield (4583 kg ha⁻¹) was obtained with cattle manure. Maximum harvest index (42.09%) was observed with poultry manure, while minimum harvest index (39.14%) was recorded with cattle manure being at par with sheep manure (39.85%). In case of AM, poultry manure application increased shelling percentage (84%); however, lower shelling percentage (81.1%) was calculated with cattle manure being at par with the sheep manure (82.2%). The increase in the yield components (length, number of grains ear⁻¹, and thousand grains weight) with the application of poultry manure (**Table 2**) over cattle and sheep manures probably may be due to the higher availability crop nutrients specially P and other macronutrients and micronutrients. These results are in accordance with those of [51, 52] that number of cobs increased with the increase in the level

of organic and inorganic fertilizers. According to many studies, application manure increased tassel length [53], 1000 grains weight [54], and number of grains ear⁻¹ in maize [55]. In our recent study, we found that the residual effect of poultry manure was also found better on the yield components of wheat under rice–wheat cropping system as compared with sheep manure and cattle manure [32]. Many researchers [56, 57] reported that poultry manure significantly increased the grain yield in maize. According to [53], increase in the poultry manure doses had significantly increased harvest index in maize, while [58] reported that poultry manure increased the shelling percentage in maize. The results published from the same study [11] indicated that phenological development delayed with the application of poultry manure as compared with other two manures (sheep and cattle manures) reported delayed in phenology with the application of poultry manure. The growth parameters were also significantly improved with application of poultry manure and there by increased grain yield and yield components in maize over sheep and cattle manures [11] suggested that poultry manure enhanced the LAI in maize. The improvement in growth and yield with the application of poultry manure probably may be due to the enhanced leaf area, total chlorophyll content, carbon content, water holding capacity, and decrease bulk density of soil [59]. Earlier the results published from the same study [11] indicated that maize biomass yield was significantly increased with the application of poultry manure as compared with cattle and sheep manure (poultry manure > sheep manure > cattle manure). The increase in biomass yield was attributed to the better growth and development of the plants due to balanced and more availability of nutrients which was associated with increased root growth due to which the plants explore more soil nutrients and moisture throughout the growing period [11, 60]. The increase in biomass yield showed positive relationship with grain yield.

Animal manure (5 t ha ⁻¹)	Ear length (cm)	Grains ear ⁻¹	Thousand grains weight (g)	Grain yield (kg ha ⁻¹)	Harvest index (%)	Shelling percentage (%)
Sheep manure	22 b	401 b	341.0 b	4786 b	39.85 b	81.2 b
Poultry manure	24 a	414 a	348.2 a	5216 a	42.09 a	84.0 a
Cattle manure	21 b	391 b	334.0 c	4583 c	39.14 c	81.1 b
LSD _{0.05}	1.38	10.93	2.16	194.93	2.12	1.14
Means followed by different letters within each category are significantly different using LSD test (P ≤ 0.05).						

Table 2. Ear length, number of grain ear⁻¹, thousand grains weight, grain yield, harvest index, and shelling percentage of maize hybrid as affected by animal manures.

3.3. Effect of PSB (biofertilizer)

The PSB had no nonsignificant effect on ear length and harvest index, while number of grains ear⁻¹, thousand grains weight, grain yield, and shelling percentage was significantly affected by PSB (Table 3). Higher number of grains ear⁻¹ (409) was obtained in the plots applied with PSB than without PSB (395). Plots with PSB had produced heavier thousand grains weight (342.0 g) than plots without PSB. The +PSB vs. –PSB comparison indicated that the plots with

PSB (+PSB) produced higher grain yield (4993 kg ha^{-1}) than plots without PSB (4730 kg ha^{-1}). Higher shelling percentage (82.9%) was obtained with PSB and lower (81.2%) at without PSB. The increase in the yield components (number of grains ear⁻¹ and thousand grains weight), grain yield, and shelling percentage of maize seed treatment with PSB over not treated maize seeds (**Table 3**) probably may be due to the higher availability of crop nutrients and increase in beneficial soil microbes. According to [10, 45, 61, 62], PSB application resulted in higher yield components and grain yield. The results published from the same study [11], however, indicated that plots with (+) and without (-) PSB had showed no significant differences in the phenological development of maize. However, other growth parameters were improved in maize crop grown under plots with (+) PSB than without (-) PSB. Application of phosphate-solubilizing microorganism improving soil fertility by releasing bound P therefore improves crop growth and increases crop productivity [29]. In contrast to our results, [45, 61] reported that the inoculation of maize with PSB under greenhouse and field conditions increased biomass yield of maize. According to [62], biofertilizer (*Pseudomonas*) significantly increased the biomass yield of maize over control. Our recent results on wheat [46] also revealed that the application of beneficial microorganisms (BMO) at the two higher levels (20 and 30 L ha⁻¹) accumulated more total DM and partitioned more DM into leaf, stem, and spike at both anthesis and PM. Because BMO applications increase the availability of plant nutrients, especially P availability to the plants that resulted in better plant growth and higher production [63–65]. Dobblaere et al. [66] assessed the inoculation effect of BMO on growth of spring wheat and observed that inoculated wheat plants had better growth, more number of grains spike⁻¹, and grain yield. Significant differences were found in number grains ear⁻¹ and grains row⁻¹, 1000 grains weight, grain yield, and shelling percentage between the plots treated with PSB (+) and without PSB (-) [10]. Plots applied with PSB (+) had produced more numbers of grains ear⁻¹ and grains row⁻¹, heavy 1000 grains weight, higher grain yield, and shelling percentage than plots without PSB (-). However, no significant differences were observed for harvest index between the plots with PSB (+) and without PSB (-).

PSB	Ear length (cm)	Grains ear ⁻¹	Thousand grains weight (g)	Grain yield (kg ha ⁻¹)	Harvest index (%)	Shelling percentage (%)
With PSB (+)	22	395 b	340.2 b	4730 b	40.00	81.2 b
Without PSB (-)	22	409 a	342.0 a	4993 a	40.73	82.9 a
Level of significance	ns	*	*	*	ns	*

Means followed by different letters within each category are significantly different using LSD test ($P \leq 0.05$). ns, nonsignificant at 5% level of probability.

*Significant at 5% level of probability.

Table 3. Ear length, number of grain ear⁻¹, thousand grains weight, grain yield, harvest index, and shelling percentage of maize hybrid as affected by with (+) and without (-) PSB inoculation.

Interactions	Ear length (cm)	Grains ear ⁻¹	Thousand grains weight (g)	Grain yield (kg ha ⁻¹)	Harvest index (%)	Shelling percentage (%)
AM × PSB	ns	ns	(Figure 4)*	ns	ns	(Figure 7)*
AM × P	ns	(Figure 1)*	(Figure 5)*	ns	ns	(Figure 8)*
PSB × P	ns	(Figure 2)*	ns	ns	ns	ns
AM × PSB × P	ns	(Figure 3)*	(Figure 6)*	ns	ns	ns

ns, nonsignificant at 5% level of probability.
*Significant at 5% level of probability.

Table 4. Ear length, number of grain ear⁻¹, thousand grains weight, grain yield, harvest index, and shelling percentage of maize hybrid as affected by interactions.

3.4. Interactive effect

All interactions (AM × PSB, AM × P, PSB × P, and AM × PSB × P) had no significant effect on ear length, grain yield, and harvest index of maize (**Table 4**). Number of grains ear⁻¹ was significantly affected by AM × P, PSB × P, and AM × PSB × P interactions (**Table 4**). Interaction between AM × P indicated that the increase in number of grains ear⁻¹ with the combination of poultry manure + 120 kg P ha⁻¹, and the plots that received cattle manure along with 40 kg P ha⁻¹ produced minimum number of grains ear⁻¹ (**Figure 1**). Significant increase in number of grains ear⁻¹ was observed with PSB + 120 kg P ha⁻¹, and plots that received 40 kg P ha⁻¹ without PSB application resulted in the lowest number of grains ear⁻¹ (**Figure 2**). The three-way interaction among AM × PSB × P indicated that the highest number of grains ear⁻¹ was recorded in plots under poultry manure + 160 kg P ha⁻¹ + PSB. Plots having cattle manure + 40 kg P ha⁻¹ without PSB produced the lowest number of grains ear⁻¹ (**Figure 3**). The results published from the same study [11] indicated that higher mean single leaf area and maximum leaf area index (4.28) were recorded with the combined application of higher P levels, viz 120 or 160 kg P ha⁻¹ + poultry manure along with PSB inoculation. The lower mean single leaf area and minimum leaf area index (3.65) were recorded with the combined application of sheep manure + 40 kg P ha⁻¹ without seed inoculation with PSB (-) and therefore resulted in significant AM × PSB × P interactions [11].

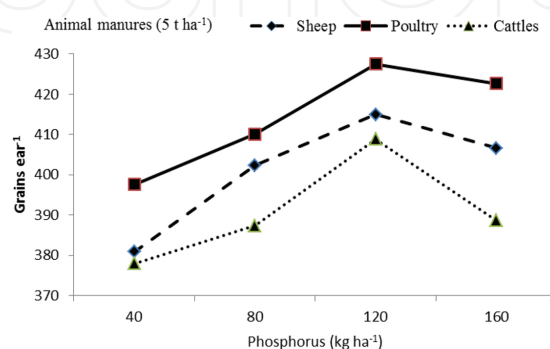


Figure 1. Response of number of grains ear⁻¹ in hybrid maize to animal manures and phosphorus interaction (AM × P).

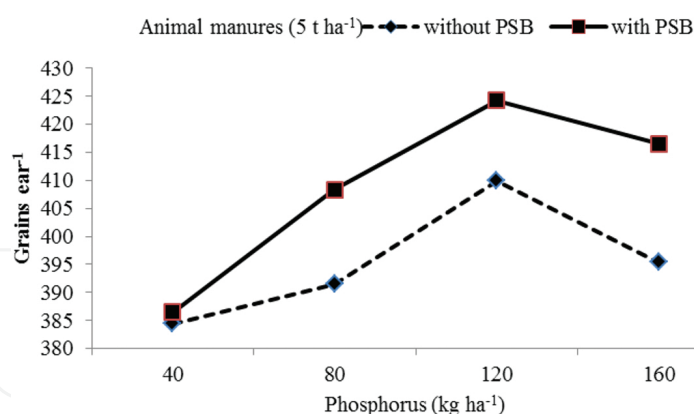


Figure 2. Response of number of grains ear⁻¹ in hybrid maize to phosphate-solubilizing bacteria and phosphorus interaction (PSB × P).

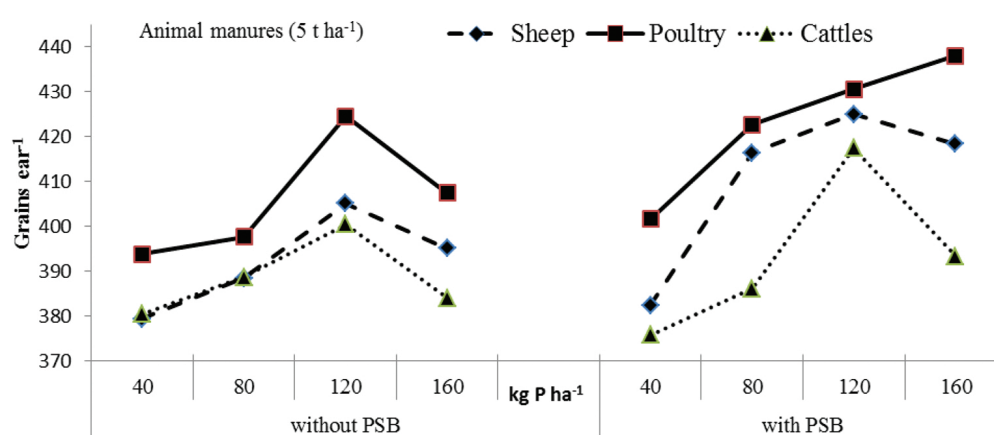


Figure 3. Response of number of grains ear⁻¹ in hybrid maize to animal manures, phosphate-solubilizing bacteria and phosphorus interaction (AM × PSB × P).

Thousand grains weight was significantly affected by AM × PSB, AM × P, and AM × PSB × P interactions (**Table 4**). Interaction between AM × PSB indicated that heavier thousand grains weight was recorded in plots applied with poultry manure under PSB, and plots that received cattle manure with no PSB applied reduced thousand grains weight (**Figure 4**). The results from the same study [11] indicated that delayed physiological maturity (104 days) was recorded with the application of poultry manure along with PSB inoculation, while early days to physiological maturity (101 days) was observed with the application of cattle manure along with PSB inoculation. The P × PSB interaction indicated that the highest thousand grains weight was observed in plots under poultry manure along with 160 kg P ha⁻¹, and plots received cattle manure with 40 kg P ha⁻¹ resulted in lowest thousand grains weight (**Figure 5**). Interaction among AM × PSB × P showed that the highest thousand grains weight was recorded in plots under poultry manure + 160 kg P ha⁻¹ + PSB (**Figure 6**). Plots having cattle manure + 40 kg P ha⁻¹ without PSB application reduced thousand grains weight to minimum (**Figure 6**).

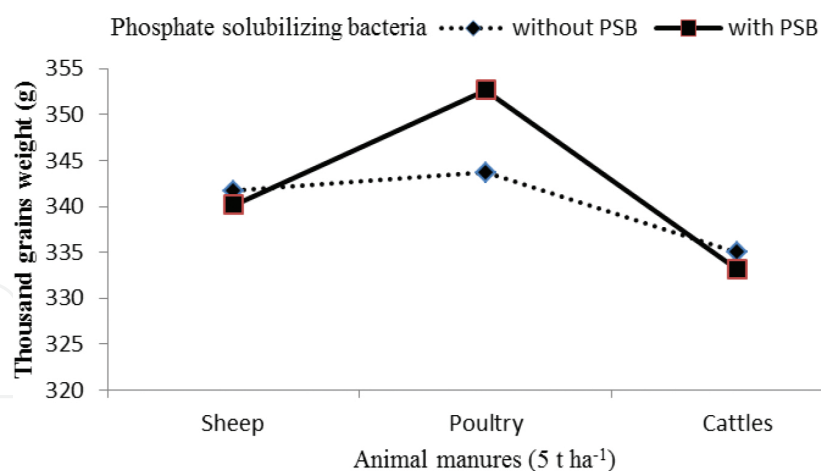


Figure 4. Response of 1000 grains weight (g) in hybrid maize to animal manures and phosphate-solubilizing bacteria interaction (AM \times PSB).

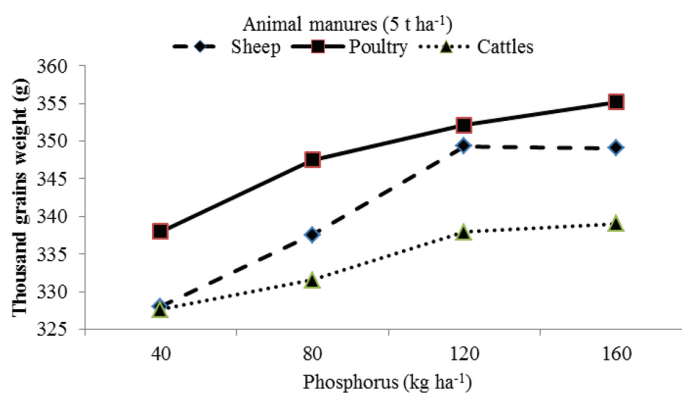


Figure 5. Response of 1000 grains weight (g) in hybrid maize to animal manures and phosphorus interaction (AM \times P).

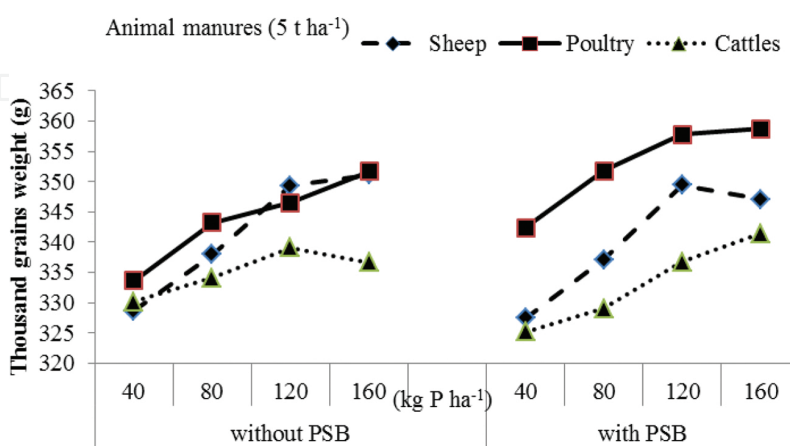


Figure 6. Response of 1000 grains weight (g) in hybrid maize to animal manures, phosphate-solubilizing bacteria and phosphorus interaction (AM \times PSB \times P).

Amanullah and Khan [10] reported that the interaction between P levels and PSB ($P \times PSB$) had significant effect on number of grains per row and grain yield. They found that the two higher P levels (75 and 100 kg P ha⁻¹) had produced significantly more number of grains per row in maize grown under both with (+) and without PSB (–) treated plots [10]. The two higher P levels (75 and 100 kg P ha⁻¹) had produced significantly higher grain yield than the two lower levels of P (25 and 50 Kg P ha⁻¹) in the plots treated with (+) and plots, where PSB was not applied [10]. Many researchers [26, 67, 68] also suggested that the seed inoculation with PSB along with the application of soluble phosphatic fertilizer decreases P fixation on calcareous, thereby increasing P use efficiency and grain yield.

Shelling percentage was also significantly affected by the interaction between AM \times PSB and AM \times P (**Table 4**). Interaction between AM \times PSB indicated that the application of poultry manure with PSB increased while the application of sheep manure without PSB decreased shelling percentage in maize (**Figure 7**). Interaction between AM \times P indicated that the highest shelling percentage was calculated with poultry manure + 120 kg P ha⁻¹, and the lowest shelling percentage was calculated for the combination of sheep manure + 40 kg P ha⁻¹ (**Figure 8**). Increase in yield and yield components of maize was reported earlier by Cheema et al. [69], Zafar et al. [70], Khan et al. [71], and Iqbal et al. [39] with integrated application of organic and inorganic fertilizers under semiarid climates. Amanullah and Stewart [72] found that wheat and rye responded differently in growth under different soil types. Both crops had better performance in terms of higher leaf area per plant, leaf area expansion rate, specific leaf area, leaf area ratio, plant height, stem elongation rate, root length, number of roots per plant, number of tillers per plant, absolute growth rate, and crop growth rate under organic soils as compared with inorganic soils at different growth stages [72]. Recently Amanullah and Khan [10] reported that integrated use of inorganic P fertilizer at higher rates + organic matter (in the form of compost) along with the seed inoculation with PSB significantly increases grain yield and yield components of maize under the semiarid climate of Peshawar Valley. Organic agriculture is important for the improvement of the environmental conditions and human health [73, 74].

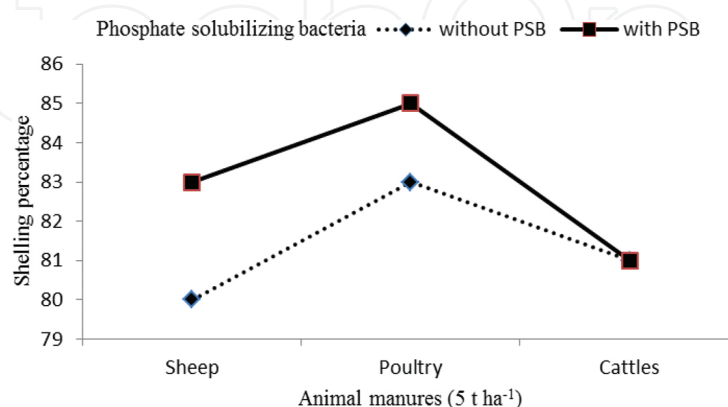


Figure 7. Response of shelling (%) in hybrid maize to animal manures and phosphate-solubilizing bacteria interaction (AM \times PSB).

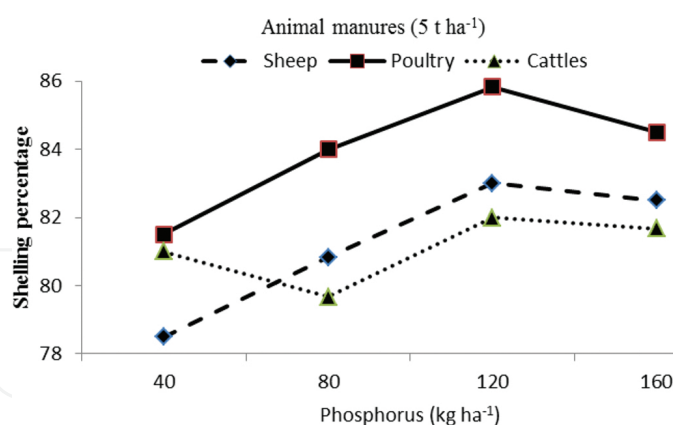


Figure 8. Response of shelling (%) in hybrid maize to animal manures and phosphorus interaction (AM × P).

4. Conclusions

Phosphorus unavailability and lack of organic matter in the soils in semiarid condition are the major reasons for low crop productivity. The results obtained from this field research work indicated that among the three AM used in the experiment (cattle manure, sheep manure, and poultry manure), poultry manure was found more beneficial in terms of better yield components (longer ear lengths, higher number of grains ear⁻¹, heavier grains) that resulted in higher grain yield, harvest index, and shelling. Among the four P levels (40, 80, 120, and 160 kg P₂O₅ ha⁻¹), application of P at the rate of 120 kg ha⁻¹ had increased the ear length, number of grains ear⁻¹, and shelling percentage. Application of P at the highest rate of 160 kg P ha⁻¹ increased grains weight, grain yield and harvest index. The plots treated with PSB (seed inoculation) had produced significantly higher yield and yield components of maize as compared with non-inoculated seeds. We concluded from these results that the integrated use of phosphorus (160 kg ha⁻¹) + poultry manure along with the seed inoculation with PSB could improve maize productivity under semiarid condition. Organic agriculture is also important for the improvement of the environmental conditions and human health.

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