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# Managing Phosphorus Availability from Organic and Inorganic Sources for Optimum Wheat Production in Calcareous Soils

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**Abstract:** In calcareous soils, wheat productivity is much lower due to improper nutrient management, especially phosphorus (P). Therefore, this study was conducted to manage P availability from various organic (Control, FYM and Sugar cane straw applied at the rate of 10 ton ha$^{-1}$) and inorganic (Control, 100% rock phosphate (RP), 50% acidulated RP, 100% acidulated RP, single super phosphate (SSP) and diammonium phosphate (DAP)) sources applied at the rate of 90 kg $P_2O_5$ ha$^{-1}$ in calcareous soil while using wheat as test crop. When averaged across the organic sources, SSP performed better in emergence m$^{-2}$ (126), tillers m$^{-2}$ (431), spikes m$^{-2}$ (419), grains spikes$^{-1}$ (61), plant height (95.1 cm), 1000-GW (40 g), biological yield (11,023 kg ha$^{-1}$), grain yield (4022 kg ha$^{-1}$), phosphorus use efficiency (10.5%), phosphorus in leaves at tillering (2.63 mg kg$^{-1}$) and anthesis stage (2.50 mg kg$^{-1}$), soil P at heading (1.73 mg kg$^{-1}$) and post-harvest stage (1.56 mg kg$^{-1}$) compared to the rest of the mineral sources. Similarly, among the organic sources, FYM performed better than others for all tested traits. Integration of inorganic P sources with organic manures further improved crop performance and post-harvest soil P content. Therefore, using 10 tons FYM ha$^{-1}$ in integration to SSP or 100% acidulated RP at the rate of 90 kg $P_2O_5$ ha$^{-1}$ is recommended for ensuring optimum wheat productivity under calcareous soils.

**Keywords:** acidulated RP; calcareous soils; phosphorus; rock phosphate; sugarcane straw

## 1. Introduction

Phosphorus is a very important and integral part of many enzymes such as ATPs, DNA, RNA and protein, which play a key role in energy transformation and biochemical reactions [1]. It hastens crop maturity and stimulates early growth and root development [2]. However, it is the second limiting nutrient, after nitrogen, in the world of agriculture crop management [3] due to high chemical bonding with soil colloidal surfaces [4]. The conversions of phosphorus through mineralization and immobilization processes alter the availability of P in topsoil and affect its supply to plants. According to different crop scientists, the average recovery of phosphorus from phosphate fertilizer is less than 45 percent in the first year of application [5]. It makes numerous kinds of fixations with others elements such as aluminum, iron and calcium and converts into an insoluble P compound [6], depending upon the soil pH.

About 80–95% of agricultural land in Pakistan is low in organic matter (<1%) and deficient in phosphorus, thus it needs P fertilizers for better crop production [7]. Additionally, the P applied to such soils becomes unavailable to the plant roots due to precipitation reactions with $Ca^{+2}$ and $Mg^{+2}$ due to the soils' calcareous nature. Rock phosphate (RP) might be used as a substitute for expensive synthetic P fertilizer to reduce the economic cost of fertilizers in farming for poor farmers who cannot afford commercially available P fertilizers [8]. However, its solubility is low in alkaline soil [9]. Acidulation of phosphorus rock could be a good strategy for enhancing its effectiveness in calcareous soils [9]. Organic sources such as farmyard manure and crop residue supply essential nutrients and improve soil health for better production [7], but it is not enough for fulfilling the nutritional requirements of high-yielding crops. Application of organic materials into the soil may also reduce P loss from the applied P fertilizers by preventing its runoff and leaching, thereby reducing the risk of water contamination [10].

Integrated application of organic and inorganic sources not only maintains P availability but also prevents its hazardous effects on the environment [11]. Wheat provides more protein than other crops; however, global challenges make it difficult to maintain its quantitative and qualitative production [12]. Although the total quantity of (P) in our soil may be high, it still does not fulfill crop nutritional requirements, because more than 80 percent of P is immobile in the soil and is unavailable to plants due to ionization, precipitation and immobilization [7]. Intensive cropping systems will meet the food requirements of the increasing population but they need or require more input in the form of different nutrients or energy, and therefore are responsible for environmental risks, and this also can be very costly [8]. Keeping in view crop phosphorus requirements and its availability in calcareous soil, this study was conducted to manage phosphorus availability by the integration of various organic and inorganic sources for optimum wheat production in calcareous soils under semi-arid climatic conditions.

## 2. Materials and Methods

### *2.1. Experimental Site and Timing*

A field experiment was conducted at Bacha Khan Agriculture Research Farm (BARF), Bacha Khan University, Charsadda (34.0704732, 72.3902938) Pakistan. The soil of the experimental site was alkaline (7.74), non-saline (0.22 dS $m^{-1}$) and calcareous (14.4%) in nature. The organic matter content (0.69%) and AB-DTPA extractable P (1.30 mg $kg^{-1}$) were low in the soil.

### *2.2. Experimental Material*

The rock phosphate (RP) containing 28% P was obtained from the Hazara rock phosphate source and its acidulation was carried out by mixing 1 kg RP with 0.6 L water and 0.5 L $H_2SO_4$ for 100% acidulation. The FYM was obtained from a local dairy farm, while the sugar cane straw was obtained from a nearby field.

### *2.3. Experimentation*

The research consisted of two factors including inorganic sources of phosphorus (Control, RPalone, 50% acidulated RP, 100% acidulated RP, SSP and DAP each applied at the rate of 90 kg $P_2O_5$ $ha^{-1}$) and organic amendments (control, FYM and sugar cane straw each applied at the rate of 10 ton $ha^{-1}$). Randomized Complete Block design (RCBD) with a split-plot layout having 3 replications was used, while inorganic sources were assigned to the main and organic sources to subplots. The Pirsabak-2013 variety of wheat was used as a trial crop. The recommended dose of nitrogen (split in two; half at sowing and half at tillering stage) and potassium was applied at the rate of 120 and 60 kg ha$^{-1}$ as urea and sulfate of potash (SOP), respectively. All other agronomic and cultural activities recommended for field experiments were equally maintained throughout the trail.

### 2.4. Laboratory Analyses

Soil pH and EC were measured by adopting the protocol described by [13,14], respectively. The soil samples were also analyzed for texture [15], lime [16] and AB-DTPA extractable P [17] at the heading and post-harvest stages. The collected plant samples were cleaned with distilled water and dried in oven at 60–70 °C for 48 h. After air drying, the samples were ground and stored in glass bottles. Phosphorus content in leaves was measured at tillering and anthesis stage by lambda, using the wet digestion technique [18]. Phosphorus use efficiency (PUE) was measured by the following formula:

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

### 2.5. Agronomic Data Collection

Spikes were counted in 4 central rows of every subplot and then changed into spikes m$^{-2}$. For recording data on grains spike$^{-1}$, ten spikes were selected randomly in each subplot threshed separately, and the number of grains of each spike was counted and then averaged. Plant height was measured by averaging the height of ten randomly selected plants from plant base to spike tip in each sub-plot. A total of 1000 grains weight was noted by weighing a thousand grains taken randomly from the grain lot of every subplot. The biological yield was collected by harvesting central 4 rows from each sub-plot, drying the air, weighing and then changing to kg ha$^{-1}$. For data concerning the grain yield, the harvested four-central rows in every sub-plot were threshed, cleaned, weighed and changed into kg ha$^{-1}$.

### 2.6. Statistical Analysis

The replicated data were run for analysis of variance (ANOVA) as appropriate for split-plot RCBD using statistical package Statistix8.1. The data were further subjected to the least significant difference (LSD) test at $\alpha$ = 0.05 where the F test was found significant [19].

## 3. Results

### 3.1. Spike m$^{-2}$, Grains Spike$^{-1}$ and Plant Height (cm) of Wheat

Data evidenced a considerable effect of organic and inorganic P practices on spikes m$^{-2}$ while their interaction effect was non-significant except for grains per spike (Table 1). FYM and sugar cane straw (Bagasse) produced significantly more (389 and 327) spikes m$^{-2}$, while fewer spikes (304) m$^{-2}$ were logged in the control plots. Regarding inorganic P application, a greater number of spikes m$^{-2}$ were noted with SSP (419), DAP (382) and 100% acidulated RP (351), followed by 50% acidulated RP (321) and RP alone (301), while minimum spikes m$^{-2}$ (267) were observed in the control plot.

A significant effect of organic, inorganic P and their interaction was noted in grains per spike (Table 1). Farmyard manure (57) and sugar cane straw (54) produced significantly higher grains spike$^{-1}$, while minimum grains spike$^{-1}$ (44) were noted in the control plots. Among the inorganic P practices, a greater number of 61, 58, and 55 grains spike$^{-1}$ were noted with SSP, DAP and 100% acidulated RP, respectively, followed by 50% acidulated RP (49) and RP alone (46), while the lowest were observed in the control. In the case of their combination SSP along with FYM, maximum (71) grains spike$^{-1}$ was given when compared to all possible interactions as presented in Figure 1.

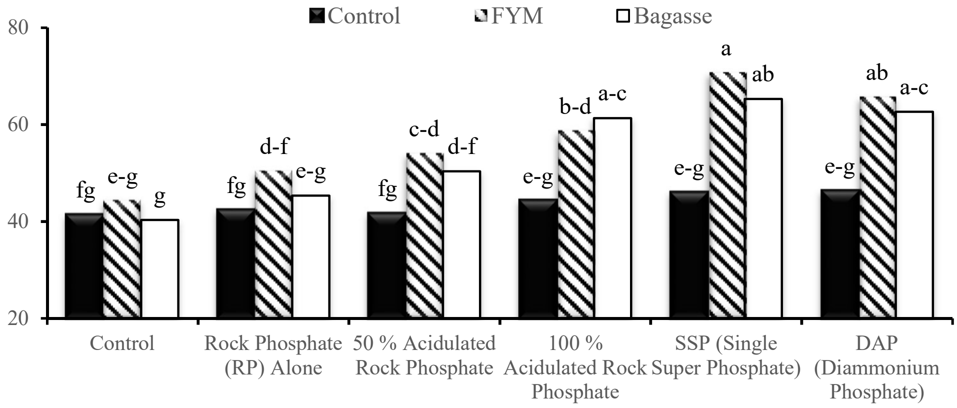


**Figure 1.** Grains spike$^{-1}$ of wheat as affected by the interaction of organic amendments and phosphorus sources. Bar chart with different letters is significantly different at α = 0.05. RP, SSP and DAP represent rock phosphate, single super phosphate and di-ammonium phosphate, respectively.

**Table 1.** Spike m$^{-2}$, grains spike$^{-1}$ and plant height (cm) of wheat as affected by organic and inorganic phosphorus management.

| Organic Amendments (10 t ha$^{-1}$) | Spike m$^{-2}$ | Grains Spike$^{-1}$ | Plant Height (cm) |
|---|---|---|---|
| Control | 304 c | 44 c | 90.2 b |
| FYM | 389 a | 57 a | 91.2 a |
| Bagasse | 327 b | 54 b | 82.0 c |
| LSD (α = 0.05) | 19.195 | 1.897 | 3.394 |
| **P Sources(90 kg ha$^{-1}$)** | | | |
| Control | 267 f | 42 f | 79.4 f |
| Rock Phosphate (RP) | 301 e | 46 e | 84.3 e |
| 50% Acidulated RP | 321 d | 49 d | 86.7 d |
| 100% Acidulated RP | 351 c | 55 c | 89.9 c |
| SSP | 419 a | 61 a | 91.5 a |
| DAP | 382 b | 58 b | 95.1 b |
| LSD (α = 0.05) | 21.622 | 4.209 | 3.754 |
| **Organic Amendments * P Sources** | | | |
| LSD (α = 0.05) | NS | 4.648 (Figure 1) | NS |

Means of the applicable group led by specific letter(s) are markedly different at 5% probability. FYM, SSP, DAP, LSD, * and NS stand for farmyard manure, single super phosphate, di-ammonium phosphate, least significant difference value, interaction, and non-significant interaction at α = 0.05, respectively.

The plant height (cm) of wheat was significantly impacted by organic and inorganic phosphorus, while their interaction effect was non-significant (Table 1). The tallest plants of 91.2 and 90.2 cm height were recorded in plots receiving FYM and sugar cane straw (Bagasse) as an organic P treatment, respectively, while the minimum plant height (82.0 cm) was observed under the control plot. Among inorganic P treatment, taller plants of height of 95.5, 91.1 and 89.9 cm were noted with the sole application of SSP, DAP and 100% acidulated RP, respectively, while in the remaining inorganic treatments including 50% acidulated RP, RP alone maintained plant height up to 86.7 and 84.3 cm, respectively. The minimum plant height (79.4 cm) was observed under the control inorganic P.

### 3.2. Thousand Grains Weight, Biological and Grain Yield (kg ha$^{-1}$) of Wheat

The analysis of variance confirmed that thousand grains weight varied significantly by organic and inorganic treatments of P, while their interaction was non-significant (Table 2). Maximum thousand grains weight (38.8 and 37.7 g) was noted with FYM and sugar cane straw (Bagasse) over the control (36.0 g)t. Between inorganic phosphorus treatment, maximum thousand grains weight (39.7, 39.2, 38.0 g) was noted with SSP, DAP and 100% acidulated RP, while 50% acidulated RP and RP alone produced 1000 grains with 37.1 and 36 g, respectively. The lighter grains were observed in the control plot.

**Table 2.** Thousand grains weight (g), grain and biological yield (kg $ha^{-1}$) of wheat as affected by organic and inorganic phosphorus management.

| Organic Amendments (10 t $ha^{-1}$) | Thousand Grains weight (g) | Biological Yield (kg $ha^{-1}$) | Grain Yield (kg $ha^{-1}$) |
|---|---|---|---|
| Control | 36.0 c | 8398.5 c | 3606.4 c |
| FYM | 38.8 a | 9981.1 a | 4058.0 a |
| Bagasse | 37.7 b | 9591.2 b | 3701.0 b |
| LSD (α = 0.05) | 1.516 | 309.269 | 154.945 |
| **P Sources(90 kg $ha^{-1}$)** | | | |
| Control | 34.9 f | 7812.7 f | 3533.8 f |
| Rock Phosphate (RP) | 36.0 e | 8509.4 e | 3661.8 e |
| 50% Acidulated RP | 37.1 d | 8996.6 d | 3777.0 d |
| 100% Acidulated RP | 38.0 c | 9485.3 c | 3819.3 c |
| SSP | 39.7 a | 11,022.9 a | 4021.9 a |
| DAP | 39.2 b | 10,114.8 b | 3917.1 b |
| LSD (α = 0.05) | 1.981 | 544.496 | 161.187 |
| **Organic Amendments * P sources** | | | |
| LSD (α = 0.05) | NS | NS | NS |

Means of the applicable group led by specific letter(s) are markedly different at 5% probability. FYM. SSP, DAP, LSD, * and NS stand for farmyard manure, single super phosphate, di-ammonium phosphate, least significant difference value, interaction and non-significant interaction at α = 0.05, respectively.

Similarly, variation in biological yield of the wheat crop was in response to organic and inorganic phosphorus, while interaction had no effect (Table 2). Farmyard manure (FYM) gave a maximum biological yield (9981.1 kg $ha^{-1}$), whereas the minimum (8398.5 kg $ha^{-1}$) was observed in the control plots. Among inorganic P treatments, the application of SSP and DAP produced maximum (11,022.9 and 10,114.8 kg $ha^{-1}$) biological yield in comparison to control (7812.7 kg $ha^{-1}$).

According to the statistical analysis, it was found that the application of both organic and inorganic sources significantly affects the grain yield of wheat, while their interaction effect was non-significant (Table 2). The maximum grain yield (4058.0 and 3701.0 kg $ha^{-1}$) was noted with the treatment of FYM and sugar cane straw (Bagasse), while the minimum (3606.4 kg $ha^{-1}$) was noted in the control plots. In the main plot treatments, the application of SSP and DAP maintained more grain yield (4021.9 and 3917.1 kg $ha^{-1}$) while the minimum (3533.8 kg $ha^{-1}$) was maintained in the control plots. This may be possibly due to the reduced pH surrounding the SSP that brought down the fixation of P with larger movement and accessibility of P from the SSP. Higher grain yield in the case of SSP over other sources of phosphatic fertilizer may be due to the additional number of SSP, which enhanced the accessibility of phosphorus to the plants.

### *3.3. Concentration of P (mg $kg^{-1}$) in the Wheat Leaves at Tillering and Anthesis Stage*

Phosphorus (P) content in wheat leaves was measured at the tillering and anthesis stage and for soil at the heading and post-harvest stages as presented in Table 3. The findings in (Figure 4) revealed considerable differences in P resulting from the interaction of various organic and inorganic P sources. Applying SSP resulted in optimum accumulation of P (2.635 mg $kg^{-1}$ tissue) at the tillering stage, while a reduced concentration (2.278 mg $kg^{-1}$ tissue) was identified in the control plots. In the case of RP treatments, the greater (2.502 mg $kg^{-1}$ tissue) was obtained in plots receiving 100% acidulated RP, while the minimum (2.461 and 2.356 mg $kg^{-1}$ tissue) was revealed in RP alone and 50% acidulated RP. In relation to organic P treatments, the application of FYM as a supplier of organic P provides maximum (2.530 mg $kg^{-1}$ tissue) P concentration in the leaves at the tillering stage, while minimum (2.423 g and 2.412 mg $kg^{-1}$ tissue) was recognized in the control and Bagasse treatments, with FYM and SSP treatments (2.756 mg of $kg^{-1}$ tissue) were indicated in the case of the highest possible combination.

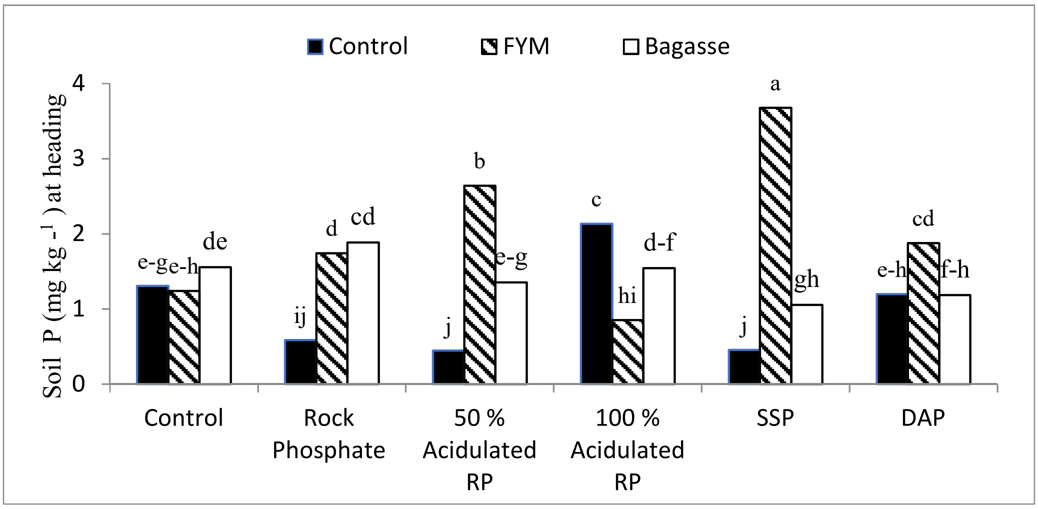


**Figure 2.** Interactive effect of organic amendments and phosphorus sources on soil P concentration at heading stage. Bar chart with different letters is significantly different at α = 0.05. RP, SSP and DAP represent rock phosphate, single super phosphate and di-ammonium phosphate, respectively.

**Table 3.** Effect of organic amendments and P sources on leaves (mg $g^{-1}$) and soil P (mg $kg^{-1}$) concentration at different growth stages.

| **Organic Amendments (10 t $ha^{-1}$)** | **Leaves P (mg $g^{-1}$)** | | **Soil P (mg $kg^{-1}$)** | |
|---|---|---|---|---|
| | **Tillering Stage** | **Anthesis Stage** | **Heading Stage** | **Post-Harvest** |
| Control | 2.423 b | 2.298 c | 1.021 c | 1.322 c |
| FYM | 2.530 a | 2.409 a | 2.006 a | 1.458 a |
| Bagasse | 2.412 b | 2.351 b | 1.430 b | 1.409 b |
| LSD (α = 0.05) | 0.0479 | 0.0315 | 0.0967 | 0.0433 |
| **P Sources(90 kg $ha^{-1}$)** | | | | |
| Control | 2.278 d | 2.165 d | 1.368 b | 1.204 e |
| Rock Phosphate (RP) | 2.356 c | 2.248 c | 1.406 b | 1.334 d |
| 50% Acidulated RP | 2.461 b | 2.384 b | 1.482 b | 1.392 cd |
| 100% Acidulated RP | 2.502 b | 2.405 b | 1.510 b | 1.477 b |
| SSP | 2.635 a | 2.499 a | 1.731 a | 1.559 a |
| DAP | 2.499 b | 2.416 b | 1.421 b | 1.412 c |
| LSD (α=0.05) | 0.0834 | 0.0549 | 0.1685 | 0.0754 |
| **Organic Amendments * P Sources** | | | | |
| LSD (α=0.05) | 0.1802 **(Figure 4)** | NS | 0.3638 **(Figure 2)** | 0.1628 **(Figure 3)** |

Means of the applicable group led by specific letter(s) are markedly different at 5% probability. FYM. SSP, DAP, LSD, * and NS stand for farmyard manure, single super phosphate, di-ammonium phosphate, least significant difference value, interaction and non-significant interaction at α = 0.05, respectively.

The wheat leaves were examined at the anthesis stage for the residual and direct influence of organic and inorganic P concentrations. Based on the statistical analysis of the data, there was a considerable variation in P concentration in the application of organic and inorganic P in wheat leaves during the anthesis stage (Table 3). For inorganic P, the application of SSP produced the maximum concentration of P (2.50 mg $kg^{-1}$ tissue) at the anthesis level, whereas the control plots observed the minimum concentration

(2.16 mg kg$^{-1}$ tissue). A greater concentration of (2.40 g kg$^{-1}$ tissue) of P was observed in plots receiving 100 percent acidulated RP treatments, while the minimum (2.38 and 2.25 mg kg$^{-1}$ tissue) was observed in 50 percent acidulated and sample RP. In relation to organic P treatments, the application of FYM as a supplier of organic P gives maximum (2.41 mg kg$^{-1}$ tissue) P content in the anthesis stage of the leaves, while the minimum (2.30 and 2.35 mg kg$^{-1}$ tissue) is noted in the control and Bagasse treatments.

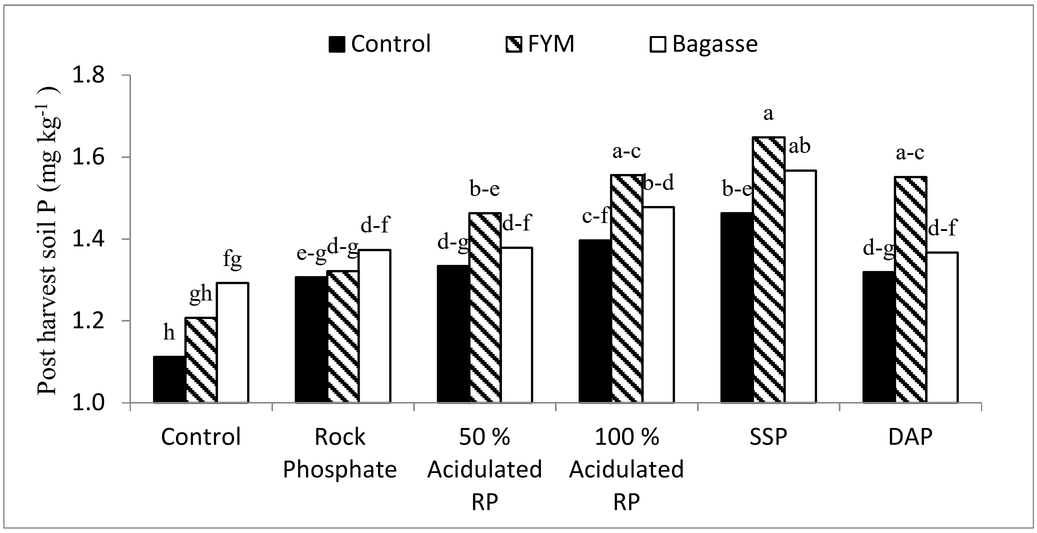


**Figure 3.** Post-harvest soil P as affected by the interaction of organic amendments and phosphorus sources. Bar chart with different letters is significantly different at α = 0.05. RP, SSP and DAP represent rock phosphate, single super phosphate and di-ammonium phosphate, respectively.

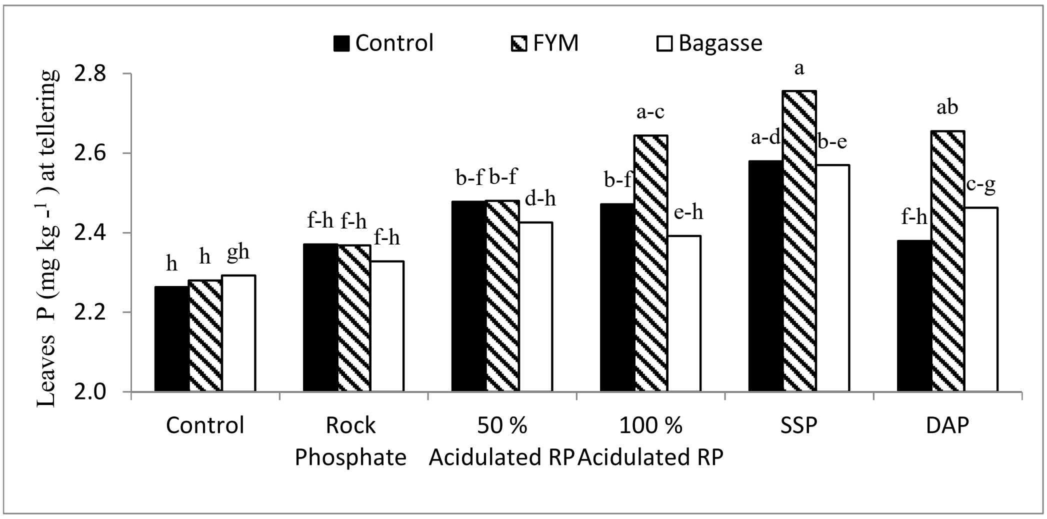


**Figure 4.** Interactive effect of organic amendments and phosphorus (P) sources on leaves P concentration at tillering stage. Bar chart with different letters is significantly different at α = 0.05. RP, SSP and DAP represent rock phosphate, single super phosphate and di-ammonium phosphate, respectively.

Results presented in Figure 2 showed a significant variation for soil P at the heading stage through organic, synthetic application and their interaction. Maximum (1.73 mg kg$^{-1}$) soil P was noted by SSP as a source of inorganic P as compared to the control plots (1.37 mg kg$^{-1}$). Regarding RP application, 100% acidulated RP gave maximum soil P (1.51 mg kg$^{-1}$) when compared to simple and 50% acidulated RP. In the case of organic phosphorus management, FYM gave the maximum (2.0 mg kg$^{-1}$) soil phosphorus over the control and Bagasse treatments, while in combination, the application of SSP with FYM was superior over other soil p treatments.

Data on soil phosphorus (P) at the post-harvest stage of wheat as affected by soil organic and inorganic phosphorus treatments are described in Figure 3. Data showed significant variation for soil P at the post-harvest stage in response to the application of organic, inorganic (Table 3) and their interaction. Maximum (1.56 mg $kg^{-1}$) soil P was noted in the plots received by the application of SSP as sources of inorganic p as a match to the control plots, which maintained (1.20 mg $kg^{-1}$). Regarding RP application, 100% acidulated RP gave maximum (1.48 mg $kg^{-1}$ over RP alone and 50% acidulated RP). In organic phosphorus management, FYM gave maximum (1.46 mg $kg^{-1}$) soil phosphorus over the control and Bagasse treatments, while in combination, the application of SSP with FYM was better over other treatments. This might be because P is long-term fertilizer that releases very slowly, so it remains in the soil.

### *3.4. Phosphorus Use Efficiency (PUE%)*

Phosphorus use efficiency (PUE) of wheat was significantly affected by organic, inorganic P, and their interaction is presented in Table 4. The maximum (9.0 and 7.8%) PUE was noted when FYM and sugar cane straw (Bagasse) was used as phosphorus management, while the minimum (5.9%) was maintained by the control plots. Regarding inorganic phosphorus management, higher PUEs of 10.5, 8.0 and 7.2% were observed in plots that received SSP, DAP and 100% acidulated RP as P fertilizers, respectively, while 50% acidulated and simple RP maintained 6.9 and 6.6 %PUE when compared to the control plots (6.3%). In the case of interaction, the combination of FYM and SSP maintained a good result and gave the maximum PUE (12.5%) as compared to other treatment combinations.

**Table 4.** Phosphorus use efficiency (%) of wheat as affected by organic and inorganic phosphorus management.

| **Phosphorus Sources (90 kg $ha^{-1}$)** | **Organic Amendments (10 t $ha^{-1}$)** | | | **Means** |
|---|---|---|---|---|
| | **Control** | **FYM** | **Bagasse** | |
| Control | 5.2 i | 7.2 gh | 6.6 h | 6.3 f |
| Rock Phosphate (RP) | 5.3 i | 7.6 fg | 6.9 gh | 6.6 e |
| 50% Acidulated RP | 5.4 i | 8.5 de | 6.8 h | 6.9 d |
| 100% Acidulated RP | 5.6 i | 8.8 cd | 7.2 gh | 7.2 c |
| SSP | 8.0 ef | 12.5 a | 10.9 b | 10.5 a |
| DAP | 5.8 i | 9.5 c | 8.6 de | 8.0 b |
| Means | 5.9 c | 9.0 a | 7.8 b | - |

LSD for organic amendments, P sources and their interaction are, 0.181, 0.250 and 0.433, respectively. Means of the applicable group led by specific letter(s) are markedly different at 5% probability. FYM. SSP, DAP and LSD stand for farmyard manure, single super phosphate, di-ammonium phosphate and least significant difference value, respectively.

## 4. Discussion

Our results of P concentration at various stages of crop growth were in line with the previous study by Naseer [20], who suggested that the maximum concentration of P in leaves at various growth stages of the crop was obtained by the supplementations of P as an SSP. Phosphorus becomes more radially available to the crop with the application of SSP as compared to RP and FYM [6]. The application of RP is not suitable for the improvement of P concentrations in calcareous soils. Mineral P provides nutrition for the early growth of sugarcane as compared to organic P [21]. Pongrac et al. [22] found that transport energy and food storage by crop leaf also depends on the concentration of P in leaves. Leaf and its chlorophyll content are structured by the phosphorus use efficiency [23].

The P uptake was positively enhanced by the supplementations of P as an SSP form as supported by Shrivastava et al. [24]. They concluded that the application of SSP gives the best result with respect to P when compared to RP, TSP and organic manures. It may be due to the improvement of available soil phosphorus and reduction in N loss from the soil with the application of SSP [25]. P transportation becomes limited at the crop maturity stage so it remains at the maximum amount in the soil profile [26]. Mineralization of RP and FYM is slow as compared to SSP because RP and FYM release P over a longer time [27].

The application of P mineral fertilizers in combination with organic fertilizers gives the best results regarding soil fertility and nutrient availability [28]. This could be attributed to the slow release of minerals from organic sources and it restricts the leaching of mineral nutrients from the soil [29]. High nutrient uptake was observed in the plots treated with both FYM and mineral fertilizers. Ghosh et al. [30] suggested that coating P fertilizer granules with layers of organic materials results in higher absorption and efficiency in the use of P compared with uncoated fertilizer [31]. Organic acids released during the decomposition process are good chelating agents for P and increase its availability from applied P fertilizers [32].

We observed that both soil P fertility and wheat productivity were significantly improved with the applications of different forms of mineral P fertilizers. The results are in accordance with [33] who reported that crop germination and its yield are mostly dependent on reserved food and P availability. Kaushal et al. [34] concluded the availability of nutrients is more rapid in mineral fertilizers as compared to organic sources, which influence seed germination [35]. These results are in agreement with [36], who stated that applications of phosphorus optimized the emergence $m^{-2}$. Our results are also confirmed by Blair et al. [37]. The application of FYM enhanced soil fertility, soil organic matter, and heightened microbial availability [38]. The application of organic matter such as poultry manure and farm yard manure showed a maximum number of tillers per meter squared, according to Patra et al. [39], which supports the findings of our research. Our results also match with Ahmad et al. [40]. Regarding inorganic P application, early (131 and 133) days to anthesis were noted with SSP and DAP treatment, while 135 days to anthesis were noted with 100% acidulated rock phosphate over the control. Khalil et al. [41] described that phosphorus fertilizers enhanced different stages of wheat growth. Our findings also agree with [42]. The same results have been reported by Ibrahim et al. [43] who stated that wheat growth and yield were significantly increased by P application. Regarding inorganic phosphorus application, SSP and DAP gave more spikes as compared to the remaining treatments. The same finding has previously been reported by Ottman et al. [44]. Both reported that the integrated approach of nutrients enhances different parameters of many crops. The same approach was discussed by [45], where among inorganic phosphorus treatments, a smaller number of non-productive tillers (12, 13, 14, 15 and 16) $m^{-2}$ were maintained by SSP, DAP, 100% acidulated RP and 50% acidulated RP; however, the application of RP alone had a lead over the control as well as all others, and (20) non-productive tillers $m^{-2}$ were maintained.

Our findings regarding the improvement in wheat grain yield in response to P application conform with that of Naing et al. [46]. They also observed improvement in rice grain yield by the integrated application of FYM with inorganic fertilizers. Adequate soil management with organic manure provides a long-lasting effect and slow release of minerals to the soil, which decreases the future cost of production and increases future crop output [47]. The agronomic parameters of the crop were significantly influenced by the application of organic manure [48]. Khalil et al. [41] described increased maturity with a greater amount of phosphorus. Similar findings have also been observed by [49]. These findings are in agreement with [50], who observed the positive influence of phosphorus sources on plant height and concluded that SSP as a source of phosphorus fertilizer performs better than others.

## 5. Conclusions

The application of 90 kg $P_2O_5$ $ha^{-1}$ as SSP or 100% acidulated rock phosphate, significantly improved wheat yield and P nutrition compared to other mineral sources including the control. When averaged across the mineral sources, the addition of 10 tons of FYM $ha^{-1}$ as an organic amendment performed better than sugarcane straw. The interactive effect of SSP or 100% acidulated RP with FYM showed better results as compared to all other possible interactions in terms of P nutrition, yield and yield components in wheat. Therefore, the application of SSP or 100% acidulated RP at the rate of 90 kg $P_2O_5$ $ha^{-1}$ along with 10 tons FYM $ha^{-1}$ can be recommended for obtaining optimum and quality production of wheat under calcareous soils in arid and semiarid regions. However, these findings should be further verified under diverse agro-climatic conditions in long-term field trials before formulating countrywide recommendations.

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