

Article

Effects of Farmyard Manure and Different Phosphorus Inorganic Fertilizer Application Rates on Wheat Cultivation in Phosphorus-Deficient Soil

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Abstract: Less phosphorus (P) availability in calcareous alkaline soils is one of the major problems in achieving an optimum crop yield. Its deficiency in plants adversely affects growth and yield attributes. To overcome this issue, growers incorporate inorganic P fertilizers. However, the need for time in the sustainable management of soil fertility in terms of P. Farmyard manure (FYM) application is one of the most popular organic amendments in this regard. Thus, the current study was conducted to explore the best application rate of FYM in combination with inorganic P fertilizer single super phosphate (SSP). There were six treatments i.e., control (0F), 100%SSP (100P), 25% FYM and 75% SSP (25F+75P), 50% FYM and 50% SSP (50F+50P), 75% FYM and 25% SSP (75F+25P), and 100% FYM (100F+0P), applied in three replications. The design of the experiment was a randomized complete block design. For assessment of treatment response, two wheat cultivars (V1 = Pirsabak and V2 = Atta Habib) were used. Results showed that the application of 50F+50P significantly improved the plant height (20.69 and 32.01%), spike/m² (35.19 and 30.10%), grain (41.10 and 38.16%), and leaf P (49.82 and 71.32%) compared to control in V1 and V2, respectively. A significant improvement in the grain and the biological yield of wheat V2 also validated the efficacious functioning of 50F+50P over control. In conclusion, 50F+50P has the potential to enhance wheat growth and nutrient concentration over control. More investigations are required for a more precise and balanced synchronization of FYM and SSP for the achievement of maximum wheat yield.

Keywords: organic fertilizers; inorganic fertilizers; growth attributes; yield attributes; nutrients concentration; wheat

1. Introduction

Wheat (*Triticum aestivum* L.) is a cereal grain crop from the Poaceae family. It is used as a primary source of food all over the world [1]. As a king of grain crops, wheat is an excellent source of carbs and proteins. A wider range of adaptability in both irrigated and Barani environments makes it most suitable for cultivation in a variety of agricultural climatic zones [2]. Thus, it shares 70% of total cereals and around 36% of cultivated land [3]. However, poor soil fertility status played a notorious role in decreasing wheat yield.

Among different essential nutrients, the deficiency of phosphorus in alkaline soils is one of the major concerns [4]. It has been observed that more than 90% of calcareous nature soils are deficient in phosphorus [5]. Most wheat harvests produced on P-deficient soil in this manner had modest yields. Phosphorus is frequently a crop-limiting supplement, particularly in calcareous soils when phosphorus is severely restricted and in large part unavailable to plant uptake [6]. Phosphorus makes up about 0.2 to 0.4% of a plant's dry weight. It is a structural component of the membrane system of the cell, the chloroplast, and the mitochondria [7]. Phosphorus plays an important role in the formation of energy-rich phosphate, i.e., adenosine triphosphate (ATP), and also controls the metabolic pathway of nucleic acids [8]. However, its deficiency not only adversely affects the morphological growth attributes of wheat but also caused a significant decline in the yield attributes [9].

Organic and inorganic fertilizers are used primarily to increase nutrient availability to plants [9–15]; however, they can also affect the population, composition, and function of soil micro-organisms [16]. The balanced fertilization with major elements (N, P, and K) for plant supply proved beneficial for the growth of roots and shoots of the crop. As the available P fraction includes available inorganic H_2PO_4 and HPO_4 , inorganic P in the soil can be replenished by adding P fertilizers to the soil and increasing the amount of available P in the soil. Applied phosphorous fertilizers are taken up and utilized by plants [17]. The apparent phosphorus use efficiency (PUE) in wheat is only about 5–10% in the year of application, and most of the applied is fixed in the soil or lost through gaseous plant emission and leaching. The next crop utilizes up to 25% of the previously used P [17].

On the other hand, organic material as a fertilizer can also enhance soil, nutrient availability, porosity, moisture in the soil, and water retention in the same way [18]. While carbon additions can give nutrition to plants, nutritional change via organic substances degradation competes substantially with plant nutrient uptake, leading to nutrient conflict among soil microbes and plants [19]. Furthermore, these systems are advantageous to the agro-general ecosystem's health [20]. Soil biodiversity and quality are improved by the creation and implementation of effective fertilization strategies, such as modifying the quantity and type of organic amendments [21].

Therefore, keeping in mind the importance of both organic and inorganic fertilizers, the current experiment was conducted to synchronize the application rate of phosphorus fertilizer with farmyard manure (FYM). The aim of the study was the selection of the best combination for single super phosphate (SSP) and farmyard manure application for the achievement of an optimum wheat yield.

2. Materials and Methods

2.1. Experimental Site and Design

The experiment was conducted at the research farm of The University of Agriculture, Peshawar, Pakistan, during the winter of 2020–2021. To conduct the above research experiment of a randomized complete block design (RCBD), two factorial arrangements were used in the experiment with three replications.

2.2. Soil Characteristics

From each plot, 3 soil samples were collected for the pre-experimental soil characterization. After that, a composite sample was made by mixing all the samples so that a true representative sample for soil characterization could be achieved. Standard testing

protocols were adopted for the analysis of soil samples. The characteristics and references of analysis protocols are provided in Table 1.

Table 1. Pre-experimental soil and water characteristics.

Soil			Analysis Methods References	Water			Analysis Methods References
Attributes	Units	Values		Attributes	Units	Values	
Sand	%	30.3		pH	-	6.02	
Silt	%	64.2	[22]	TSS	ppm	567	
Clay	%	5.5		Carbonates		0	[23]
Texture	Silt Loam			Bicarbonates	meq./L	5.34	
pHs	-	8.01	[24]	Chloride		0.45	
ECe	dS/m	2.54	[25]	Ca+Mg		4.21	
Organic matter	%	0.35	[26]				
Total N	%	0.0175	[27]				
Available P	mg/kg	2.34	[28]				
Extractable K	mg/kg	89	[29]				

ECe = electrical conductivity of extract. TSS = total soluble salts.

2.3. Treatment Plan

The treatments in this experiment were combinations of farmyard manure and SSP given to the crop varieties from both sources @ 120 kg of P₂O₅ ha⁻¹. Farmyard manure was first analyzed in the laboratory for N, P, and K, and, after analysis, treatments were given to the field for 120 kg P₂O₅ from FYM and SSP. The P concentration in FYM was 0.2% and calculation was carried out based on this value. The attributes of FYM include: C:N = 20:1, cation exchange capacity = 62 cmol_c/100g, and organic matter = 25%. There were 6 treatments including control (0F), 100%SSP (100P), 25% FYM and 75% SSP (25F+75P), 50% FYM and 50% SSP (50F+50P), 75% FYM and 25% SSP (75F+25P), and 100% FYM (100F+0P).

2.4. Fertilizer Application

The field was supplied with the recommended nitrogen and potassium @ 120 kg of N and 60 kg of K ha⁻¹. Sowing cultured practices were adopted for the whole season.

2.5. Wheat Varieties and Sowing Methods

Two varieties of wheat, i.e., Pirsabak and Atta Habib, were sown in main plots. The seeds were collected from a local certified seed dealer. All the seeds were initially screened out manually to remove damaged or broken seeds. For the sowing of healthy wheat seeds, the drill sowing method was adopted.

2.6. Irrigation

Throughout the experiment field, a capacity of 65% was maintained when required by providing irrigation to the wheat plants. The characteristics of irrigation water are provided in Table 1.

2.7. Harvesting

Plants were harvested at the time of physiological maturity (when the flag leaf and spikes turn yellow = 150 days after sowing). The harvesting was conducted manually. Soon after harvesting, morphological attributes data were collected at the site. A meter-scale rod was used for the determination of plant height.

2.8. Spikes m^{-2}

The central three rows counted the number of spikes present in these rows. After the number of spikes was counted in three rows, it was converted into the number of spikes per meter square using the following formula:

$$\text{Spike } m^{-2} = \frac{\text{Total number of spikes}}{\text{Number of rows} \times R - R \text{ distance} \times \text{Row length}}$$

2.9. Grain Yield ($kg \text{ ha}^{-1}$)

For grain yield to be obtained, grains from the selected rows were measured in kilograms and then converted into grain yield per hectare. For this reason, the central three rows of each plot were harvested. After harvesting, they were sun-dried and then threshed separately. The grain obtained from each plot in (kg/plot) was then converted into grains (kg/ha) using the following formula:

$$\text{Grain yield (kg/ha)} = \frac{\text{Grain in selected rows (kg)}}{\text{Number of rows} \times R - R \text{ distance} \times \text{Row length}} \times 10000$$

2.10. Thousand-Grain Weight (g)

For the determination of the thousand-grain weight, grains were counted manually. After that, the weight of the grains was assessed on an analytical grade balance.

2.11. Biological Yield ($kg \text{ ha}^{-1}$)

To measure the biological yield, three central rows were harvested and weighed on a balance.

$$\text{Biological yield (kg } \text{ha}^{-1}\text{)} = \frac{\text{Biological yield in selected rows}}{R - R \text{ distance} \times \text{Row length} \times \text{Number of rows selected}} \times 10000$$

2.12. Harvest Index (%)

The harvest index of the crop was calculated by the following formula:

$$\text{Harvest Index (\%)} = \frac{\text{Economic yield (kg } \text{ha}^{-1}\text{)}}{\text{Biological yield (kg } \text{ha}^{-1}\text{)}} \times 100$$

2.13. P Uptake

For the determination of P uptake in the plant, we first calculated the amount of nitrogen in plant tissue in percentage. After finding the percentage of P, we converted this percentage into the P-uptake using the given formula. The unit was $kg \text{ P}_2\text{O}_5 \text{ ha}^{-1}$.

$$\text{P uptake} = \text{P concentration (\%)} \times \text{biological yield}$$

2.14. N Concentration in Leaves

For the determination of N in leaves, the Kjeldhal's method was followed [30].

$$\text{N (\%)} = \frac{(\text{Blank} - \text{Reading}) \times 0.005 \times 0.014 \times 100 \times 100}{\text{wt of sample} \times \text{sample taken}}$$

2.15. P and K Concentration in Leaves

For P and K determination in leaves, the Soltanpour and Schawab [31] procedure was followed. The plant samples were grinded, and a 1 g sample was taken in a 250 mL flask. HNO_3 was added and, after 24 h, 4 mL of perchloric acid was added and digested on a hot plate. P was analyzed with a spectrophotometer (Hitachi U-2000 dual-beam

UV–vis spectrophotometer). K determination was determined with a flame photometer (JENWAY PFP-7).

2.16. Soil Mineral N

To determine the mineral nitrogen in the soil, we collected soil samples from the experimental plot and brought them to the laboratory in plastic bags. The sample was kept in shade and dried, grinded, and sieved. Then, 10 g of the soil was taken with 50 mL of KCl and shaken [30].

2.17. AB-DTPA Extractable Soil P and K

Soil P determination was carried out using the Soltanpour and Schawab [31] method.

2.18. Statistical Analysis

A standard procedure was adopted for the statistical analysis of the data [32]. Two factorial ANOVA was applied for the comparison of each factor's significance. After that, Fisher LSD was applied to compute the significant difference among each treatment. Origin2021b software was used for paired comparison, Pearson correlation, and principal component analysis graphs [33].

3. Results

The effect of different application rates of farmyard manure (FYM) and single superphosphate (SSP) was significant on plant height and the 1000-grain weight. In V1 wheat cultivar, 50F+50P and 75F+25P were the best for improving plant height compared to the control (0F = noSSP + noFYM). Treatments 25F+75P and 100F+0P also differed significantly more than 0F for enhancing the plant height of V1. No significant change was noted between 100P and 0F, in terms of plant height improvement in V1. In V2, 100P, 50F+50P, and 25F+75P were better for increasing plant height compared to 0F. Treatments 75F+25P and 100F+0P did not differ significantly for plant height in V2 compared to 0F (Figure 1A). Maximum increases of 17.75 and 8.00% in the plant height were observed when 75F+25P and 25F+75P were applied over 0F in V1 and V2, respectively. For an improvement in the 1000-grain weight, 50F+50P and 25F+75P performed significantly better over T1 in V1. It was noted that 100P, 75F+25P, and 100F+0P remained statistically alike to each other and with T1 for V1 1000-grain weight. In V2, treatments i.e., T3, T4, T5, and T6 enhanced the 1000-grain weight significantly differently. No significant change in the 1000-grain weight of V2 was observed when T2 was applied over T1 (Figure 1B). Maximum increases of 20.69 and 32.01% in the plant height were observed when 50F+50P was applied compared to T1 in V1 and V2, respectively.

Results show that the variable application rates of FYM and SSP were significant on the spike/m², grain yield, biological yield, and harvesting index. For V1, T4 remained significantly better for increasing spikes/m² compared to T1. Treatments T2, T3, T5, and T6 were also significantly better for improving spikes/m² of V1 compared to T1. No significant change was noted between T3 and T4 regarding improvements in V2 spikes/m². However, in V2, T3 and T4 remained significantly better for increasing spikes/m² compared to T1. Treatments T2, T5, and T6 also significantly changed spikes/m² in V2 compared to T1 (Figure 2A). Maximum increases of 35.19 and 30.10% in the spike/m² were observed when T4 was added over T1 in V1 and V2, respectively. Regarding improvements in the grain yield (Figure 2B), biological yield (Figure 2C), and harvesting index (Figure 2D), no treatment performed significantly better than T1 in V1.

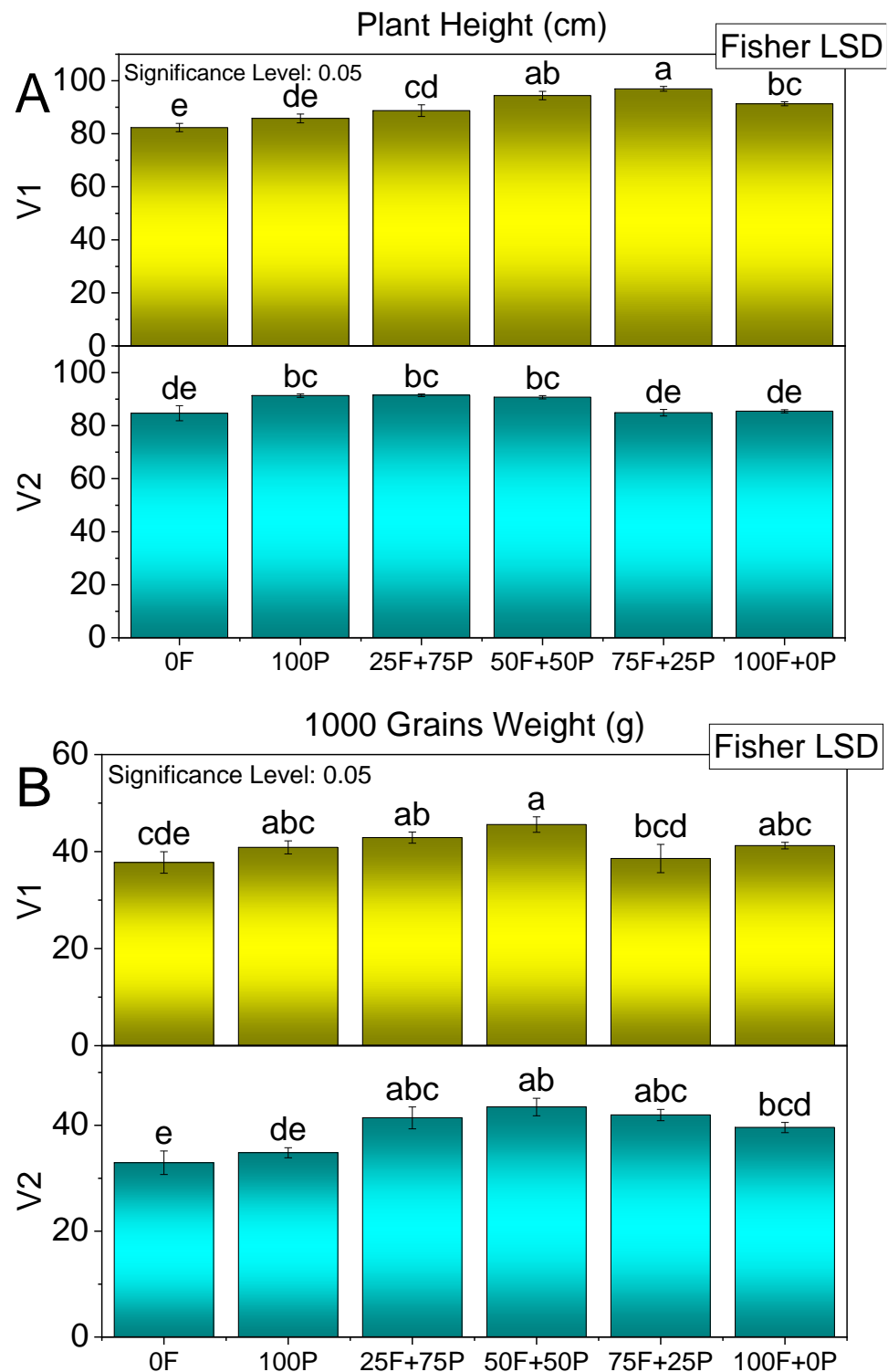


Figure 1. Effect of variable application rates of farmyard manure (F) and single super phosphate (P) on plant height (A) and 1000-grain weight (B) of wheat cultivars V1 and V2. Different values on bars show significant changes at $p \leq 0.05$; Fisher LSD.

It was noted that FYM and SSP significantly affected the wheat grain and leaf P concentration. In V1 and V2, T4 performed significantly better in increasing grains in the P concentration over T1. Treatments T3, T5, and T6 also enhanced grains in the P concentration of V1 and V2 differently compared to T1. No significant change was noted between T2 and T1 when enhancing V1 grains in the P concentration. However, in V2,

T2 was significantly better than T1 at increasing grains in the P concentration (Figure 3A). Maximum increases of 41.10 and 38.16% in grains in the P concentration were observed when T4 was applied over T1 in V1 and V2, respectively. For the leaf P concentration, all treatments performed significantly better over T1 in V1 and V2. However, T4 gave the significantly highest leaf P concentration in V1 and V2 compared to T1 (Figure 3B). Maximum increases of 49.82 and 71.32% in the leaf P concentration were observed when T4 was applied over T1 in V1 and V2, respectively.

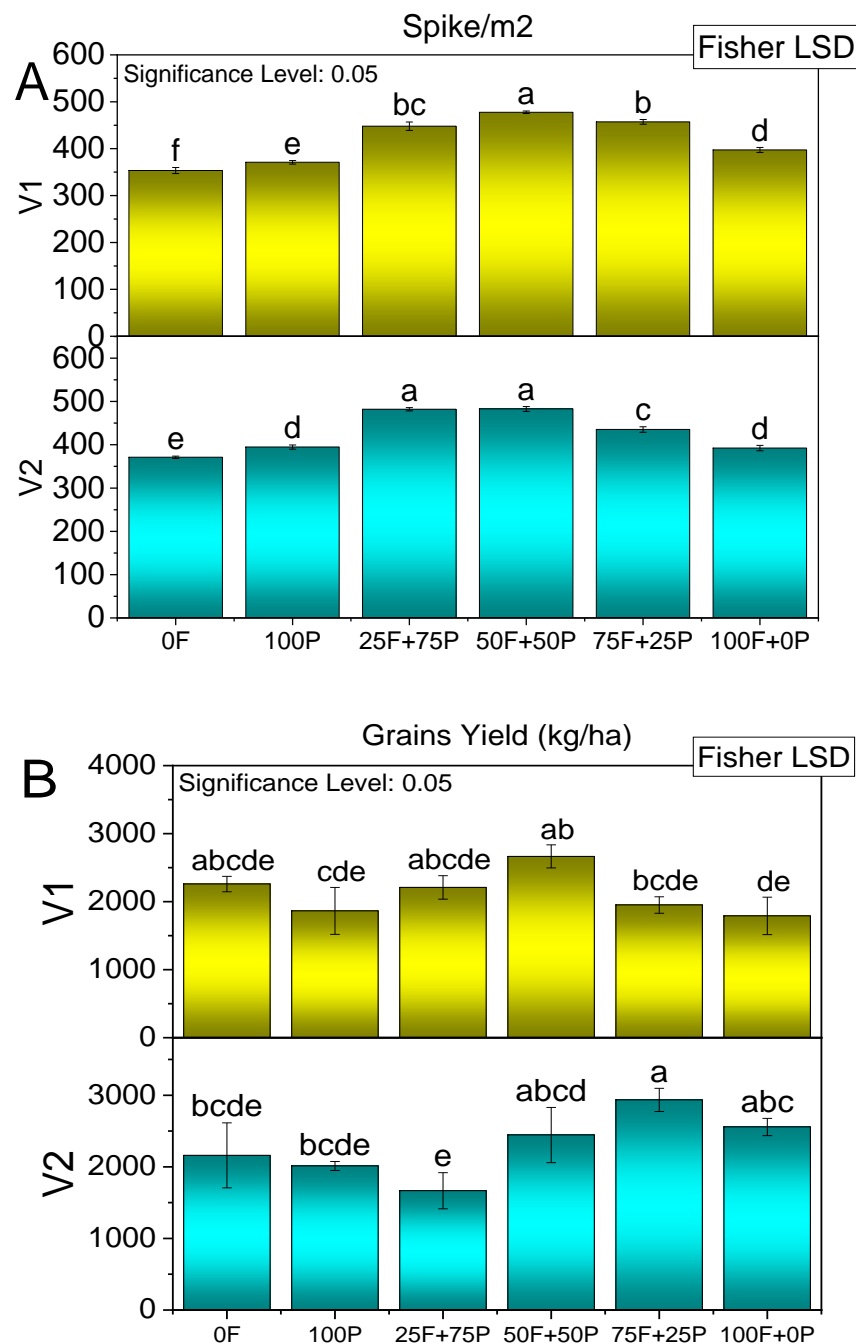


Figure 2. Cont.

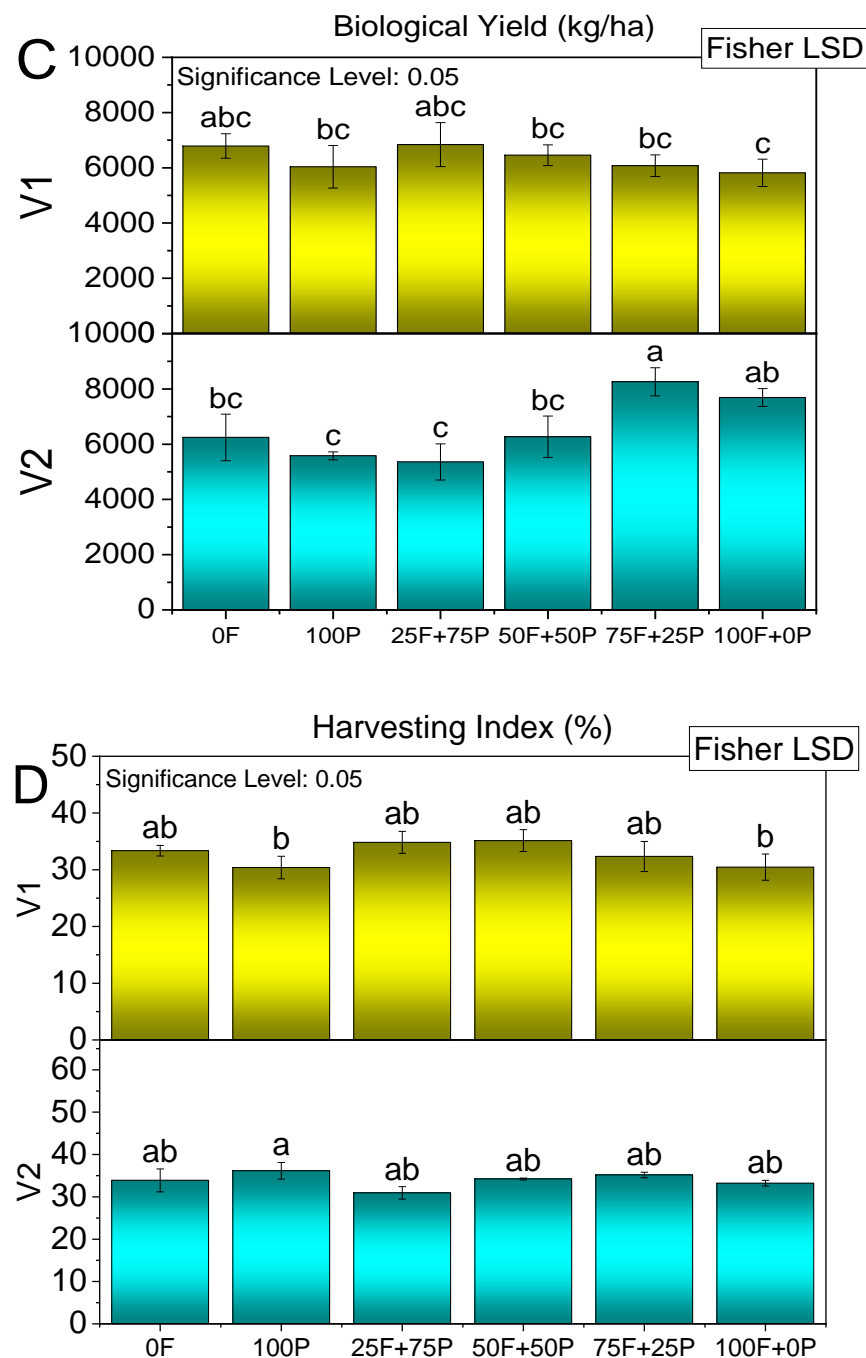


Figure 2. Effect of variable application rates of farmyard manure (F) and single super phosphate (P) on the spike/m² (A), grain yield (B), biological yield (C), and harvesting index (D) of wheat cultivars V1 and V2. Different values on bars show significant changes at $p \leq 0.05$; Fisher LSD.

Results show that in V1, T4 was the only treatment that remained significantly better at enhancing the soil K concentration compared to T1. Treatments T2, T3, T5, and T6 were non-significant for increasing the soil K concentration when V1 was cultivated compared to T1. A significant increase in the soil K concentration was noted when T2, T3, T4, and T5 were applied for the cultivation of V1 compared to T1 (Figure 4A). Maximum increases of 14.62 and 28.42% in the soil K concentration were noted when T4 was added over T1 in V1 and V2, respectively. For the leaf K concentration, the performances of T3, T4, T5, and T6 were significantly better compared to T1 in V1. However, T2 non-significantly changed the leaf K concentration in V1 compared to T1. In V2, T2, T3, and T4 differed significantly

more than T1 for the leaf K concentration. However, T5 and T6 were statistically alike to T1 for the leaf K concentration in V2 (Figure 4B). Maximum increases of 99.29 and 58.30% in the leaf K concentration were noted in T4 compared to T1 in V1 and V2, respectively.

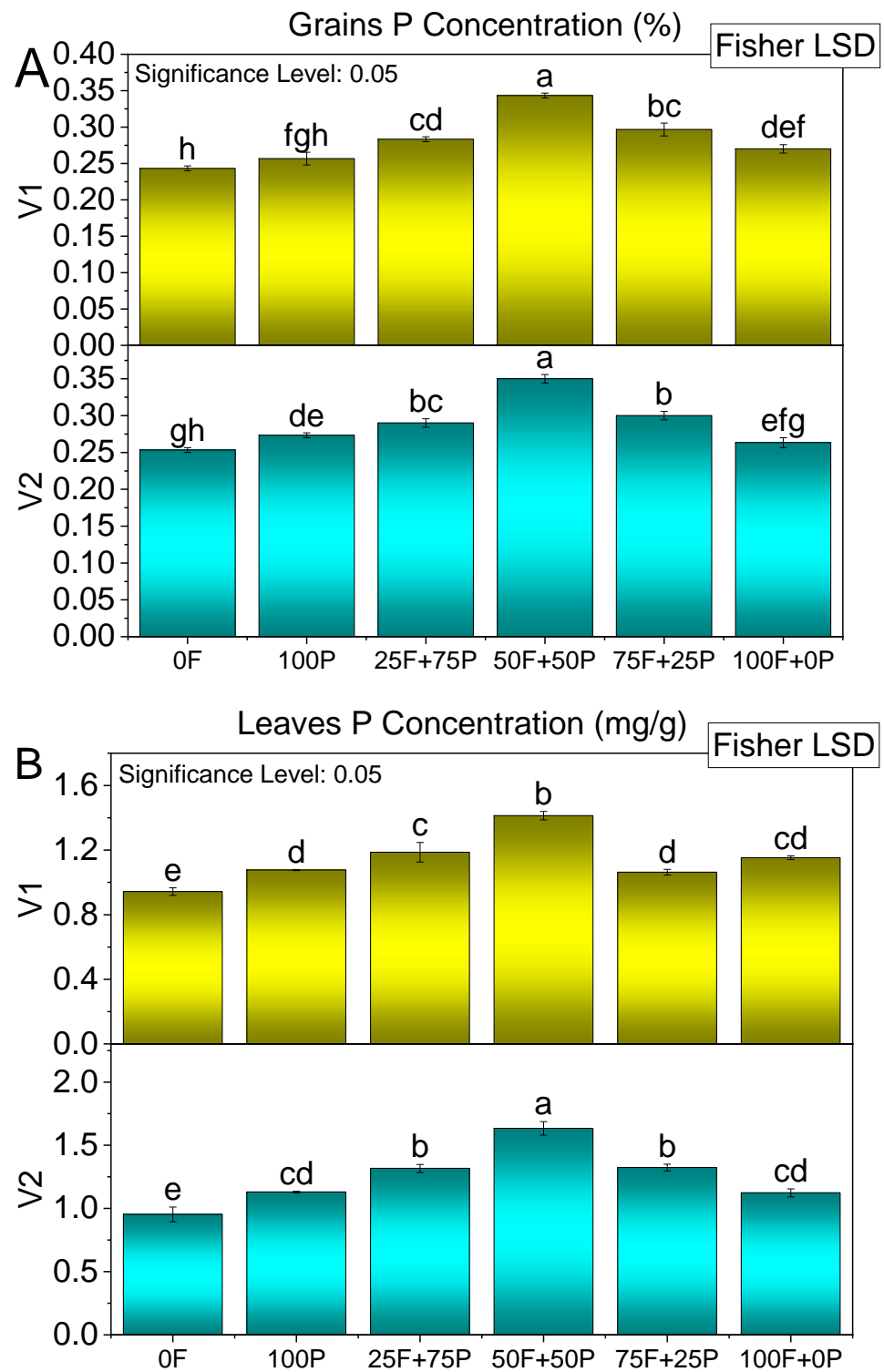


Figure 3. Effect of variable application rates of farmyard manure (F) and single super phosphate (P) on the grain P (A) and leaf P concentration (B) of wheat cultivars V1 and V2. Different values on bars show significant changes at $p \leq 0.05$; Fisher LSD.

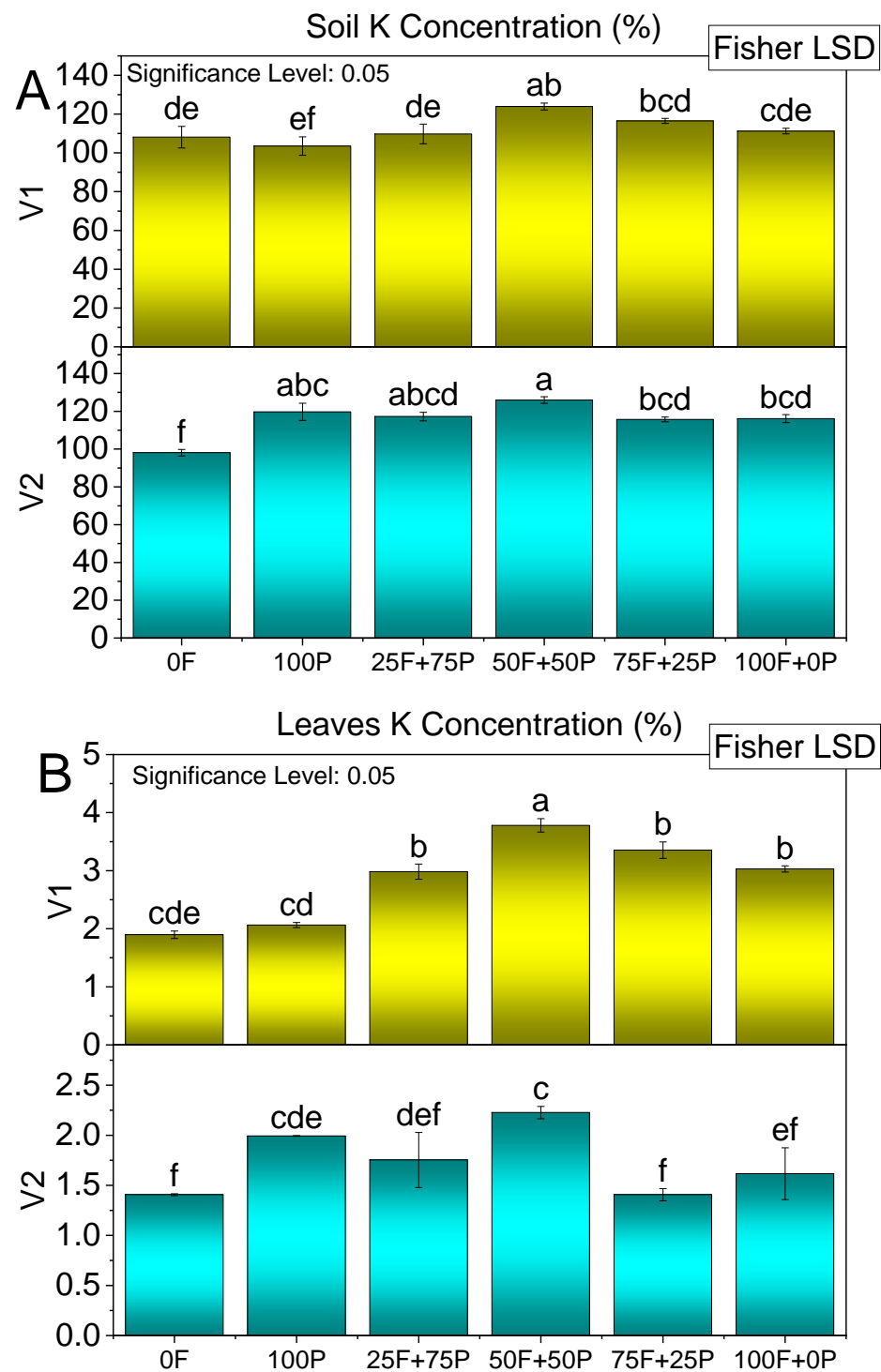


Figure 4. Effect of variable application rates of farmyard manure (F) and single super phosphate (P) on the soil K (A) and leaf K concentration (B) of wheat cultivars V1 and V2. Different values on bars show significant changes at $p \leq 0.05$; Fisher LSD.

The impact of treatments was significant on the soil mineral and wheat leaf N concentrations. In V1, T2, T3, T4, and T6 caused a significant increase in soil mineral N concentration compared to T1. Treatment T5 was non-significant for enhancing the soil mineral N concentration when V1 was grown compared to T1. A significant increase in the soil mineral N concentration was noted in T2, T3, T4, T5, and T6 compared to T1 when V1 was cultivated. However, in V1 and V2, T4 was significantly better than T1 for increasing the soil mineral N concentration (Figure 5A). Maximum increases of 25.91 and 36.89% in

the soil mineral N concentration were observed when T4 was applied over T1 in V1 and V2, respectively. For the leaf N concentration, T3, T4, T5, and T6 were significantly better than T1 in V1 and V2. However, T2 non-significantly enhanced the leaf N concentration in V1 and V2 compared to T1. T6 remained significantly better in V1 but did not differ significantly in V2 compared to T1 for the leaf N concentration (Figure 5B). Maximum increases of 47.07 and 47.23% in the leaf N concentration were observed when T4 was applied over T1 in V1 and V2, respectively.

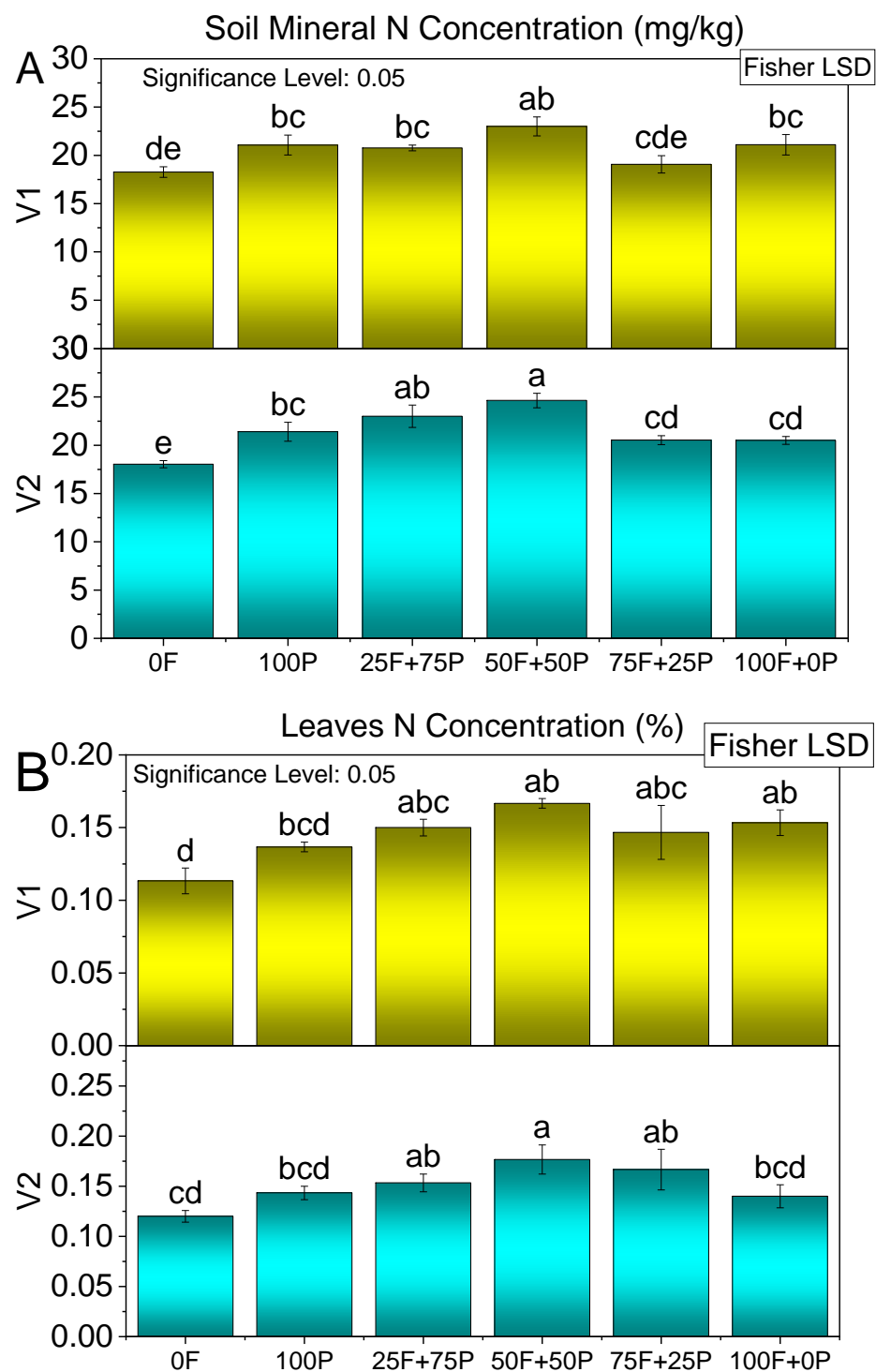


Figure 5. Effect of variable application rates of farmyard manure (F) and single super phosphate (P) on the soil mineral N (A) and leaf N concentration (B) of wheat cultivars V1 and V2. Different values on bars show significant changes at $p \leq 0.05$; Fisher LSD.

Pearson correlation showed that the plant height, 1000-grain weight, spike/m², grain P, and leaf P were significantly positively correlated with soil mineral N and soil K concentration. The leaf P and grain P concentrations were also significantly positively correlated with the leaf N concentration. There was also a significant positive correlation between the harvesting index and the grain yield (Figure 6). Principal component analysis showed that variables explained 64.2% of the variation in the first two axes (Table 2; Figure 7), i.e., 44.7% and 19.5% variances were accounted for the first and second principal components, respectively. The first principal component (PC1) captured a higher number of attributes compared to the second principal component (PC2). Most studied attributes were closely linked to 50F+50P, except the grain yield, biological yield, and harvesting index. The grain yield, biological yield, and harvesting index were more responsive towards soil 75F+25P. Plant height, leaf N, and K were more responsive towards 25F+75P. A parallel plot also shows the dominance of 50F+50P (light blue lines) and 75F+25P (dark blue) as compared to all other combinations. Most of studied attributes of plants showed maximum enhancement when 50F+50P and 75F+25P combinations were provided as a treatment (Figure 8). Red lines for 0F were the most recessive combination for studied attributes.

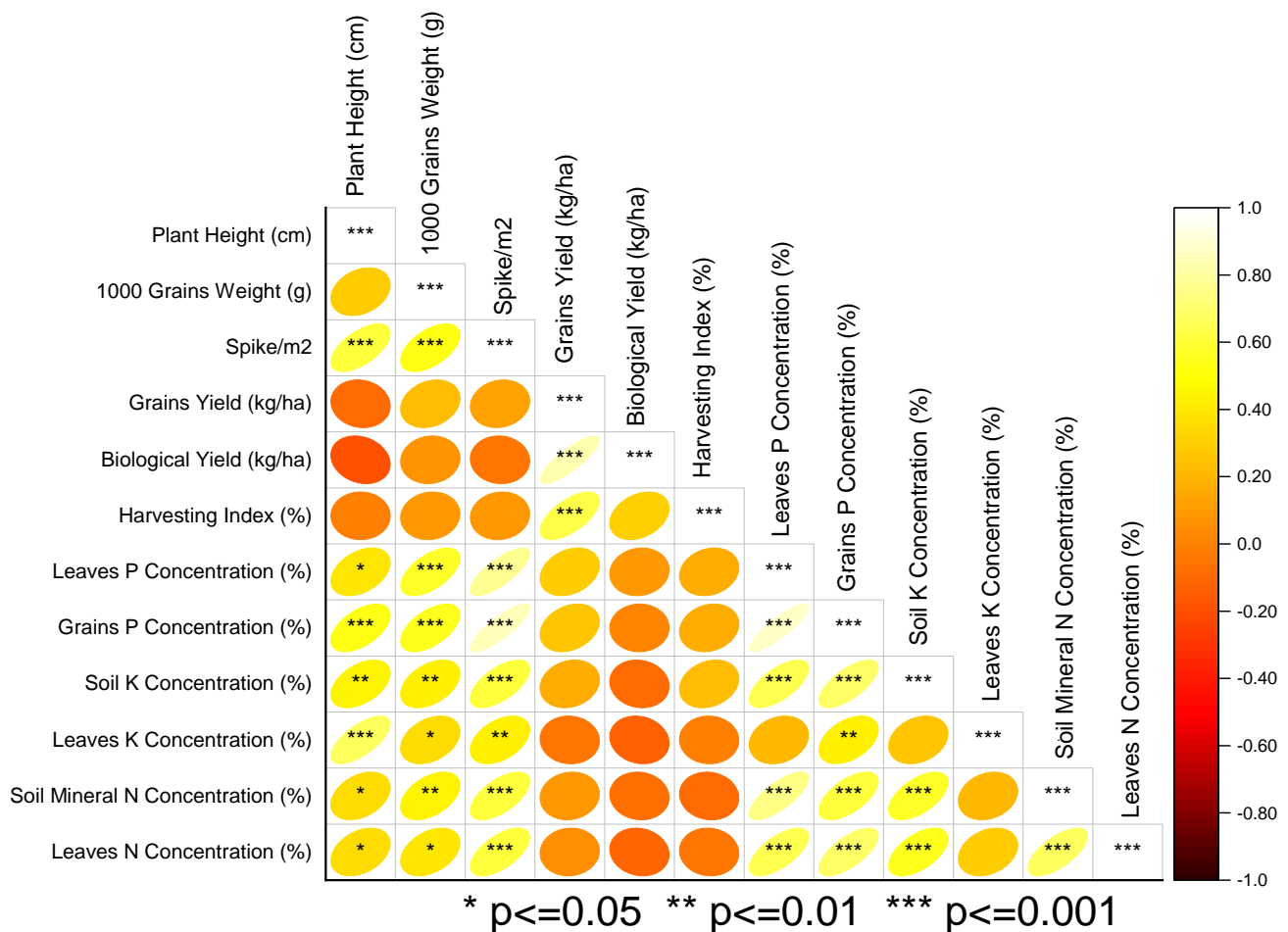


Figure 6. Pearson correlation for studied wheat and soil attributes. The yellow color indicates a positive while the red color indicates a negative correlation. Ellipse with no stars are non-significant in correlation.

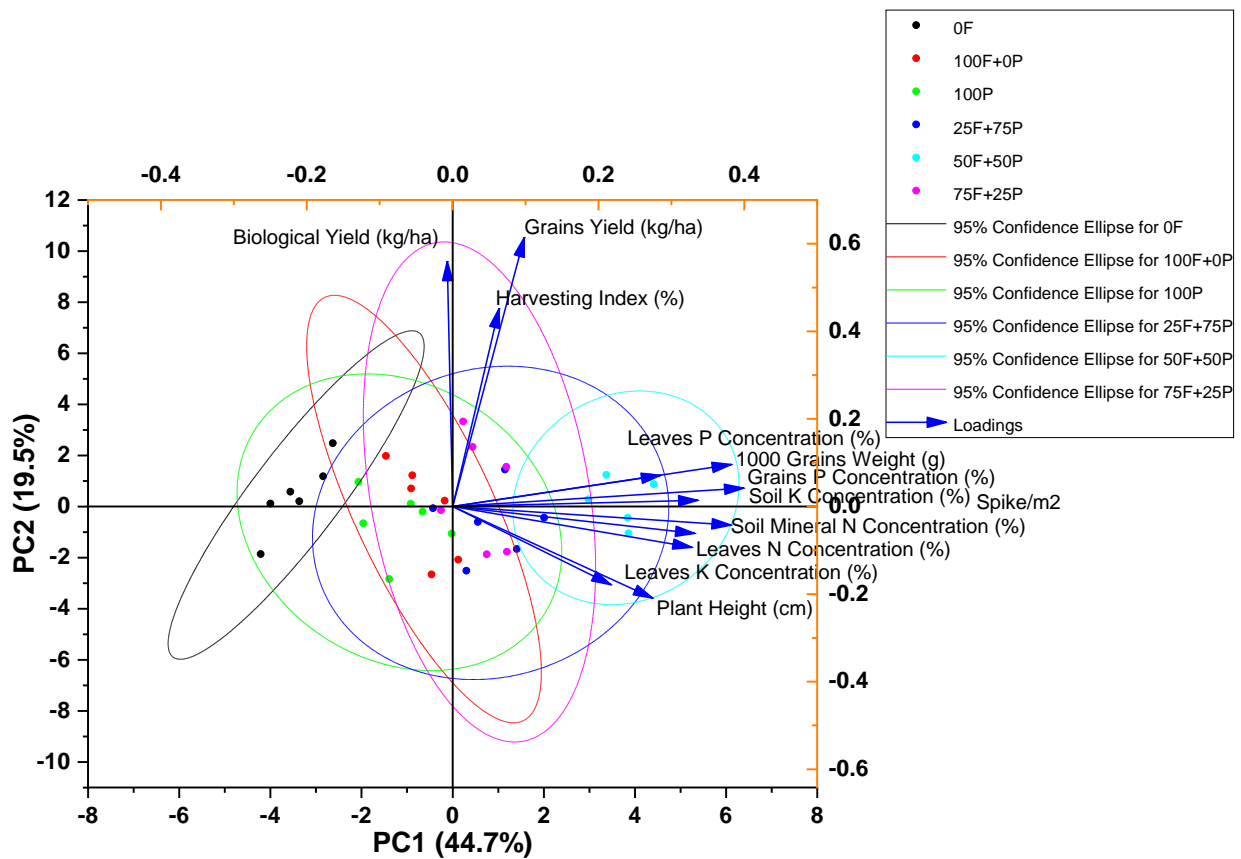


Figure 7. Principal component analysis for studied soil and wheat attributes.

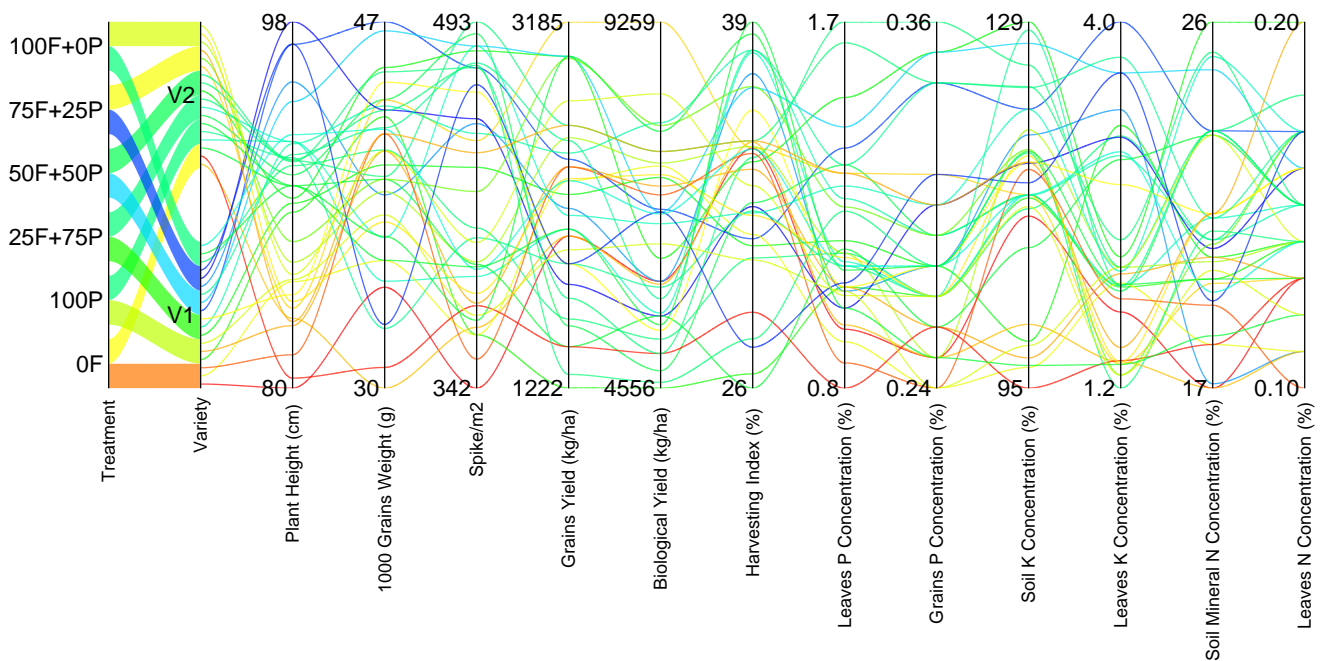


Figure 8. Parallel plots showing data range of studied plant and soil attributes in the context of applied treatments and variety types. All the data values range from the highest and lowest values of studied attributes.

Table 2. Eigenvalues, loadings, percentage of variance, and cumulative of studied PCA attributes.

Principal Component	Eigenvalue	PC1	PC2	Percentage of Variance (%)	Cumulative (%)
		Loadings			
Plant height (cm)	5.36924	0.27434	−0.2091	44.74368	44.74368
1000-grain eight (g)	2.33501	0.28526	0.07137	19.45838	64.20206
Spike/m ²	1.19411	0.382	−0.04231	9.95091	74.15296
Grain yield (kg/ha)	0.8141	0.09821	0.61369	6.78418	80.93714
Biological yield (kg/ha)	0.61524	−0.00731	0.55953	5.127	86.06414
Harvesting index (%)	0.41689	0.06365	0.45174	3.4741	89.53824
Leaf P concentration (%)	0.38629	0.38231	0.09609	3.21911	92.75735
Grain P concentration (%)	0.33157	0.39911	0.04185	2.7631	95.52045
Soil K concentration (%)	0.23143	0.33621	0.01405	1.92858	97.44903
Leaf K concentration (%)	0.17116	0.21705	−0.17873	1.42631	98.87534
Soil mineral N concentration (%)	0.10103	0.33207	−0.06154	0.84189	99.71723
Leaf N concentration (%)	0.03393	0.32835	−0.09347	0.28277	100

4. Discussion

Results showed that the application of different rates of SSP and FYM caused significant improvements in the growth and yield attributes of wheat. It was noted that 50% FYM application with 50% SSP remained a significantly better treatment for enhancing the growth attributes of wheat compared to other treatments. The application of farmyard manure significantly increased the organic fraction of the soil. This improvement in organic matter helps the microbial population to grow and increase their diversity in the rhizosphere [34]. An improvement in the microbial population also secretes growth-regulating hormones and enzymes which play an important role in the elongation of plant roots [35]. Healthy plant roots increased the water uptake, as well as nutrient bioavailability, which played an imperative role in the improvement of plant height and other morphological growth attributes [36–38]. In the current study, similar results were also noted when 75% FYM, in combination with 25% single super phosphate, caused significant improvements in the plant height of wheat. The application of organic matter in soil also improves soil health through the improved retention of nutrients [39]. The higher cation exchange capacity of organic matter facilitates the exchange of essential nutrients which play an important role in increasing their bioavailability [40]. Furthermore, the decomposition of organic matter also releases organic acids which decrease the pH of alkaline soil [41]. A significant decrease in soil pH caused the mobilization of immobile essential nutrients [42]. The findings of the current study also validated the above arguments. A significant improvement in the P uptake in grains and leaves confirmed the efficacious role of 50% farmyard manure in combination with a 50% single super phosphate. A significant improvement in soil nitrogen and potassium also improves the uptake of these nutrients in beet leaves when 50% farmyard manure and a 50% SSP rate were applied. The ample uptake of macro essential nutrients in plants plays an important role in improving the yield. They become deposited in the plant leaves when photosynthates are developed and transferred into the grains. The translocation of photosynthates in leaves and grains significantly improves the enhancement of yield attributes [43,44]. On the other hand, the required amount of P uptake in plants stimulates crop maturity. It also triggers photosynthesis and metabolic activity, resulting in the improved generation of photosynthate and the improved plant height [45]. The balanced uptake of P also regulates the carbohydrate-associated mechanisms in plants which are the most critical points in the reproductive phase [46]. Similar results were also noted in the current study where the application of SSP significantly enhanced the grains, the biological yield, and the 1000-grain weight. Benbella and Paulsen [47] also documented a significant increase in the yield when P (2.2 and 4.4 kg P ha^{−1}) was applied in sufficient amounts at the anthesis stage of wheat.

5. Conclusions

It is concluded that the combined application of FYM and SSP is more beneficial for the achievement of better wheat growth compared to the sole application. Growers can apply 50% FYM and 50% SSP for the maximization of wheat phosphorus uptake in less P fertilized soils. The addition of 50% FYM and 50% SSP can also improve nitrogen and potassium concentration in leaves and grains in wheat. More research is also proposed in variable agroclimatic zones to explore different wheat cultivars as a future perspective to improve balance and provide the best combination of SSP and FYM on wheat.

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