Effect of various levels of phosphorus and plant spacing on the growth and yield of black wheat (*Triticum aestivum* L.)

Abstract

The study examined the effects of different phosphorus levels and plant spacing on the growth, yield, and economic viability of black wheat (*Triticum aestivum* L.), a variety known for its nutritional benefits. The experiment was conducted during the 2023–24 rabi season at the Crop Research Farm of Dev Bhoomi Uttarakhand University in Dehradun, India. A factorial randomized block design with three replications was employed. Four phosphorus levels (40, 50, 60, and 70 kg P_2O_5 ha^{-1}) were applied as diammonium phosphate (DAP) at planting, in combination with three plant spacings (15 cm x 10 cm, 20 cm x 10 cm, and 25 cm x 10 cm).The results showed that 70 kg P_2O_5 ha^{-1} significantly improved growth parameters, yield attributes, and nitrogen uptake, while the optimal plant spacing of 25 cm x 10 cm further enhanced these outcomes. The highest grain and straw yields were obtained with 70 kg P_2O_5 ha^{-1}, though 60 kg P_2O_5 ha^{-1} provided similar yields with greater cost-effectiveness. Economic analysis indicated that the combination of 70 kg P_2O_5 ha^{-1} and optimal spacing(25 cm X 10 cm)resulted in the highest net returns. These findings suggest that strategic phosphorus application, combined with appropriate plant spacing, can improve both the productivity and profitability of black wheat cultivation, offering a sustainable approach to agriculture.

Keywords: Black wheat, Growth, Nitrogen uptake, Phosphorus, Yield

Introduction

Black wheat (*Triticum aestivum* L.) is gaining attention due to its rich anthocyanin content and associated nutritional benefits, such as anti-inflammatory and anti-cancer properties **(Nguyen et al., 2023; Sharma et al., 2021**). This unique variety presents a nutrient-dense alternative to conventional wheat, prompting increased interest in its cultivation. Phosphorus (P_2O_5) management is critical for optimizing growth and yield in black wheat, as phosphorus is essential for energy transfer and root development **(Khan et al., 2023).** However, phosphorus availability in soil can be limited, leading to the necessity of fertilizer applications. Excessive use of fertilizers raises concerns regarding environmental sustainability **(Weeks & Hettiarachchi, 2019; Liu et al., 2023).**

While recent studies on colored wheat varieties, such as purple wheat in China, have demonstrated that optimized phosphorus levels can enhance anthocyanin content and overall yield **(Liu et al., 2023;**Ahmadi et al., 2024; Zhang et al., 2022**),** research specifically targeting black wheat—particularly within the context of Indian agriculture—is still sparse. Existing literature often emphasizes high-yielding varieties and advanced agronomic practices to improve wheat production in India **(Mishra et al., 2005; Joshi et al., 2007**), yet the impact of phosphorus levels and plant spacing on black wheat has not been thoroughly investigated.

This study is warranted to fill this knowledge gap and provide insights into the effective management of phosphorus and plant spacing for black wheat cultivation. It aims to assess the combined effects of various phosphorus levels (40, 50, 60, and 70 kg P_2O_5 ha^{-1}) and plant spacings (15 cm × 10 cm, 20 cm × 10 cm, and 25 cm × 10 cm) on growth and yield parameters. By exploring these factors, the research seeks to establish innovative agronomic practices that can enhance productivity and sustainability in black wheat farming. The objective of this study is to identify optimal phosphorus application rates and plant spacing that maximize growth, yield, and economic viability, thereby supporting farmers in adopting sustainable agricultural practice.

MATERIAL AND METHODS

Experimental site

The experiment was conducted during the 2023–2024 rabi season at the Crop Research Farm of Dev Bhoomi Uttarakhand University, Dehradun, Uttarakhand, India. This region experiences a subtropical climate, with summer temperatures reaching 35–39°C and winter lows of around 0.5°C. The average annual rainfall is approximately 1200 mm, primarily between November and April, with some additional winter rainfall.

Before establishing the experimental layout, soil samples were collected from various points within the 0–20 cm depth to assess the site's physical and chemical properties. These samples were pooled into a single representative composite sample for analysis. The soil at the study site was classified as sandy loam, with low organic carbon content but moderate levels of available phosphorus, nitrogen, and potassium. The wheat variety used in the study was Black 76.

Field preparation and experimental details

The experiment followed a Randomized Complete Block Design (RCBD) with 12 treatment combinations, each replicated three times. Treatments were randomly arranged within each replication, resulting in a total of 36 plots. Each plot measured 4 m^2 (2 × 2 m). The area was irrigated before initial ploughing with a tractor-pulled disc plow. Additional cultivation included cross-ploughing and levelling (planking) to achieve a finely textured soil surface. Before cross-ploughing, nitrogen and potassium were uniformly applied across the field and thoroughly incorporated into the soil during ploughing.

Table 1. Chemical analysis of soil at pre -experiment stage

Parameter	Value	Method	References
Organic carbon (%)	0.24%	Walkley and Black Method	Walkley and Black Method 1934
Available Nitrogen	237 kg ha^{-1}	Alkaline Permanganate Method	Subhaiah and Asija, 1956
Available Phosphorus	19.60 kg ha^{-1}	Olsen's Colorimetric Method	Olsen *et al.*, 1954
Available Potassium	95.00 kg ha^{-1}	Flame Photometer method	Jackson, 1973
Soil pH	7.6	Glass electrode pH meter	Jackson, 1973

Details of Treatment

The treatments comprised four levels of phosphorus, specifically 40 kg P_2O_5 ha^{-1} (P1), 50 kg P_2O_5 ha^{-1} (P2), 60 kg P_2O_5 ha^{-1} (P3), and 70 kg P_2O_5 ha^{-1} (P4), combined with three plant spacings: 15 cm × 10 cm (S1), 20 cm × 10 cm (S2), and 25 cm × 10 cm (S3).

Phosphorus was applied in the form of diammonium phosphate (DAP) at the time of planting, with the rates corresponding to the phosphorus levels (P_2O_5). The specific application rates were calculated to ensure that the respective phosphorus levels were accurately met.

The experiment followed standard agronomic practices for black wheat production to ensure optimal growth and yield. A high-yielding, disease-resistant black wheat variety was sown at a seed rate of 100 kg ha^{-1}. The soil was prepared through ploughing, cross-ploughing, and leveling to create a fine-textured seedbed. Phosphorus was applied as per treatment levels at sowing, with nitrogen and potassium uniformly incorporated during soil preparation. Optimal soil moisture was maintained through timely irrigation, while weeds were managed using manual and chemical methods, and pest control followed recommended guidelines. These practices established a healthy crop, providing a reliable foundation for assessing the treatment effects.

The plot size for each treatment was standardized to ensure consistent measurements and comparisons, with each plot measuring 4 × 3 m This design facilitated a thorough examination of the combined effects of phosphorus application and plant spacing on the performance of black wheat.A tube-well served as the irrigation source. In addition to pre-sowing irrigation, five irrigations were applied, each corresponding to a critical stage of plant growth. The crop was harvested once it reached maturity, determined through visual assessments on April 20, 2024. To ensure accuracy, two border rows on both sides of the field were excluded, and half a meter was trimmed from each plot's length. The harvested yield from the designated area was collected to calculate biomass yield. Each participant small plot was threshed using a manual thresher.

Growth and yield estimations

Plant height (cm)

For each plot, five plants were selected at random and marked for measuring their height at different time intervals. Height was measured at 30, 60, and 90 DAS and also at harvest by using a meter scale from the ground to the top leaf pre-heading, and from the ear head base post-heading.

Number of tillers(m^{-2})

The number of tillers per plant was recorded at 60 and 90 days post-sowing. This was done by counting the total number of tillers on five randomly selected plants per plot.

Leaf area index (LAI)

The leaf area index was determined by measuring the leaf area at 30, 60, and 90 days post-sowing. Plants were chosen with a row length of 0.25m, and their green leaves were separated to measure surface area with an automatic leaf area meter (LI-3100C Area Meter (LI-COR Biosciences)**.**

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Dry Matter accumulation (g m^{-2})

Plants selected randomly from the area marked for the purpose of dry matter estimation. Plants were cut at the soil surface at 30, 60, and 90 days and at maturity. Samples were sun-dried and finally oven-dried at 70°C to a constant weight for estimation of dry matter accumulation and ground to 20 mesh and preserved for subsequent chemical analysis.

2.6.3. Economics

2.6.3.1. Cost of cultivation (₹ ha^{-1})

The cost of cultivation was worked out on thebasis of input rates at the farm. Treatment's costwas calculated separately. The common cost ofcultivation (₹ ha-1) was worked out byconsidering all the expenses incurred in thecultivation and added variable cost due totreatments (including interest of working capital)in order to get total cost of cultivation.

2.6.3.2. Gross return (₹ ha^{-1})

The overall income was determined by multiplying the crop and straw production with the prevailing market rate in various conditions. The total income (₹ /ha) was calculated by adding up the earnings from both the grain and straw harvest.

Gross return (₹ ha^{-1})= Total incomefrom the grain and straw harvest

2.6.3.3. Net return (₹ ha^{-1})

Net profit is the outcome received by subtractingthe cost of cultivation from gross income (₹ ha^{-1}). The net return was worked out by usingfollowing formula:

Net return (₹ ha^{-1}) = Gross return (₹ ha^{-1}) -Cost of cultivation (₹ ha^{-1})

2.6.3.4. B: C ratio (₹ ha^{-1}):

$$B:C = \frac{\text{Net return (} ha^{-1})}{\text{Cost of cultivation (} ha^{-1})}$$

Statistical analysis

The data collected for various characteristics underwent statistical analysis using Fisher's method of analysis of variance (ANOVA). Critical difference (CD) values were calculated when the 'F' test was found significant at the 5% level. Heatmap clustering using SRPLOT (http://www.bioinformatics.com.cn/en?keywords=heatmap) was employed to visually summarize the data, highlighting key features and their interrelationships.

RESULT AND DISCUSSION

Growth attributes

Plant height showed significant growth until 90 days after sowing (DAS), primarily influenced by phosphorus levels starting from 60 DAS. The tallest plants were recorded with 70 kg P_2O_5 ha^{-1}, followed by 50 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} Row spacing also impacted height, with 25x10 cm resulting in taller plants compared to 20x10 cm. Dry matter accumulation peaked at 90 DAS and harvest, with P4, P2, and P3 outperforming P1 (40 kg P_2O_5 ha^{-1}). Increased row spacing correlated with higher dry matter. Both phosphorus levels and row spacing affected shoot density, with the highest densities observed at 90 DAS and harvest.

The leaf area index rose significantly up to 60 DAS due to phosphorus and spacing **(Table 2)**. Overall, growth followed a sigmoid curve, characterized by initial slow growth followed by rapid acceleration until 60 DAS. While phosphorus levels did not significantly affect initial plant population, wider row spacing led to increases **(Singh, 2019; Williams *et al*., 2021)**. Growth rates between 30 and 90 DAS were attributed to improved light absorption, photosynthetic activity, and nutrient uptake **(Styles *et al*., 2018)**.

Phosphorus application significantly enhanced tiller number, plant height, leaf area index, dry matter accumulation, and maturity, with peak values at P4. Initial plant population and maturity showed no significant differences among phosphorus levels. Maximum dry matter (1097.25 g m^2) and height (91.18 cm) were recorded at P4. Similarly, increasing row spacing improved initial population, tillers, height, leaf area index, and dry matter, with the highest values at 25 cm x 10 cm spacing (S3)**(Sendhil *et al*., 2019;Qin *et al*., 2013)**.

Overall, both phosphorus levels and row spacing significantly influenced the growth parameters of black wheat. Optimal phosphorus levels and appropriate spacing can enhance black wheat productivity and yield, suggesting effective agronomic practices for farmers.

Table2.**Effect of different phosphorus levels and row spacing on growth parameters of wheat**

Treatments	**Initial plant population (m^{-2})**	**Number of tillers (m^{-2})**	**Plant height (cm)**	**Leaf area index (%)**	**Dry matter accumulation (g m^{-2})**	**Maturity (Days)**
Phosphorus (P)						
40 kg P_2O_5 ha^{-1}	181.17	370.50	80.75	4.10	971.85	118.27
50 kg P_2O_5	186.93	398.47	86.87	4.40	1045.02	122.03

ha^{-1}						
60 kg P□O□ ha^{-1}	189.67	406.33	88.58	4.49	1065.90	124.03
70 kg P□O□ ha^{-1}	**189.33**	**418.37**	**91.18**	**4.62**	**1097.25**	**125.10**
SEd (±)	4.94	10.31	2.28	0.10	22.49	2.56
CD (P= 0.05)	NS	30.24	6.69	0.32	65.97	NS
Row spacing						
15 cm X 10 cm	170.95	378.50	82.50	4.18	992.75	121.83
20 cm X 10 cm	194.95	402.40	87.74	4.45	1055.48	122.35
25 cm X 10 cm	**208.93**	**414.35**	**90.30**	**4.58**	**1086.79**	**122.90**
SEd (±)	8.7	8.93	1.97	0.09	19.48	1.47
CD (P= 0.05)	25.7	26.19	5.79	0.27	57.13	NS

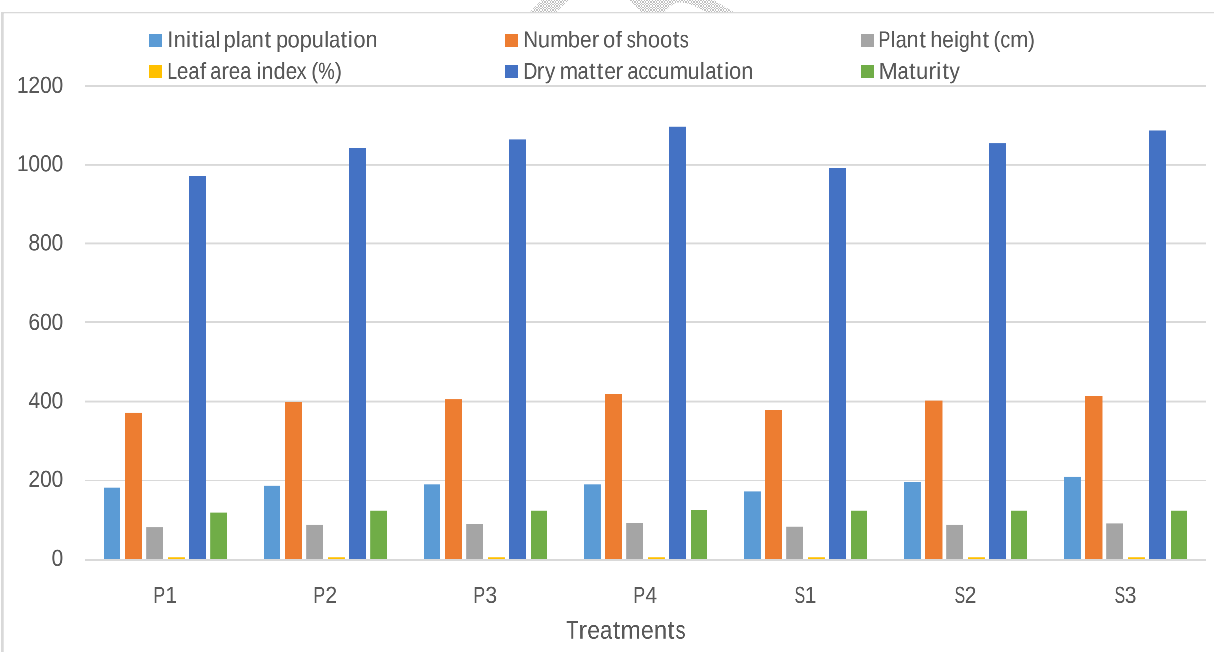

Fig. 1. Effect of different phosphorus levels and row spacing on growth parameters of wheat

Yield parameters

The impact of phosphorus levels on wheat spike characteristics was significant, with the highest spike number (316.05) observed at 70 kg P□O□ ha^{-1} equalling the performance of 50 kg P□O□ ha^{-1} and 60 kg P□O□ ha^{-1} treatments and surpassing 40 kg P□O□ ha^{-1}. Similarly, spike length reached its peak (8.93) with P4, matching P2 and P3 but outperforming P1. Grain number per spike (40.12) was also highest with P4, comparable to P2 and P3. Sowing at 25x10 cm spacing resulted in a higher number of grains per spike (39.75), similar to 20x10 cm spacing. Phosphorus levels significantly influenced grain yield, with the highest yield (33.81 q ha^{-1}) achieved at 70 kg P□O□ ha^{-1} (P4), similar to P2 and P3, and superior to P1. Straw yield followed a similar pattern, with P4 producing 42.84 q ha^{-1}, comparable to P2 and P3. Nitrogen content in grain (1.88%) and straw (0.37%) was also highest with P4, showing superiority over lower phosphorus levels**(Table 3).** Row spacing did not significantly affect test weight but influenced nitrogen content, with higher levels observed at 25x10 cm spacing. The findings underscore the role of phosphorus and row spacing in influencing yield attributes and overall wheat productivity, aligning with previous research (**Patra, 2024; Kolarić*et al.*, 2021).**

Table3. Effect of different phosphorus levels and row spacing on yield parameters of wheat

Treatment	Number of spikes/m^2	Length of spike (cm)	Grain spike^{-1}	Grain yield (qha^{-1})	Straw yield (qha^{-1})	Test weight (g) 10000 grain weight	Nitrogen content (%)	
							Grain	Straw
Phosphorus level								
40 kg P□O□ ha^{-1}	279.95	7.92	35.53	29.95	39.75	36.17	1.67	0.29
50 kg P□O□ ha^{-1}	301.02	8.52	30.22	32.22	41.27	36.93	1.80	0.33
60 kg P□O□ ha^{-1}	307.03	8.67	38.97	32.85	41.19	37.20	1.81	0.36
70 kg P□O□ ha^{-1}	**316.05**	**8.93**	**40.12**	**33.81**	**42.84**	**37.50**	**1.88**	**0.37**
SEm(±)	7.78	0.19	1.07	0.68	4.11	0.92	0.02	0.004
CD(p=0.05)	22.83	0.56	3.14	2.00	1.06	NS	0.06	0.012
Row spacing(cm)								
15 cm X 10 cm	285.96	8.09	36.29	30.95	39.63	36.65	1.78	0.33
20 cm X 10 cm	304.01	8.59	38.59	32.54	41.90	37.15	1.80	0.34
25 cm X 10 cm	**313.06**	**8.85**	**39.75**	**33.49**	**42.26**	37.05	1.84	0.34
SEm±	6.74	0.16	0.92	0.59	0.92	0.80	0.01	0.004
C.D. (p=0.05)	19.77	0.48	2.72	1.73	2.71	NS	0.05	0.010

Nitrogen uptake in grain, straw and total Nitrogen uptake:

Higher nitrogen uptake by grain and straw (63.53 kgha^{-1} and 15.98 kgha^{-1}) was recorded with 70 kg P_2O_5 ha^{-1}, matching the performance of 50 kg P_2O_5 ha^{-1} and 60 kg P_2O_5 ha^{-1} , significantly surpassing 40 kg P_2O_5 ha^{-1} . Similarly, higher total nitrogen uptake (79.51 kgha^{-1}) by grain and straw was observed with P4 (125% RDF), lower (61.68 kgha^{-1}) with P1 (50% RDF + 50% N through FYM), showing superiority over P1, P2, and at par with P3 treatments. Row spacings significantly influenced nitrogen uptake in seed and straw, with higher uptake (61.59 kgha^{-1} and 14.73 kgha^{-1}) observed at 25x10 cm spacing, comparable to 20x10 cm. Phosphorus levels also affected phosphorus content in grain, with the highest content (0.36%) under 70 kg P_2O_5 ha^{-1}, comparable to P2 and P3, superior to P1 (**Table 4).** Nutrient uptake reflects dry matter accumulation and content in plants, with nitrogen and phosphorus uptake correlating with growth and dry matter production. Potassium uptake was notably influenced by phosphorus levels and row spacings, with nutrient uptake increasing with higher nutrient supply systems, enhancing plant growth and soil nutrient absorption. Row spacings, affecting tiller density, also played a significant role in nutrient uptake efficiency, aligning with previous research **(Abichou*et al*., 2019; Jat *et al*., 2021).**

Table 4. Nitrogen uptake in grain and straw and total nitrogen uptake as influenced by Phosphorus level and row spacing on wheat crop.

Treatment	**Nitrogen uptake (kgha^{-1})**		**Total Nitrogen uptake**
	Grain	**Straw**	
Phosphorus level			
40 kg P_2O_5 ha^{-1}	49.94	11.73	61.68
50 kg P_2O_5 ha^{-1}	51.87	13.86	71.74
60 kg P_2O_5 ha^{-1}	61.50	15.19	76.68
70 kg P_2O_5 ha^{-1}	**63.53**	**15.98**	**79.51**
SEm±	1.40	0.46	1.73
C.D. (P=0.05)	4.12	1.35	5.08
Row spacing (cm)			
15 cm X 10 cm	54.36	13.42	67.77
20 cm X 10 cm	58.69	14.43	73.12
25 cm X 10 cm	**61.59**	**14.73**	**76.12**
SEm±	1.21	0.39	1.50
C.D. (p=0.05)	3.57	1.16	4.40

Phosphorus uptake in grain, straw and total Phosphorus uptake:

The data presented in **Table 5** show that the highest total phosphorus uptake (15.24 kg ha^{-1}) by grain and straw was recorded with the treatment of 75 kg P/ha (P4), which was at par with the 50 kg P/ha (P2) and 60 kg P/ha (P3) treatments. These treatments demonstrated significant superiority over the 40 kg P/ha (P1) treatment. Additionally, different row spacings had a significant effect on total phosphorus uptake in both grain and straw. The highest total phosphorus uptake (14.62 kg ha^{-1}) was observed with the 25x10 cm row spacing, which was at par with the 20x10 cm spacing.

Table 5. Phosphorus uptake in grain and straw and total nitrogen uptake as influenced by Phosphorus level and row spacing on wheat crop.

Treatment	Phosphorus uptake (kg ha^{-1})		Total Phosphorus uptake
	Grain	Straw	
Phosphorus level			
40 kg P_2O_5 ha^{-1}	8.94	2.51	11.45
50 kg P_2O_5 ha^{-1}	11.23	2.71	13.93
60 kg P_2O_5 ha^{-1}	12.00	2.82	14.82
70 kg P_2O_5 ha^{-1}	12.28	2.95	15.24
SEm±	0.25	0.07	0.30
C.D. (P=0.05)	0.65	0.21	0.89
Row spacing (cm)			
15 cm X 10 cm	10.28	2.60	12.88
20 cm X 10 cm	11.27	2.80	14.07
25 cm X 10 cm	11.78	2.84	14.62
SEm±	0.22	0.06	0.26
C.D. (p=0.05)	0.65	0.18	0.77

Economics:

The data clearly demonstrates that cultivation costs increased linearly with higher phosphorus levels across all row spacings. The highest cultivation cost (Rs 33,710.09₹ ha^{-1}) was incurred with 70 kg P_2O_5 ha^{-1} across all row spacings. Conversely, the treatment combination of 70 kg P_2O_5 ha^{-1} with 25x10 cm row spacing yielded the highest gross return (75,894.50₹ ha^{-1}) and net return (45,064.00₹ ha^{-1})**(Table 6).** This combination also achieved the highest benefit-cost ratio (1.46). In contrast, the combination of higher phosphorus level (70 kg P_2O_5 ha^{-1}) and wider row spacing (25x10 cm) incurred the highest cultivation cost (33,710₹ ha^{-1}) due to additional expenses associated with increased phosphorus application and row spacing (**Qin *et al*., 2013).**

Table6. Economics of various treatment combinations of wheat

Treatment combination	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio

P_1S_1	28864.60	48416.00	19551.40	0.67
P_2S_1	29255.62	53650.00	24394.38	0.83
P_3S_1	29121.09	66901.00	37780.00	1.29
P_4S_1	29580.22	68260.00	38679.78	1.30
P_1S_2	29489.60	46555.00	17065.40	0.57
P_2S_2	29880.62	46955.00	17074.38	0.57
P_3S_2	29746.09	55507.00	25760.91	0.86
P_4S_2	30105.22	71425.00	41319.78	1.37
P_1S_3	30114.60	49127.00	19012.40	0.63
P_2S_3	30505.62	52489.00	21983.38	0.75
P_3S_3	30830.22	63805.00	30094.91	0.89
P_4S_3	33710.09	75894.50	45064.00	1.46

Heat map clustering

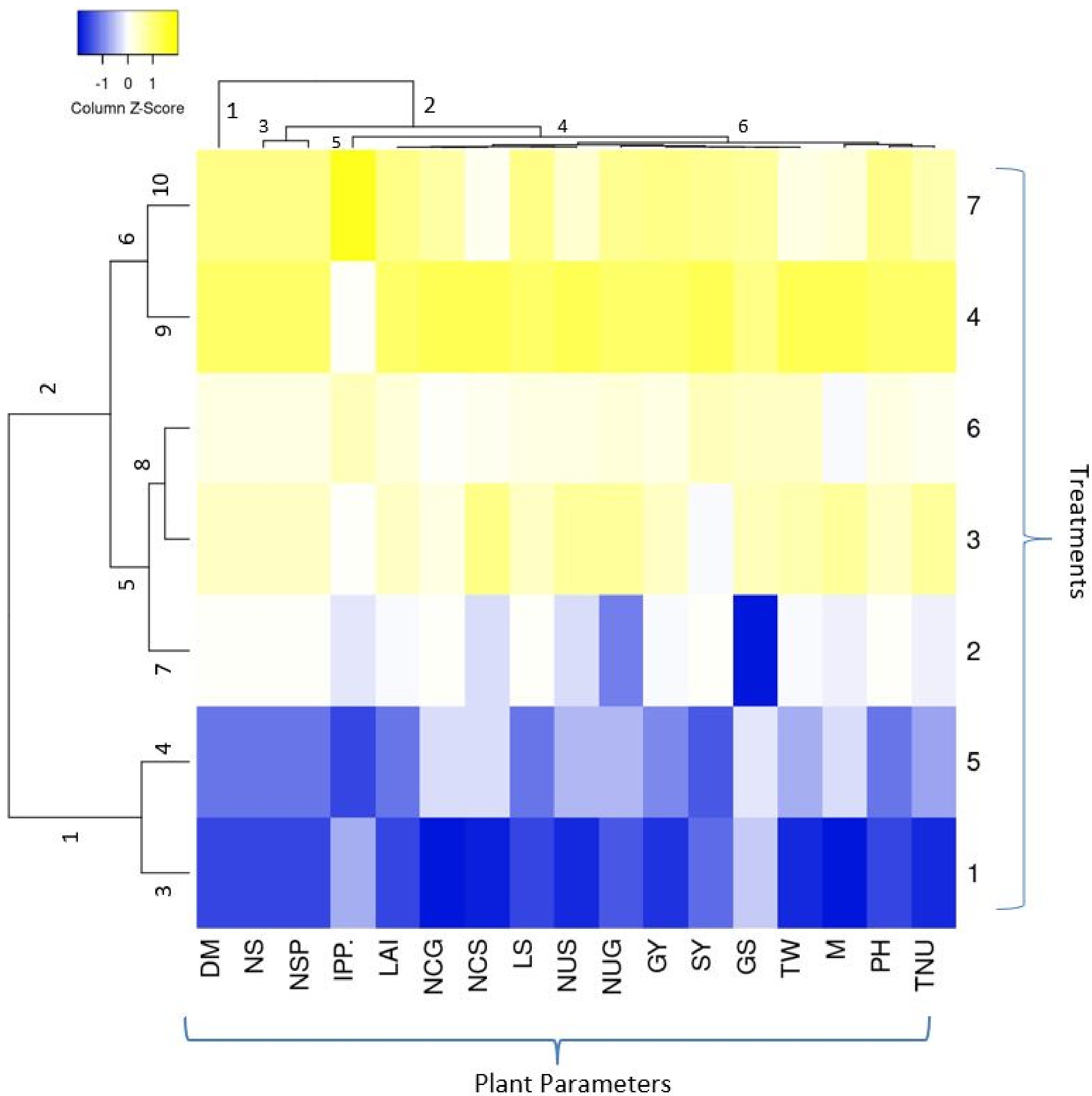

Fig. 2. Clustered heat map of the effect of different treatment combination on growth, yield and economic parameters of wheat; DM= Dry matter accumulation; NS= No. of shoots, NSP=No. od spike/m^2; IPP= Initial plant population; LAI= Leaf area index; NCG=Nitrogen content in grain;NCS=Nitrogen content in spike; LS= Length of spike; NUS=Nitrogen uptake in spike;NUG=Nitrogen uptake in grain; GY= Grain yield; SY= Straw yield; GS= Grain spike^{-1}; TW= Test weight; M= Maturity; PH= Plant height; TNU= Total Nitrogen uptake.

To observe the variation in black wheat parameters and treatment effects, a heat map clustering analysis was performed **(Arya*et al*., 2022).** The results illustrate three distinct data groups: plant growth, yield, and economics. This classification is represented by two types of dendrograms: a horizontally oriented plant parameters dendrogram and a vertically oriented treatments dendrogram **(Figure 2).** In the heat map, traits are visually represented by colors, with blue indicating the maximum value and yellow the minimum.

The plant parameter dendrogram shows two primary clusters (Cluster 1 and Cluster 2). Cluster 1 contains only the trait DM, while Cluster 2 further divides into two sub-clusters (Cluster 3 and Cluster 4). Cluster 3 contains two traits, NS and NSP. Cluster 4 further divides into two sub-clusters (Cluster 5 and Cluster 6). Cluster 5 contains only the trait IPP, while Cluster 6 encompasses all remaining plant parameters.

The treatment dendrogram, positioned vertically, distinctly separates all samples into two main clusters (Cluster 1 and Cluster 2) based on their treatments. The first main cluster further divides into two sub-clusters (Cluster 3 and Cluster 4). Similarly, the second main cluster splits into two sub-clusters (Cluster 5 and Cluster 6). Cluster 3, there are only single treatment (Treatment 1) and another with treatments (Treatment 5). Cluster 5 also divides into two sub-clusters (Cluster 7 and Cluster 8). Cluster 7 includes only Treatment 2, while Cluster 8 includes Treatments 3 and 6. Cluster 6 also divides into two sub-clusters (Cluster 9 and Cluster 10). Cluster 9 includes only Treatment 4, while Cluster 10 includes only Treatment 7.

The analysis of heat maps and dendrograms offers valuable insights into the relationships between plant characteristics and treatment effects. The plant parameter dendrogram groups traits like No. of shoots (NS) and No. of spikes (NSP), highlighting their similarities and importance for the number of shoots and spikes. The treatment dendrogram clusters treatments based on their effects, identifying the most effective and redundant options, which aids in optimizing agricultural practices and reducing costs. Temporal data comparison, distinguishing pre-harvest from post-harvest, provides a deeper understanding of how traits evolve over time, guiding the timing of interventions for maximum benefit. By revealing which traits are influenced similarly by various treatments, we can pinpoint key genetic or physiological pathways, aiding in breeding for desirable traits and stress resistance. This precise visualization simplifies complex data, enabling farmers, agronomists, and researchers to make informed decisions that promote sustainable and effective agricultural practices.

TNU	Total Nitrogen Uptake

Conclusion

The study highlighted the significant effects of phosphorus levels and plant spacing on black wheat (*Triticum aestivum* L.) growth, yield, nitrogen uptake and economic viability. Results showed that applying 70 kg P□O□ ha^{-1} notably improved plant growth, yield parameters, and nitrogen uptake. The 25 cm x 10 cm spacing further enhanced these attributes by reducing competition for resources. The highest grain and straw yields, as well as nitrogen uptake, were observed at 70 kg P□O□ ha^{-1}, though 60 kg P_2O_5 ha^{-1} proved almost equally effective, suggesting it as a cost-effective strategy. Economically, the combination of 70 kg P_2O_5 ha^{-1} and optimal spacing (15 cm × 10 cm (S1), 20 cm × 10 cm (S2), and 25 cm × 10 cm (S3)) yielded the highest returns, but 60 kg P_2O_5 ha^{-1} offered similar benefits, making it a recommended practice for maximizing yield and profit. Thus, strategic phosphorus application and appropriate plant spacing were crucial for sustainable black wheat cultivation, providing a balanced approach to improving crop productivity and economic returns.

Abbreviations

RDF	Recommended Dose of Fertilizer
SEM	Standard Error of Mean
C.D.	Critical Difference
DM	Dry Matter Accumulation
NS	Number of Shoots
NSP	Number of Spikes per square meter
IPP	Initial Plant Population
LAI	Leaf Area Index
NCG	Nitrogen Content in Grain
NCS	Nitrogen Content in Straw
LS	Length of Spike
NUS	Nitrogen Uptake in Spike
NUG	Nitrogen Uptake in Grain
GY	Grain Yield
GS	Grains per Spike
SY	Straw Yield
TW	Test Weight
M	Maturity
PH	Plant Height

Disclaimer (Artificial intelligence)

Option 1:

The author hereby declares that no generative AI technologies, including but not limited to Large Language Models (such as ChatGPT, COPILOT, etc.) and text-to-image generators, have been used in the writing, editing, or creation of content within this manuscript.

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