

# Response of Wheat (*Triticum aestivum* L.) to Phosphorus Fertilization under Urozgan's Agro-Climatic Conditions

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## ABSTRACT

### Purpose:

This study aimed to evaluate the effects of different phosphorus application rates on the growth, yield, and yield components of wheat (*Triticum aestivum* L.) under the agro-climatic conditions of Urozgan province.

### Method:

A field experiment was conducted during the winter season of 2020–2021 at the experimental farm of the Faculty of Agriculture, Urozgan Institute of Higher Education. The experiment was laid out in a randomized complete block design (RCBD) with four replications and five phosphorus levels: 0, 30, 60, 90, and 120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. The soil was sandy loam in texture, slightly alkaline (pH 7.9), and contained moderate amounts of available phosphorus and potassium. Growth and yield parameters were recorded and statistically analyzed to assess treatment effects.

### Results:

Phosphorus application significantly improved all growth and yield attributes of wheat. The treatment receiving 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> resulted in the highest plant height (92.93 cm at 120 days after sowing), number of effective tillers per square meter (359.25), number of spikes per square meter (334.5), spike length, number of grains per spike, 1000-grain weight (40.73 g), grain yield, straw yield, biological yield, and harvest index. Increasing phosphorus beyond this level did not result in further yield improvement.

### Practical Implications:

Application of 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> is recommended for wheat cultivation in Urozgan province, as it provides the most effective and economically viable balance between fertilizer input and yield output under local soil and climatic conditions.

### Originality/Novelty:

This study provides location-specific experimental evidence on the optimal phosphorus requirement for wheat grown in the sandy loam, slightly alkaline soils of Urozgan province, contributing valuable guidance for site-specific nutrient management in regions with similar agro-ecological conditions.

**Keywords:** Phosphorus fertilization; Wheat yield; Nutrient management; Randomized complete block design; Sandy loam soil; Yield components; Urozgan province

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## 1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide, contributing substantially to global food security by providing carbohydrates, protein, and dietary energy (Costa et al. 2013). It was domesticated approximately 10,000 years ago and is mainly cultivated in temperate regions, accounting for about 17% of global cereal production (Peng et al., 2011).

In Afghanistan, wheat is the principal staple food crop and plays a crucial role in national food security. Although wheat occupies a large proportion of cultivated land, national production remains insufficient to meet domestic demand, partly due to low soil fertility and inefficient fertilizer management practices (Khanzada & Raza, 2012). In provinces such as Urozgan, wheat productivity is further constrained by alkaline soils with limited nutrient availability.

Phosphorus is the second most essential macronutrient after nitrogen and is vital for root development, energy transfer, tillering, flowering, and grain formation (Brady & Weil, 2002; Salisbury & Ross, 2003). However, in alkaline soils, phosphorus is readily fixed by calcium compounds, reducing its availability to plants. Although numerous studies have demonstrated the beneficial effects of phosphorus fertilization on wheat growth and yield, optimum phosphorus requirements vary with soil type, climate, and crop management practices.

Despite the importance of phosphorus management, location-specific information regarding optimum phosphorus application rates for wheat under the agro-climatic conditions of Urozgan province is scarce. Most fertilizer recommendations used by farmers are generalized and not supported by local experimental evidence, which may lead to inefficient fertilizer use and reduced productivity. Therefore, this study was conducted to generate site-specific recommendations for phosphorus fertilization in irrigated wheat.

The objectives of the study were: (i) to evaluate the effect of different phosphorus application rates on the growth and yield of wheat (*Triticum aestivum* L.); (ii) to assess the economic benefits of phosphorus fertilization; and (iii) to determine the optimum phosphorus rate for sustainable wheat production in the study area.

## 2. Literature review

### Effect of Phosphorus on Wheat Growth

Phosphorus plays a critical role in early root development and vegetative growth of wheat. Significant increases in plant height and tiller number with phosphorus fertilization have been reported by Alam et al. (2003) and Sharma et al. (2009). Enhanced tillering and biomass accumulation under increasing phosphorus levels have also been documented (Fioreze et al., 2012), highlighting the importance of adequate phosphorus supply during early growth stages.

### Effect on Yield Attributes and Grain Yield

Several studies have shown that phosphorus application improves yield components such as spike length, grains per spike, and thousand-grain weight. Hussain et al. (2002) reported increased grain yield and yield attributes with adequate phosphorus supply. Similarly Improved grain yield and yield attributes with adequate phosphorus supply have been reported across different soil types (Hussain et al., 2002; Memon et al., 2011).

## Optimum Phosphorus Application Rates

While phosphorus fertilization generally enhances wheat yield, excessive application does not always result in proportional yield increases. Rahim et al. (2010) reported diminishing returns at higher phosphorus levels, emphasizing the need for identifying optimum rates under specific agro-ecological conditions.

### 3. Material and Methods

The field experiment was conducted at the research farm of Urozgan Higher Education Institute during the 2020–2021 winter season. Soil samples were collected before sowing and analyzed at the laboratory of Afghanistan National Agricultural Sciences and Technology University. The soil was sandy loam in texture with a pH of 7.9. Available phosphorus: 25.35 kg/ha and Available potassium: 99.45 kg/ha.

The experiment was laid out in a randomized complete block design (RCBD) with four replications. Five phosphorus levels were applied: 0, 30, 60, 90, and 120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. A locally adapted irrigated wheat variety was sown on 22 November 2020. Each plot measured 3 m × 2 m with row spacing of 25 cm.

Phosphorus was applied as diammonium phosphate (DAP) as a basal dose at sowing. Nitrogen and potassium were applied uniformly to all treatments at rates of 100 kg N ha<sup>-1</sup> and 50 kg K ha<sup>-1</sup>, respectively. Standard agronomic practices were followed uniformly across all treatments throughout the growing season.

Data were recorded on growth parameters, yield attributes, and yield. Statistical analysis was performed using statistics' (SPSS and OPSTAT) software. Analysis of variance (ANOVA) was conducted, and treatment means were compared using the critical difference (CD) test at the 5% probability level.

### 4. Results

#### Growth Parameters

##### Plant Height (cm)

Plant height of wheat was significantly influenced by phosphorus application at different growth stages (Table 1). At 30 days after sowing (DAS), plant height ranged from 10.92 to 12.22 cm, and differences among treatments were not statistically significant. At 60 DAS, phosphorus application resulted in significant variation in plant height, with the tallest plants recorded under 60 and 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, while the lowest height was observed in the control treatment.

At 90 DAS, plant height increased further across all treatments; however, the differences were not statistically significant. A marked and significant increase in plant height was observed at 120 DAS, where application of 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> produced the tallest plants (92.92 cm). At harvest, plant height ranged from 90.00 to 94.95 cm, with the maximum height recorded under 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. Overall, plant height increased with increasing phosphorus levels up to 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, beyond which no appreciable improvement was observed.

##### Number of Tillers per Hill

The number of tillers per hill was significantly affected by phosphorus application at most growth stages (Table 1). At 30 DAS, tiller number ranged from 17.50 to 22.50, with the highest tiller production observed under 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. At 60 DAS, tiller number showed slight variation among treatments, with phosphorus-applied plots maintaining higher tiller counts than the control.

At 90 DAS, tiller number increased substantially in all treatments, although differences were not statistically significant. At 120 DAS and at harvest, phosphorus application significantly increased tiller number, with the maximum tillers per hill consistently recorded at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. These results indicate that phosphorus application enhanced tiller initiation and survival, particularly at the optimum level of 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>.

Table 1 summarizes the effects of different phosphorus (P<sub>2</sub>O<sub>5</sub>) fertilizer levels (0, 30, 60, 90, and 120 kg/ha) on wheat plant height (at different days after sowing, DAS) and number of tillers per hill.

Treatments	Growth Attributes									
	Plant height (cm)					Numbers of tillers/hill				
	30 DAYS*	60 DAYS*	90 DAS*	120 DAS*	At Harvest	30 DAYS*	60 DAYS*	90 DAS*	120 DAS*	At Harvest
0 Kg P <sub>2</sub> O <sub>5</sub> /ha	11.55	28.20	57.42	87.75	91.00	20.75	30.25	61.25	63.75	60.00
30 Kg P <sub>2</sub> O <sub>5</sub> /ha	11.37	28.80	55.25	84.85	90.00	17.50	29.25	58.75	63.00	58.50
60 Kg P <sub>2</sub> O <sub>5</sub> /ha	12.22	29.70	56.25	89.50	91.50	21.00	30.00	59.25	63.25	62.50
90 Kg P <sub>2</sub> O <sub>5</sub> /ha	11.70	30.17	57.25	92.92	94.95	22.50	33.75	66.75	68.25	69.25
120 Kg P <sub>2</sub> O <sub>5</sub> /ha	10.92	28.82	56.75	89.10	91.10	21.00	30.50	62.75	65.75	63.50
CD	N/A	1.30	N/A	4.45	N/A	1.54	N/A	N/A	N/A	5.25
SE(m)	0.85	0.42	1.46	1.42	1.23	0.49	1.22	2.21	1.37	1.68
CV	14.78	2.88	5.17	3.21	2.68	4.82	7.93	7.15	4.24	5.38

## Yield and Yield Attributes

### Number of Effective Tillers per Square Meter:

Phosphorus application significantly influenced the number of effective tillers per square meter (Table 2). The highest number of effective tillers (359.25 m<sup>-2</sup>) was recorded at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, followed by 120 and 30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. The lowest number of effective tillers was observed at 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, which was slightly lower than the control. These results indicate that optimum phosphorus availability enhanced tiller productivity.

### Number of Spikes per Square Meter:

The number of spikes per square meter increased with increasing phosphorus levels (Table 2). The highest spike density (334.50 spikes m<sup>-2</sup>) was recorded under 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, while the control treatment produced the lowest number of spikes (300 spikes m<sup>-2</sup>). Differences among treatments were statistically significant, as indicated by the critical difference value.

### Spike Length (cm):

Spike length was positively influenced by phosphorus application (Table 2). The longest spikes (8.03 cm) were observed at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, whereas the shortest spikes (7.50 cm) were recorded in the control treatment. Although phosphorus-treated plots generally produced longer spikes, differences among treatments were not statistically significant.

### 1000 Grain Weight (g):

Thousand-grain weight increased significantly with phosphorus application (Table 2). The maximum thousand-grain weight (40.73 g) was obtained at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, while the minimum was recorded under 30 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. These results suggest improved grain filling under optimum phosphorus supply.

### Number of Grains per Spike:

The number of grains per spike was significantly affected by phosphorus application (Table 2). The highest number of grains per spike (39.25) was recorded at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, whereas the lowest was observed in the control treatment (34.25). Grain number increased progressively with phosphorus application up to the optimum level and declined slightly at the highest phosphorus rate.

Table 2 presents the effects of different phosphorus (P<sub>2</sub>O<sub>5</sub>) application levels (0, 30, 60, 90, and 120 kg/ha) on various wheat yield components.

Treatment	Yield Attributes				
	No. of Effective Tillers/m	No. of Spike/m <sup>2</sup>	Spike Length (cm)	1000 Grain weight (g)	No. of grain/Spike
0 Kg P <sub>2</sub> O <sub>5</sub> /ha	326.000	300.000	7.500	37.900	34.250
30 Kg P <sub>2</sub> O <sub>5</sub> /ha	340.750	303.000	7.650	37.150	35.750
60 Kg P <sub>2</sub> O <sub>5</sub> /ha	319.750	307.500	7.600	37.625	36.000
90 Kg P <sub>2</sub> O <sub>5</sub> /ha	359.250	334.500	8.025	40.725	39.250
120 Kg P <sub>2</sub> O <sub>5</sub> /ha	335.750	324.250	7.575	39.675	38.000
CD	N/A	12.985	N/A	1.994	1.615
SE(m)	8.768	4.168	0.227	0.640	0.518
CV	5.214	2.656	5.921	3.316	2.829

## Grain Yield and Yield Components

### Grain Yield (ton ha<sup>-1</sup>):

Grain yield was significantly influenced by phosphorus application (Table 3). Grain yield increased progressively with increasing phosphorus levels, reaching a maximum of 4.4 t ha<sup>-1</sup> at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. A slight reduction in grain yield was observed at 120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, although yield at this level remained

higher than at lower phosphorus rates. The lowest grain yield (2.5 t ha<sup>-1</sup>) was recorded in the control treatment.

#### Straw Yield (ton ha<sup>-1</sup>):

Straw yield varied only slightly among treatments (Table 3). Straw yield remained nearly constant at lower phosphorus levels and increased marginally at 90 and 120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, indicating that phosphorus had a greater effect on grain yield than on vegetative biomass production.

#### Biological Yield (ton ha<sup>-1</sup>):

Biological yield increased steadily with increasing phosphorus application (Table 3). The highest biological yield (9.7 t ha<sup>-1</sup>) was obtained at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>, followed by 120 and 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. The lowest biological yield was recorded in the control treatment.

#### Harvest Index (HI, %):

Harvest index was significantly affected by phosphorus application (Table 3). Harvest index increased with increasing phosphorus levels, with the highest value recorded at 90 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>. A decline in harvest index at 120 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> suggests reduced efficiency of assimilate partitioning at higher phosphorus levels.

The table 3 summarizes the effects of different phosphorus (P<sub>2</sub>O<sub>5</sub>) application levels (0, 30, 60, 90, and 120 kg/ha) on wheat grain yield, straw yield, biological yield, and harvest index (HI).

Treatment	Yield (ton ha <sup>-1</sup> )			
	Grain	Straw	Biological	HI
0 Kg P <sub>2</sub> O <sub>5</sub> /ha	2.5	4.9	7.3	50.2
30 Kg P <sub>2</sub> O <sub>5</sub> /ha	3.0	4.9	7.9	61.0
60 Kg P <sub>2</sub> O <sub>5</sub> /ha	3.9	4.9	8.8	78.7
90 Kg P <sub>2</sub> O <sub>5</sub> /ha	4.4	5.2	9.7	85.3
120 Kg P <sub>2</sub> O <sub>5</sub> /ha	4.1	5.2	9.3	78.6
C.D. (5%)	0.15	0.26	0.32	4.56
SE(m)	0.05	0.08	0.10	1.48
C.V.	2.65	0.26	0.32	4.18

## 5. Discussion

The response of irrigated wheat to phosphorus fertilization observed in the present study is consistent with findings reported in several earlier studies conducted under comparable agro-ecological conditions. Improvements in growth parameters with increasing phosphorus application have been widely attributed to the role of phosphorus in enhancing root development, energy transfer, and

photosynthetic activity (Mengel & Kirkby, 2003; Alam et al., 2003). Adequate phosphorus supply promotes early crop establishment, which is critical for achieving higher yield potential in wheat.

The positive effect of phosphorus application on yield attributes such as effective tillers, spike length, and grains per spike observed in this study is in agreement with the findings of Sharma et al. (2009) and Fioreze et al. (2012), who reported that balanced phosphorus nutrition improves assimilate production and translocation to reproductive organs. These studies emphasized that optimum phosphorus availability enhances both source strength and sink capacity, resulting in improved grain yield.

The decline in grain yield at the highest phosphorus level ( $120 \text{ kg P}_2\text{O}_5 \text{ ha}^{-1}$ ) reflects the phenomenon of diminishing returns, which has also been documented by Rahim et al. (2010) and Memon et al. (2011). Excessive phosphorus application may lead to reduced phosphorus use efficiency due to fixation in alkaline soils and nutrient imbalance, particularly involving micronutrients such as zinc and iron (Alam & Shereen, 2002). Such imbalances can negatively affect enzymatic processes and grain development, ultimately limiting yield response at higher phosphorus rates.

Similar yield plateaus or reductions at excessive phosphorus levels have been reported by Chaturvedi (2006), who noted that wheat responds positively to phosphorus only up to an optimum level, beyond which additional inputs do not translate into yield gains. This suggests that plant phosphorus demand becomes saturated, and further fertilizer application results in inefficient nutrient use rather than productivity enhancement.

Phosphorus use efficiency was maximized at moderate phosphorus levels in the present study, which aligns with the conclusions of Jiang et al. (2006) and Rahim et al. (2010). These authors highlighted that efficient phosphorus management not only improves yield but also reduces nutrient losses and production costs. From an environmental standpoint, excessive phosphorus accumulation in soil can increase the risk of nutrient runoff and long-term soil imbalance, even in semi-arid regions (Brady & Weil, 2002).

Overall, the findings support the concept that optimum phosphorus application is essential for sustainable wheat production. Balanced phosphorus fertilization enhances productivity while maintaining nutrient use efficiency and minimizing environmental risks. These results reinforce the importance of site-specific fertilizer recommendations, particularly for regions like Urozgan province where localized agronomic data have been limited.

## 6. Conclusion

Phosphorus fertilization plays a vital role in improving the growth and productivity of irrigated wheat under the agro-climatic conditions of Urozgan province. The study confirms that wheat response to phosphorus is rate-dependent, with yield benefits increasing up to an optimum level and declining at excessive application rates due to reduced efficiency and nutrient imbalance.

The results suggest that moderate and balanced phosphorus application is more effective than excessive fertilization in achieving sustainable wheat production. The identified optimum phosphorus rate can be applied as a practical guideline for irrigated wheat cultivation in Urozgan province and in other regions with similar soil and climatic conditions. Although the study was conducted during a single growing season, the consistency of the observed responses with established physiological principles indicates that the findings are broadly applicable and can support long-term fertilizer management strategies aimed at enhancing productivity, efficiency, and sustainability.

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