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Enhancing Growth and Yield of Wheat (*Triticum aestivum* L.) using Organic and Inorganic Phosphatic Fertilizers

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ABSTRACT

A pot experiment was conducted at the Nuclear Institute for Food and Agriculture (NIFA), Tarnab, Peshawar to increase the wheat (*Triticum aestivum* L.) growth and yield parameters by using different phosphatic fertilizers alone and in combination with organic source (FYM). Twelve treatments of inorganic and organic sources in sole or mixed ratios including control were applied in completely randomized design with three replications. Highly significant differences were noted for all the studied parameters except the harvest index. The soil used for the experiment was clay loam, alkaline in nature with lime content of 12.82% and low organic matter contents of 0.76%. The total nitrogen, extractable P and K were 0.13%, 2.89 mg kg⁻¹, and 88 mg kg⁻¹, respectively. Statistical analysis of the data showed that triple superphosphate (60 kg P) integrated with farm yard manure (5 t ha⁻¹) significantly enhanced the plant height (61.76 cm), number of tillers pot⁻¹ (13), spike length (6.81 cm), number of grains spike⁻¹ (73), thousand grains weight (40.67 g), grain yield (33.60 g pot⁻¹), and biological yield (69.50 g pot⁻¹) of wheat plants. Chemical analysis of the wheat plants showed the significant effect of combined use of TSP and FYM (5 t ha⁻¹) on plant P concentration in grains and straws, which was 0.50% and 0.17%, respectively. Whereas the maximum P uptake of 168.17 g pot⁻¹ and 62.84 g pot⁻¹ in grains and straws was recorded. It is suggested that the combined application of chemical fertilizers and organic manures could increase the growth and yield of crops under sustainable agriculture.

1. INTRODUCTION

Pakistan is located in the subtropical zone and its soils are generally phosphorus (P) deficient. The unavailability and fixation of P poses significant challenges in these soils [1][2]. It is a major nutrient for crops and an essential component for both animal and plant life. Phosphorus plays a crucial role in many

metabolic activities, including energy transfer through ATP and the synthesis of nucleic acids during biosynthesis [3]. The climatic conditions of the area along with soil type, water, and management of phosphatic fertilizer are important factors in optimizing crop yield [4]. Phosphorus is the second most essential macronutrient absorbed by plants after nitrogen [5]. The use of inorganic phosphatic fertilizers is widely acknowledged, as phosphorus plays a

vital role in crop production and plant growth [6]. However, various companies provide phosphorus fertilizers in different formulations that are essential for plant development. These inorganic phosphorus fertilizers applications including single super phosphate (SSP), diammonium phosphate (DAP), mono-ammonium phosphate (MAP), and nitrophos (NP). SSP and NP are produced locally, whereas DAP is imported from countries such as the USA, Jordan, and Morocco. Phosphorus fertilizers are more costly than nitrogen fertilizers in terms of application cost, achieving their maximum use efficiency requires careful and proper management [6].

High amounts of P minerals are found in rock phosphate (RP), which contains apatite. Hazara is famous for phosphorite deposits, a raw material source used for the production of phosphatic fertilizer. RP as a primary mineral source of P, serves as a raw material for phosphatic fertilizers that also contain industrial chemicals and additives for animals. It is estimated that nearly 90% of RP is used for fertilizer production and animal feed supplements [7][8]. It is a naturally occurring source of phosphorus that is applied to the soil. It contains rich amount of phosphate minerals but releases P extremely slowly, which limits its broad use as an easily available supply of P [9][10]. Previous studies have reported that the combined application of organic and inorganic P fertilizers showed better performance in terms of improving P availability and overall plant growth as compared to their sole application [11]. For instance, the efficiency of RP application was enhanced when coupled with P-solubilizing microbes, which improved the solubility of RP and availability of P. Bacteria and fungi have been used as P-solubilizing microbes; which produce different types of acids in their metabolic processes that facilitate the release of P from the RP [12]. Similarly, farmyard manure (FYM) is a decomposed mixture of livestock dung, urine, litter, and

remnants of consumed fodder. FYM consists of N (0.5–1.5%), P_2O_5 (0.2–0.4%), and K_2O (0.5–1.0%). It serves as a valuable source of organic carbon, promotes microbial activity and enhance the biodiversity of soil ecosystems, and improves water and nutrient holding capacity [13][14]. By adding nutrients to the soil, FYM application lowers the overall need for chemical fertilizers and increases the P availability. Organic materials application supports in microbial synthesis of polysaccharides by improving the soil structure [15]. Along with the availability of native soil nutrients, organic manure is also a rich source of plant nutrients and energy for microorganisms. In this regard, the integration of FYM with inorganic P fertilizers could be a promising strategy to improve the efficiency of P fertilizers in soils where P is deficient [16][17]. Integrated nutrient management strategies for P can maintain P availability and also reduce the adverse effects on the environment [2,18]. The organic matter or manure added to soil can improve the soil microbial activity and plays a key role in mineralization of organic P source. They also form chelates with other cations that are responsible for P fixation in the soil. This integration of organic and inorganic P sources can also facilitate slow release of P and maintain its availability for plants [18][19][20].

Pakistan cultivates wheat (*Triticum aestivum* L.), a self-pollinated plant that thrives under long-day conditions as a winter crop. It accounts for approximately 10.3% to the agriculture sector and 2.2% to GDP. Wheat is a staple grown crop worldwide, with top producers including Pakistan, USA, China, India, France, Australia, Argentina, and Canada [21]. It is the main source of nutrition for Pakistanis and provides over 50% of the calories and protein needed for a typical diet [22]. Although Pakistan has the potential for higher yields, its wheat yield per hectare remains lower than that of other major wheat-

producing countries (with approximately global average of 3.48 tons per hectare). Several factors contribute to this low yield, with one key reason being the inefficient use of phosphate fertilizers. Phosphorus is an essential nutrient required by plants in significant amounts to perform various biological processes (such as energy transfer through ATP, nucleic acid synthesis and photosynthesis). However, despite its critical role, plants often struggle to absorb sufficient phosphorus from the soil due to its low availability. This challenge is not unique to Pakistan, as phosphorus is among the least available nutrients in agricultural systems worldwide [23]. Therefore, this study aimed to measure the combined effect of synthetic P and organic fertilizers on the growth of wheat crop while considering the previously described roles of phosphorus and organic fertilizers in boosting crop development and productivity.

2. METHODOLOGY

2.1 Pot Experiment

A pot experiment was carried out at the Nuclear Institute of Food and Agriculture (NIFA), Tarnab, Peshawar, to evaluate the effectiveness of several phosphatic fertilizers on P uptake in wheat, using both organic and inorganic sources. The experiment was conducted in a greenhouse where the temperature was maintained between 25-30°C. A Complete Randomized Design (CRD) was used for the study, and it was repeated three times. The wheat genotype (NRL-1105) was seeded and four identical seedlings per pot were maintained after germination.

In the experiment, the following treatments were applied:

T₁ = Control

T₂ = Farmyard manure (5 t ha⁻¹)

T₃ = Farmyard manure (2.5 t ha⁻¹)

T₄ = Triple superphosphate (60 kg P ha⁻¹)

T₅ = Triple superphosphate (60 kg P ha⁻¹) + Farmyard manure (5 t ha⁻¹)

T₆ = Triple superphosphate (60 kg P ha⁻¹) + Farmyard manure (2.5 t ha⁻¹)

T₇ = Single superphosphate (60 kg P ha⁻¹)

T₈ = Single superphosphate (60 kg P ha⁻¹) + Farmyard Manure (5 t ha⁻¹)

T₉ = Single superphosphate (60 kg P ha⁻¹) + Farmyard Manure (2.5 t ha⁻¹)

T₁₀ = Rock phosphate (60 kg P ha⁻¹)

T₁₁ = Rock phosphate (60 kg P ha⁻¹) + Farmyard manure (5 t ha⁻¹)

T₁₂ = Rock phosphate (60 kg P ha⁻¹) + Farmyard manure (2.5 t ha⁻¹)

Potassium and nitrogen were applied to wheat at basal doses of 150 and 60 kg ha⁻¹, respectively. In control treatment, no fertilizer was applied. Clay pots measuring 45 cm in height and 30 cm in diameter were used, and 5 kg of the prepared soil was filled into each pot. The pots were lined with polythene bags to prevent leaching and contamination. Eight seeds of the wheat genotype (NRL-1105) were sown in each pot. RP, SSP, and TSP were used as inorganic phosphorus sources, and each applied at a rate of 60 kg ha⁻¹. FYM was applied as an organic fertilizer at the rate of 2.5 and 5 t ha⁻¹. Thinning was done, and four plants were grown in each pot. The pots were irrigated with distilled water at 50% of their water holding capacity according to the plants' requirement during the whole crop period. One plant from each pot was collected after 80 days of growth, whereas the remaining plants were harvested at maturity after 135 days of development. Recommended cultural practices were followed throughout the experiment. A composite soil sample (0-15 cm surface layer) was examined for physicochemical characteristics.

2.2 Physiological Parameters

The data were recorded based on the following specifications.

2.2.1 Height of Plant (cm) and Number of Tillers Pot⁻¹

The height of all wheat plants in each pot was measured in centimeters from the soil surface to the spike of the plant with measuring tape. The mean value was calculated for each pot. The tillers of each plant were counted in pots and their means were also calculated.

2.2.2 Spike Length (cm), Spike⁻¹ Number of Grains, and Thousand Grains Weight (g)

Five randomly selected plant spikes were measured from the base of spike to its tip in centimeters and average measurements were noted. To calculate the quantity of grains spike⁻¹, 5 spikes were randomly chosen from each pot, and their average (number of grains spike⁻¹) was calculated. While harvesting, the spikes of each pot were dried in sunlight and the weight of one thousand grains were measured using an electronic balance.

2.2.3 Biological Yield and Grain Yield (g pot⁻¹)

The plants from each pot were collected separately when fully grown, and the bundle was weighed after sun drying. The yield of grains was calculated after harvesting by threshing the plants in each pot. The total grain yield for each pot was weighed and averaged.

2.2.4 Harvest Index (%)

The harvest index was computed using the formula below:

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

2.2.5 P uptake in Grain and Straws

The following formula was used to calculate P uptake in grain and straw:

$$P \text{ uptake (\%)} = \frac{P \text{ concentration in treatment sample} \times \text{Grain Yield}}{100} \times 1000$$

Table 1. Effect of organic and inorganic phosphatic fertilizers on plant height and number of tillers per pot of wheat

Treatments	Plant height (cm)	No. of tillers pot ⁻¹
T ₁ = Control	51.37 e	7 f
T ₂ = FYM (5 t ha ⁻¹)	55.70 bcd	9 cde
T ₃ = FYM (2.5 t ha ⁻¹)	54.98 cde	8 def
T ₄ = TSP (60 kg P ha ⁻¹)	57.33 abc	10 c
T ₅ = TSP + FYM (5 t ha ⁻¹)	61.76 a	13a
T ₆ = TSP + FYM (2.5 t ha ⁻¹)	58.81 abc	10c
T ₇ = SSP (60 kg P ha ⁻¹)	56.53 abc	9cd
T ₈ = SSP + FYM (5 t ha ⁻¹)	60.98 ab	12 ab
T ₉ = SSP + FYM (2.5 t ha ⁻¹)	58.28 abc	10 bc
T ₁₀ = RP (60 kg P ha ⁻¹)	52.77 de	8 ef
T ₁₁ = RP + FYM (5 t ha ⁻¹)	59.34 abc	10 bc
T ₁₂ = RP + FYM (2.5 t ha ⁻¹)	54.40 cde	8 de
LSD at 0.05%	05.32	2.48

Using the LSD test, the means in the columns that are followed by the identical letters do not differ substantially at the 0.05% level of probability.

2.3 Statistical Analysis

The experimental data were analyzed by using analysis of variance technique in MSTAT-C software following Steel and Torrie [24]. The least significant difference (LSD) test was used to determine the differences between the treatments.

3. RESULTS

3.1 Height of Plant (cm)

The data on plant height as influenced by organic and inorganic sources are presented in Table 1. The results showed that each treatment differed significantly ($P \leq 0.05$) from the control. The maximum plant height (61.76 cm) was recorded in the treatment receiving TSP 60 kg P ha⁻¹ combined with 5 t FYM ha⁻¹, followed by the treatment where SSP at 60 kg P ha⁻¹ was mixed with the same quantity of FYM. The minimum plant height of 51.37 cm was recorded in the control. The increased plant height resulting from the combined application of TSP and FYM is likely due to the higher P availability and beneficial effects of FYM. Together, they enhanced the nutrient uptake, which in turn promoted greater crop vegetative growth. Murugan and Ramesh [25] reported that the plant height increased by the application of superphosphate with tri-calcium phosphate (1:3) coupled with phosphate solubilizing bacteria.

3.2 Number of Tillers Pot⁻¹

The amount of the tillers of wheat pot⁻¹ was significantly ($P \leq 0.05$) influenced by phosphorus and FYM application, as shown in Table 1. Analysis of variance indicated that the maximum number of tillers pot⁻¹ (13) was recorded with the combined application of TSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹), followed by the number of tillers pot⁻¹ (12) in the treatment where SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹) were applied, respectively. The minimum number of tillers pot⁻¹ (7) was recorded in the

control treatment. The reason for a greater number of tillers pot⁻¹ with P + FYM application might be due to the role of organic and inorganic sources of nutrients in vegetative plant growth and development. These results align with Hussain et al. [26], who reported that the combination application of phosphate and FYM applied improved plant development by increasing plant height, tiller number pot⁻¹, and wheat spike length.

3.3 Spike Length (cm)

Both organic (FYM) and inorganic (P) sources had a significant ($P \leq 0.05$) impact on spike length. According to the Table 2, the results indicated that maximum spike length (6.81 cm) was recorded by TSP (60 kg P ha⁻¹) combined with FYM (5 t ha⁻¹) utilization. However, this treatment value was statistically similar to spike length (6.71 cm) where SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹) were applied. Minimum spike length (5.14 cm) was noted during the control period. Reason for increased spike length may be the availability of sufficient nutrients to plants, which enhanced root growth and plant development. Similar findings were reported by Hussain et al. [26] showing that integrated application of synthetic P sources and organic fertilizers can increase plant growth, which results in ultimately taller plants, highest tillers and increased spike length of wheat.

3.4 Number of Grains Spike⁻¹

The data about number of grain spike⁻¹ (Table 2) was significantly ($P \leq 0.05$) influenced by utilization of fertilizer from both organic and inorganic sources. The average data values demonstrated that the highest number of grains spike⁻¹ (73) observed in the pots where TSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹) were applied together, followed by the treatment (67) where SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹) were applied. In the control treatment, minimum number of grains spike⁻¹ (33) was recorded. The higher number of grains spike⁻¹ may be due

Table 2. Influence of organic and inorganic phosphatic fertilizers on spike length and number of grains per spike of wheat

Treatments	Spike length (cm)	No. of grains spike ⁻¹
T ₁ = Control	5.14 c	33 g
T ₂ = FYM (5 t ha ⁻¹)	5.99 abc	53 def
T ₃ = FYM (2.5 t ha ⁻¹)	5.78 bc	53 ef
T ₄ = TSP (60 kg P ha ⁻¹)	5.98 abc	59 cde
T ₅ = TSP + FYM (5 t ha ⁻¹)	6.81 a	73 a
T ₆ = TSP + FYM (2.5 t ha ⁻¹)	6.24 ab	63 bc
T ₇ = SSP (60 kg P ha ⁻¹)	5.97 abc	57 cde
T ₈ = SSP + FYM (5 t ha ⁻¹)	6.71 a	67 ab
T ₉ = SSP + FYM (2.5 t ha ⁻¹)	6.39 ab	61 bcd
T ₁₀ = RP (60 kg P ha ⁻¹)	5.66 bc	48 f
T ₁₁ = RP + FYM (5 t ha ⁻¹)	6.08 ab	59 cde
T ₁₂ = RP + FYM (2.5 t ha ⁻¹)	6.26 ab	56 cde
LSD at 0.05%	0.88	7.63

Using the LSD test, the means in the columns that are followed by the identical letters do not differ substantially at the 0.05% level of probability.

to the P + FYM application. Phosphorus plays a vital role in the production of heavier and greater number of grains spike⁻¹. Similar results were reported by Sial et al. [27], who found that applying phosphorus and bacteria simultaneously increased the number of grains spike⁻¹. According to Ahmad et al. [28], combine application of chemical fertilizer with compost can be more advantageous than applying commercial fertilizer alone.

3.5 Thousand Grains Weight (g)

Table 3 shows the results obtained on thousand grain weight (g) as influenced by organic and inorganic P sources. The maximum thousand grain weight (40.67 g) was calculated by the pots treated with a combined application of TSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹). This weight was statistically similar to the grain weight (38.46 g) which was recorded in pots that received SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹) (Table 3). A minimum 1000 grain weight (19.70 g) was recorded in the control treatments. The increase in 1000 grain weight might result from the use of inorganic and organic P sources, which increase nutrients in

soil, and their availability to plant roots which improve the plant growth, height, and healthy grains. A similar study by Samad et al. [29] stated that the combined application of P + FYM produced healthy plants with heavier grain weight.

3.6 Grain Yield (g pot⁻¹)

The values showing the effects of inorganic and organic fertilizers on grain yield are given in Table 3. Analysis of variance showed that the maximum grain yield (33.60 g pot⁻¹) was observed in the pots treated with TSP (60 kg P ha⁻¹) in combination with FYM (5 t ha⁻¹), followed by the grain yield (31.83 g pot⁻¹) produced by the pots given SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹). However, a minimum grain yield (14.83 g pot⁻¹) was recorded in the control. All the treatments applied showed a significant increase compared to the control. The release of nutrients, particularly P, following the combined application of inorganic and organic fertilizers may be linked to an increase in grain production. According to Waheed et al. [30], applying phosphatic fertilizers in combination with FYM improved

Table 3. Influence of organic and inorganic phosphatic fertilizers on thousand grain weight and grain yield of wheat

Treatments	1000 grain weight (g pot ⁻¹)	Grain yield (g pot ⁻¹)
T ₁ = Control	19.70 f	14.83 f
T ₂ = FYM (5 t ha ⁻¹)	33.60 b	25.13 cde
T ₃ = FYM (2.5 t ha ⁻¹)	30.00 de	24.37 de
T ₄ = TSP (60 kg P ha ⁻¹)	34.10 b	27.37 bcd
T ₅ = TSP + FYM (5 t ha ⁻¹)	40.67 a	33.60 a
T ₆ = TSP + FYM (2.5 t ha ⁻¹)	34.53 b	25.23 cd
T ₇ = SSP (60 kg P ha ⁻¹)	30.46 cde	25.23 cd
T ₈ = SSP + FYM (5 t ha ⁻¹)	38.47 a	31.83 a
T ₉ = SSP + FYM (2.5 t ha ⁻¹)	32.66 bcd	27.83 bc
T ₁₀ = RP (60 kg P ha ⁻¹)	28.66 e	21.86 e
T ₁₁ = RP + FYM (5 t ha ⁻¹)	35.00 b	27.03 cd
T ₁₂ = RP + FYM (2.5 t ha ⁻¹)	19.70 f	25.47 cd
LSD at 0.05%	2.69	3.29

Using the LSD test, the means in the columns that are followed by the identical letters do not differ substantially at the 0.05% level of probability.

wheat growth, grain weight, and production. Higher grain yields and qualities were also reported by Nanwal and Kumar [31], when inorganic fertilizers, FYM, and vermicompost were applied together. Other studies have also reported that high crop yield was obtained after organic amendments [32][33].

3.7 Biological Yield (g pot⁻¹)

Statistical analysis of the data revealed that the maximum biological yield (69.50 g pot⁻¹) was obtained from the pots receiving a combined application of TSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹), followed by 65.33 g pot⁻¹ in pots treated with SSP (60 kg P ha⁻¹) and FYM (5 t ha⁻¹). However, the lowest biological yield (31.77 g pot⁻¹) was noted in the control treatment (Table 4). This increase in biological yield is likely due to the high accumulation of P and other nutrients by the plants for their optimum growth and grain yield. The combined use of organic and inorganic fertilizers allows the release of necessary P and other nutrients by offering adequate nutrients to improve the growth and development of wheat crop. Samad et al. [29] reported similar findings that

combined application of P and FYM enhance the biological yield of wheat. According to Shah et al. [34], the best way to achieve sustainable production is to combine organic sources with mineral N and P fertilizers. Dawar et al. [35] also reported increased wheat yield after integration of FYM with synthetic fertilizers. However, in another study, minimal or no improvement in yield was reported after organic amendment [36].

3.8 Harvest Index (%)

The application of organic and inorganic fertilizers influenced the harvest index as shown in Table 4. The harvest index among all the treatments was non-significant. The data show a maximum harvest index (49.86%), which was observed with the combined application of single superphosphate (60 kg P) and FYM (2.5 t ha⁻¹). Subsequently, TSP (60 kg P ha⁻¹) and FYM (2.5 t ha⁻¹) were combinely applied to achieve the maximum harvest index (49.12%) in the treatment. In the meanwhile, a minimum harvest index (46.45%) was recorded in controlled pots.

Table 4. Influence of organic and inorganic phosphatic fertilizers on biological yield and harvest index of wheat

Treatments	Biological yield (g pot ⁻¹)	Harvest index (%)
T ₁ = Control	31.77 f	46.45
T ₂ = FYM (5 t ha ⁻¹)	54.00 d	46.55
T ₃ = FYM (2.5 t ha ⁻¹)	51.33 d	47.41
T ₄ = TSP (60 kg P ha ⁻¹)	56.50 cd	48.38
T ₅ = TSP + FYM (5 t ha ⁻¹)	69.50 a	48.34
T ₆ = TSP + FYM (2.5 t ha ⁻¹)	61.93 bc	49.12
T ₇ = SSP (60 kg P ha ⁻¹)	53.76 d	46.95
T ₈ = SSP + FYM (5 t ha ⁻¹)	65.33 ab	48.67
T ₉ = SSP + FYM (2.5 t ha ⁻¹)	55.93 d	49.86
T ₁₀ = RP (60 kg P ha ⁻¹)	45.33 e	48.27
T ₁₁ = RP + FYM (5 t ha ⁻¹)	55.33 d	48.86
T ₁₂ = RP + FYM (2.5 t ha ⁻¹)	52.66 d	48.35
LSD at 0.05%	5.91	NS

Using the LSD test, the means in the columns that are followed by the identical letters do not differ substantially at the 0.05% level of probability.

3.9 P Concentration in Grain and Straw

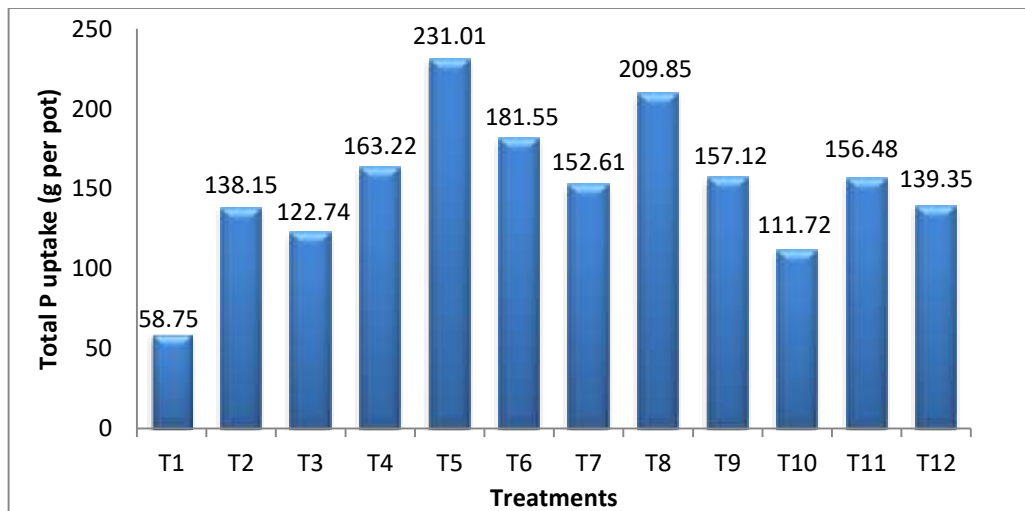
The use of both organic and inorganic P greatly increased the P concentration in grain ($P \leq 0.05$) (Table 5). The results showed that the highest average grain P concentration, 0.50% was observed with the application of TSP (60 kg P ha⁻¹) combined with FYM (5 t ha⁻¹), while lightly a lower concentration of 0.48% was recorded when SSP (60 kg P ha⁻¹) was applied with the same rate of FYM. In contrast, the control treatment showed minimum P content in grain (0.29%). A similar study conducted by Hossain and Sattar [37] found that the addition of phosphate-solubilizing bacteria to the soil with inorganic phosphorus improved the content of nutrients in wheat. According to Thakur et al. [38], mycorrhiza and phosphorus combinely enhanced P uptake and concentration in wheat plants. A previous study also reported higher yield when organic manure was applied with synthetic P fertilizers [33]. P concentration in straw increased significantly ($P \leq 0.05$) with organic and inorganic P fertilizers (Table 5). The results revealed that the highest P concentration (0.17%) was noted in pots treated with TSP (60

kg P ha⁻¹) and FYM (5 t ha⁻¹), followed by 0.16% in the pots treated with SSP alone (60 kg P ha⁻¹) or in combination with FYM (5 t ha⁻¹). However, the minimum P concentration (0.09%) was recorded in control pots. The increase in straw P concentration could be due to the application of P fertilizers, which improved the plant root growth and nutrient uptake from the soil. The results are in line with a previous study which showed that combined application of soil amendments improved maize productivity and P uptake [39]. Shah et al. [40] also confirmed that the integrating FYM with mineral fertilizers significantly enhanced P concentration and uptake by wheat, ultimately improving plant root growth. When the FYM is integrated with TSP, SSP and RP, it can further improve the labile-P pool in soil. The possible mechanism is that, upon decomposition, FYM releases organic acids which lower the soil pH by promoting the slow release of P to soil and enhancing its availability to plants. The addition of FYM to soils may improve their organic matter content, physical, chemical, and biological properties [18][19][20].

Table 5. Effect of organic and inorganic phosphatic fertilizers sources on P concentration and uptake in wheat grains and straw

Treatments	% P in grains	% P in straws	P uptake by grains (g pot ⁻¹)	P uptake by straws (g pot ⁻¹)
T ₁ = Control	0.29 f	0.09 e	43.12 g	15.63 f
T ₂ = FYM (5 t ha ⁻¹)	0.39 de	0.14 bcd	98.55 def	39.60 cde
T ₃ = FYM (2.5 t ha ⁻¹)	0.36 e	0.12 de	89.46 ef	33.28 de
T ₄ = TSP (60 kg P ha ⁻¹)	0.43 cd	0.16 abc	116.48 cd	46.74 bc
T ₅ = TSP + FYM (5 t ha ⁻¹)	0.50 a	0.17 a	168.17 a	62.84 a
T ₆ = TSP + FYM (2.5 t ha ⁻¹)	0.44 bc	0.15 abcd	134.41 bc	47.14 bc
T ₇ = SSP (60 kg P ha ⁻¹)	0.43 cd	0.16 abc	107.56 de	45.05 bc
T ₈ = SSP + FYM (5 t ha ⁻¹)	0.48 ab	0.16 ab	154.03 ab	55.82 ab
T ₉ = SSP + FYM (2.5 t ha ⁻¹)	0.41 cde	0.15 abcd	113.79 cd	43.33 cd
T ₁₀ = RP (60 kg P ha ⁻¹)	0.36 e	0.13 cd	80.33 f	31.39 e
T ₁₁ = RP + FYM (5 t ha ⁻¹)	0.42 cd	0.15 abcd	112.55 d	43.93 cd
T ₁₂ = RP + FYM (2.5 t ha ⁻¹)	0.39 de	0.15 abcd	99.31 def	40.04 cde
LSD at 0.05%	0.04	0.032	20.64	10.85

The LSD test indicates that, at the 0.05% probability level, the means in the columns that are followed by the same letters do not differ significantly.

**Figure 1.** Effect of organic and inorganic phosphatic fertilizers on total phosphorus uptake by wheat crop

3.10 Total P Uptake

Figure 1 shows that the use of both organic and inorganic phosphorus fertilizers significantly influenced total P uptake in wheat plants ($P \leq 0.05$). The statistical analysis revealed that the

highest P uptake (231.01 g pot⁻¹) was recorded in pots treated with TSP (60 kg P ha⁻¹) + FYM (5 t ha⁻¹). This was followed by a total uptake of 209.85 g pot⁻¹ in pots treated with SSP (60 kg P ha⁻¹) + FYM (5 t ha⁻¹). In contrast, the minimum P uptake (58.74 g pot⁻¹) was

observed in the control pots. The highest P uptake by wheat plants can be attributed to crop improvements that enhanced nutrient uptake in grains and straw, leading to better growth and higher yields. These results are similar to the Hossain and Sattar [37], who revealed that the phosphorus application with some P-solubilizing bacteria enhanced the soil P availability and its uptake by wheat. The findings of current study are in accordance with previous studies [2,18,32,33], which also reported that the combined application of inorganic and organic P sources enhances P availability, improves P uptake, better growth, and yield of crops.

4. STUDY LIMITATIONS

Although this study provides some insights into the impacts of organic and inorganic P fertilizers sources on wheat growth and P dynamics, however, it has certain limitations. This study was conducted in a pot experiment under controlled conditions which may not fully represent the field conditions such as soil structure, climatic conditions, and root development etc. Another limitation of this study is that it used only one wheat genotype (NRL-1105), which may restrict the generalization of its results to other varieties of wheat that may respond differently to inorganic and organic P fertilizers treatments and combinations. Additionally, this study showed the short-term effects of P fertilizers sources on wheat growth and didn't evaluate the longterm effects on residual P and microbial dynamics.

5. CONCLUSION

Based on the findings of this study, it can be concluded that applying phosphatic fertilizers in combination with organic sources significantly benefits crop growth, yield, and phosphorus use efficiency. The use of TSP and SSP at the rate of 60 kg P ha⁻¹ combined with 5 t FYM ha⁻¹ significantly enhanced crop growth,

yield, and total P uptake. Further research is recommended to confirm the findings of this study under diverse agro-climatic conditions. Different combinations of inorganic fertilizers (SSP, TSP, and RP) and organic fertilizer (FYM) should be applied to explore multiple wheat cultivars and to optimize wheat productivity.

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Author's Contribution

Fazal-e-Rabi, Nasrullah: Conceptualization, Supervision, Methodology, Data curation, Writing – original draft, Writing –review & editing.

Quratulain Hanif, Muhammad Izhar Shafi, Parvez Khan: Writing –review & editing, Visualization, Formal analysis.

Zia Ullah: Software, Validation, Writing –review & editing.

Tufail Shah: Formal analysis, Resources, Writing –review & editing, Funding acquisition.

Conflict of Interest

The authors show no conflict of interest.

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