

"Response of Two Wheat (*Triticum aestivum* L.) Cultivars to Levels and Application Methods of Phosphorus Fertilizer in Desert Soils"

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I. Abstract :

To investigate the effect of phosphorus fertilization on growth traits and yield of two wheat cultivars grown in desert regions, a field experiment was conducted in the Al-Lahis area, Basrah Governorate, during the 2025 winter season. The experiment was arranged in a randomized complete block design (RCBD) using a split-split plot layout with three replications. The main plots included two wheat cultivars (*Babel* and *Baghdad*), the sub-plots comprised three fertilizer application methods (soil application, foliar spraying, and combined soil and foliar application), and the sub-sub-plots included four phosphorus fertilizer levels. The results showed that the Baghdad cultivar outperformed in most of the studied traits, achieving the highest plant height (84.43 and 80.60 cm), number of tillers (300.03 and 268.58 tillers plant⁻¹), and flag leaf area (30.35 cm²). The P3 level recorded the highest grain yield (3.736- and 3.805-tons ha⁻¹) and harvest index (35.14% and 32.6%). The treatment combining Baghdad cultivar with foliar application resulted in the highest grain yield (3.073 tons ha⁻¹). Moreover, the combination of Baghdad cultivar with the P3 level produced the highest plant height (95.06 and 93.94 cm), number of tillers (383.33 and 379.78 tillers plant⁻¹), flag leaf area (42.39 cm²), and grain yield (3.926 tons ha⁻¹). The highest values for plant height (96.47 and 98.74 cm), number of tillers (438.00 and 470.67 tillers plant⁻¹), flag leaf area (48.57 cm²), and grain yield (4.367 tons ha⁻¹) were recorded under the treatment combining the Baghdad cultivar with foliar spraying and P3 fertilizer level.

Keywords: Phosphorus fertilization, cultivars, flag leaf area, number of tillers, application methods.

This research is extracted from the Ph.D. dissertation of the first author.



II. Introduction

Wheat plays a strategic role in global food security, ranking first among cereal crops in terms of production, consumption, and cultivated area worldwide. Global wheat productivity has reached 3.59 tons per hectare (USDA, 2023), while in Iraq, the average yield is 1.79 tons per hectare (Agricultural Statistics Directorate, 2023). High and quality wheat production largely depends on the balanced availability of macro- and micronutrients in accordance with the crop's growth requirements. These requirements vary depending on soil properties, crop type and cultivar, environmental conditions, and the management of soil and nutrient inputs (Salman, 2016; Ali, 2015; Panuccio, 2009; Ali, 2001). Phosphorus (P) plays a vital role in plant nutrition, being the primary element responsible for energy supply in various metabolic activities. Often referred to as the "key to life", phosphorus is directly involved in the formation of energy compounds (ATP, ADP), enzyme cofactors (NADP, NADPH, NADH, FAD), and in the synthesis of nucleic acids (DNA and RNA), phospholipids, and phosphoproteins (Al-Mawsili, 2018). However, when phosphorus fertilizers are applied to the soil, they often undergo fixation and precipitation reactions, reducing their availability to as low as 30% (Huang et al., 2015; Zhu et al., 2018). In the soils of southern Iraq, phosphorus availability ranges between 15% and 20% (Al-Halfi et al., 2018). To enhance phosphorus use efficiency, researchers have explored various application methods, including banding, placement between rows, furrow application, fertigation, and foliar spraying (Al-Rashidi et al., 2010). Foliar feeding is considered an effective strategy to improve phosphorus use efficiency, bypassing soil-related constraints by applying lower doses directly to meet plant needs, thus enhancing yield and grain quality (Mosali et al., 2006). Studies have shown that some crops can meet up to 80% of their nutrient requirements through aerial tissues such as stems and leaves, with the remainder absorbed via roots. Moreover, several studies have reported the superiority of foliar application over soil application in improving crop growth and productivity. This is often attributed to the alkaline nature of most agricultural soils, which limits phosphorus solubility and root uptake (Al-Alousi, 2003). Given the expansion of wheat cultivation into desert regions—characterized by poor nutrient and water retention—and the lack of prior studies on the impact of phosphorus on the growth and productivity of sprinkler-irrigated wheat cultivars in such environments, this study aimed to evaluate the effect of different phosphorus fertilizer levels on the growth traits and yield of two wheat cultivars grown under desert conditions.



III. Materials and Methods

A field experiment was conducted during the 2025 growing season in the Al-Lahis region of Basrah Governorate to study the effect of phosphorus fertilizer application methods and levels on two wheat cultivars. Soil samples were collected from the experimental field at a depth of 0–30 cm before sowing, and the physical and chemical properties of the soil were analyzed in the Central Laboratory of the College of Agriculture, University of Basrah. Soil organic matter content was determined by measuring organic carbon using the Walkley-Black method, as described by Page et al. (1982). Soil particle size distribution was determined using the pipette method according to Black (1965). The experimental field was plowed, leveled, and prepared according to a Randomized Complete Block Design (RCBD) in a split-split plot arrangement with three replications, resulting in a total of 72 experimental units. A 1-meter buffer zone was maintained between the plots. Each plot consisted of 10 rows, each 3 meters long, with a row spacing of 20 cm. Wheat was sown on November 23, 2024. Phosphorus fertilizer was applied in the form of monoammonium phosphate (MAP, 62% P), according to the treatments specified in the experiment. All agronomic practices were carried out as needed throughout the growing season.

Table 1. Some physical and chemical properties of the experimental field soil before planting

مفصولات التربة (%)		القيمة	الصفة
785.00	Sand	6.8	Electrical Conductivity (E.C) (dS/m)
75.00	Silt	7.60	Soil pH
130.00	Clay	33.00	Available Nitrogen (mg/kg)
Sandy clay	Soil Texture	2.50	Available Phosphorus (mg/kg)
Irrigation water		3.85	Available Potassium (mg/kg)
4.70	ds.m ⁻¹ (E.C)	6.90	Organic Matter (%)
7.85	(pH)		

Study Treatments

- **Main plots:** Two wheat cultivars were used in the experiment: *Babel* and *Baghdad*.

Year of Registration	Genetic Background	Cultivars
2000/10/8	Mexipak X Resistance Source (R23)	Babel
2012/9/24	MX105-06 MULT 40IBWSN	Baghdad

Secondary Plots: Phosphorus Fertilizer Application Methods Phosphorus fertilizer in the form of monoammonium phosphate (MAP) was applied using three methods: a) **Soil application (S):** A single basal dose applied to the soil at planting according to the specified levels. b) **Foliar application (F):** The total fertilizer dose was divided into three equal parts and applied as foliar spray at three growth stages: tillering, stem elongation, and flowering. (c) **Mixed application (M):** Half of the required fertilizer dose

was applied to the soil at planting, while the remaining half was divided into two equal parts and applied as foliar spray at the stem elongation and flowering stages.

. **The foliar spray** solution was prepared by dissolving the required amount of phosphorus fertilizer according to the treatments in distilled water, with the addition of Enforce as a surfactant to the spray tank. After adding the fertilizer, the solution was mixed slowly until the spray solution turned pink. Plants were sprayed using a 16-liter backpack sprayer until complete wetting, applied in the evening.

Studied Traits

- **Plant Height (cm):** Measured as the average height of ten randomly selected plants at the flowering stage. Height was measured from the base of the plant to the tip of the terminal spike (excluding the awns).
- **Flag Leaf Area at Flowering Stage (cm²):** Calculated as the average of ten randomly selected tillers per experimental unit at the flowering stage. The flag leaf area was calculated using the formula:
Flag Leaf Area (cm²) = Leaf Length × Maximum Width × 0.95 (Thomas, 1975).
- **Number of Tillers at Heading Stage (m⁻²):** Determined by counting the number of plants harvested from the middle rows within an area of one square meter in each experimental unit at harvest.
- **Grain Yield (ton ha⁻¹):** Estimated by weighing the grain yield from a randomly selected one square meter area within the experimental unit. After threshing the harvested sample, the weight was converted to tons per hectare.
- **Harvest Index (%)** was calculated according to Allan (1980) using the formula:

$$\text{Harvest Index (\%)} = \frac{\text{Grain Yield (ton ha}^{-1}\text{)}}{\text{Biological Yield (ton ha}^{-1}\text{)}} \times 100$$



Discussion of Results

Plant Height at Full Flowering Stage (cm)

The results presented in Table 2 revealed a significant effect of wheat cultivar on plant height, with the *Baghdad* cultivar exhibiting a higher mean height (80.60 cm) compared to *Babel*. This variation is attributed to differences in the length of internodes, which is a key trait distinguishing plant height among cultivars (Mohammed, 2000). Regarding fertilization methods, foliar application resulted in the highest average plant height of 82.07 cm, significantly surpassing soil application, which recorded the lowest average height of 76.17 cm. This superiority is likely due to the direct foliar uptake of phosphorus by stomata, facilitating rapid translocation through cell membranes and swift metabolic assimilation. Such efficient phosphorus availability promotes cell division and elongation, contributing to increased plant height (Mohammed et al., 2016; Drostkar et al., 2016). Furthermore, plant height increased significantly with rising phosphorus levels, ranging from 60.91 cm in the control treatment (P0) to 92.53 cm at the highest phosphorus level (P3). This enhancement reflects phosphorus's vital role in stimulating physiological processes, as it is a crucial element in ATP synthesis, providing the energy necessary for cellular division and the development of new tissues. These findings are consistent with previous studies conducted by Elea et al. (2018) and Al-Shaari (2021). The interaction effects were also significant, with the highest plant height (98.47 cm) observed in the triple interaction between the *Baghdad* cultivar, the highest phosphorus level (P3), and foliar application.

Number of Tillers (Tillers m⁻²)

The results in Table 3 indicated a significant effect of wheat cultivar on the number of tillers, with the *Baghdad* cultivar outperforming *Babel*, recording an average of 268.58 tillers m⁻². This variation is likely due to inherent genetic differences between the cultivars, consistent with findings reported by Pirevatlou-Johari et al. (2010). Regarding fertilization methods, foliar application yielded the highest mean tiller count at 278.42 tillers m⁻², while soil application recorded a lower value of 220.29 tillers m⁻². The combined application method (soil plus foliar) resulted in intermediate values (233.92 tillers m⁻²), surpassing soil application alone but falling short of foliar spray. The superiority of foliar phosphorus application is likely attributed to its rapid absorption and effective translocation within plant tissues, directly promoting lateral growth and stimulating tiller production (Reda, 2022). Moreover, the tiller count significantly increased with higher phosphorus levels, rising from 182.50 tillers m⁻² in the control (P0) to 334.67 tillers m⁻² at the highest phosphorus level (P3). This increase may be due to phosphorus's essential role in stimulating lateral root formation, enhancing root hair development, strengthening stems, and increasing tiller numbers. Phosphorus is a key source promoting cell division and growth, especially in the plant's most active regions. These results align with those of Anum et al. (2020) and Binder and Singh (2018), who highlighted the significant impact of elevated phosphorus levels on tiller number enhancement. Significant interaction effects were observed among the studied factors, with the highest tiller count (470.67 tillers m⁻²) recorded for the triple interaction involving the *Baghdad* cultivar, the highest phosphorus level (P3), and foliar application.



Flag Leaf Area (cm²)

The results presented in Table 4 revealed a significant effect of cultivar on flag leaf area, with the *Baghdad* cultivar outperforming *Babel*, recording an average area of 30.35 cm². The superiority of *Baghdad* in flag leaf area can be attributed to its superior genetic and physiological efficiency in producing better vegetative growth and enhanced photosynthetic capacity, which positively impacts overall crop productivity. In contrast, the reduced flag leaf area in *Babel* may be related to limited vegetative growth or faster leaf senescence (Anis and Al-Majma'i, 2020). The results also showed that plants receiving phosphorus through soil application had a smaller flag leaf area compared to those treated with foliar phosphorus application or combined soil and foliar applications across both growing seasons. Specifically, soil application recorded an average flag leaf area of 24.48 cm², whereas foliar application and combined application treatments yielded 31.86 cm² and 31.55 cm², respectively. The superior performance of foliar application can be explained by the direct supply of phosphorus to the aerial parts, avoiding the fixation and adsorption processes that reduce phosphorus availability in soil applications. Foliar feeding ensures rapid and balanced nutrient availability during the critical development phase of the flag leaf (Weeks & Hettiarachchi, 2019). Table 4 further indicates that increasing phosphorus levels significantly enhanced flag leaf area across both seasons, rising from 18.40 cm² in the control treatment (P0) to 40.98 cm² at the highest phosphorus level (P3). This improvement is likely due to phosphorus's role in enhancing photosynthetic efficiency, regulating oxidative metabolism, and improving water relations during the vegetative growth stage, thereby positively affecting plant growth and development, which ultimately reflects in larger flag leaf areas. These findings are consistent with those reported by Al-Mousawi (2020). Significant interaction effects were observed among the studied factors, with the highest flag leaf area (48.57 cm²) recorded for the triple interaction involving the *Baghdad* cultivar, the highest phosphorus level (P3), and foliar application.

Grain Yield (ton ha⁻¹)

The results presented in Table 5 indicated a significant effect of cultivar on grain yield, with the *Baghdad* cultivar outperforming *Babel*, achieving an average yield of 2.751 ton ha⁻¹. The superiority of *Baghdad* can be attributed to its enhanced traits such as larger flag leaf area, higher number of spikes, and greater 1000-grain weight. These findings align with Akram et al. (2002), who reported yield variation among cultivars due to their genetic makeup, as well as the results of Sial et al. (2009). Furthermore, foliar phosphorus application significantly surpassed soil and combined application methods, producing the highest grain yield averaging 2.874 ton ha⁻¹. Conversely, soil application resulted in the lowest grain yield of 2.303 ton ha⁻¹. The superiority of foliar fertilization is likely due to its efficiency in nutrient uptake and availability during critical growth stages, which positively impacted grain yield across both growing seasons (Izhar Shafi et al., 2020). Table 5 also revealed that increasing phosphorus levels led to a significant increase in grain yield, rising from 1.418 ton ha⁻¹ in the control treatment (P0) to 3.805 ton ha⁻¹ at the highest phosphorus level (P3). This enhancement can be attributed to phosphorus's critical role in numerous physiological processes, including the development of a robust and dense root system that enhances nutrient. plant height, flag leaf area, tiller number, and spike length, which facilitated efficient translocation of photosynthates to the grains, thereby increasing grain number per spike and 1000-grain weight (Figures 22 and 25). These results. concur with findings from Islam et al. (2017) and Al-Maeni & Al-Bajary (2019),





who demonstrated the significant positive impact of increased phosphorus levels on wheat grain yield absorption from the soil. This improvement subsequently promoted vegetative growth traits such as Significant interactions among the studied factors were observed, with the highest grain yield (4.367 ton ha⁻¹) recorded for the triple interaction involving the *Baghdad* cultivar, the highest phosphorus level (P₃), and foliar application method.

Harvest Index (%)

The results presented in Table 6 revealed no significant differences between the cultivars for the harvest index trait. The highest harvest index value was observed in the foliar phosphorus application treatment, reaching 27.8%, while the soil application method recorded the lowest harvest index at 25.6%. Additionally, the data showed a clear increase in harvest index with increasing phosphorus levels across both growing seasons, rising from 21.3% in the control treatment (P₀) to 32.6% at the highest phosphorus level (P₃). This improvement is likely due to enhanced resource allocation within the plant, supporting a greater translocation of photosynthates to the economic yield components (grains), thus increasing the harvest index These findings are consistent with those reported by Izhar Shafi et al. (2020) and Ali et al. (2020), who demonstrated the significant positive effect of elevated phosphorus levels on harvest index.

Table 2: Effect of Cultivars, Phosphorus Fertilizer Application Methods, Levels, and Their Interactions on Wheat Plant Height (cm).

Application Methods* Cultivars	Levels				Application Methods	Cultivars
	P ₄	P ₃	P ₂	P ₁		
75.04	85.64	83.63	72.93	57.97	S	Babel
80.14	95.13	89.80	76.97	58.67	F	
75.93	92.60	86.60	66.84	57.67	M	
77.30	88.83	80.20	77.17	63.00	S	Baghdad
83.99	98.47	94.90	78.77	63.83	F	
80.50	94.53	89.20	73.93	64.32	M	
Mean of Cultivars						
77.04	91.12	86.68	72.24	58.10	Babel	Cultivars* Levels
80.60	93.94	88.10	76.62	63.72	Baghdad	
Mean of Methods						
76.17	87.24	81.92	75.05	60.48	S	Application Methods* Levels
82.07	96.80	92.35	77.87	61.25	F	
78.21	93.57	87.90	70.39	60.99	M	
	92.53	87.39	74.43	60.91	Average of Levels	
P*A*V	P*A	P*V	A*V	P	A	V
1.442	1.028	0.835	0.741	0.607	0.557	0.762



Table 3: Effect of wheat cultivars, phosphate fertilizer application methods, levels, and their interactions on the number of tillers per wheat plant (tillers plant⁻¹).

Application Methods* Cultivars	Levels				Application Methods	Cultivars
	P ₄	P ₃	P ₂	P ₁		
210.00	256.00	217.67	194.33	172.00	S	Babel
251.75	378.00	262.33	191.67	175.00	F	
195.75	234.67	189.33	182.67	176.33	M	
230.58	272.67	238.33	219.00	192.33	S	Baghdad
305.08	470.67	322.33	234.00	193.33	F	
270.08	396.00	297.67	200.67	186.00	M	
Mean of Cultivars						
219.17	289.56	223.11	189.56	174.44	Babel	Cultivars* Levels
268.58	379.78	286.11	217.89	190.56	Baghdad	
Mean of Methods						
220.29	264.33	228.00	206.67	182.17	S	Application Methods* Levels
278.42	424.33	292.33	212.83	184.17	F	
232.92	315.33	243.50	191.67	181.17	M	
	334.67	254.61	203.72	182.50	Average of Levels	
P*A*V	P*A	P*V	A*V	P	A	V
11.861	8.376	7.073	6.459	4.926	4.601	7.198

Table 4: Effect of wheat cultivars, phosphate fertilizer application combinations, and their interactions on flag leaf area of wheat plants (cm²).

Application Methods* Cultivars	Levels				Application Methods	Cultivars
	P ₄	P ₃	P ₂	P ₁		
23.10	29.40	25.07	19.80	18.13	S	Babel
30.67	46.63	35.53	22.23	18.27	F	
30.97	42.67	39.23	24.07	17.90	M	
25.85	34.80	27.95	21.73	18.93	S	Baghdad
33.05	48.57	42.07	22.73	18.83	F	
32.14	43.80	41.10	25.33	18.33	M	
Mean of Cultivars						
28.24	39.57	33.28	22.03	18.10	Babel	Cultivars* Levels
30.35	42.39	37.04	23.27	18.70	Baghdad	
Mean of Methods						
24.48	32.10	26.51	20.77	18.53	S	Application Methods* Levels
31.86	47.60	38.80	22.48	18.55	F	
31.55	43.23	40.17	24.70	18.12	M	
Average of Levels						
	40.98	35.16	22.65	18.40		
P*A*V	P*A	P*V	A*V	P	A	V
2.132	1.346	1.611	N.S	0.814	0.667	2.103



Table 5: Effect of wheat cultivars, phosphate fertilizer application methods, levels, and their interactions on grain yield of wheat plants (ton ha⁻¹).

Application Methods* Cultivars	Levels				Application Methods	Cultivars
	P ₄	P ₃	P ₂	P ₁		
2.200	3.033	2.607	1.727	1.433	S	Babel
2.563	4.060	3.093	1.730	1.370	F	
2.675	3.960	3.477	1.890	1.373	M	
2.406	3.250	3.150	1.813	1.410	S	Baghdad
3.073	4.367	3.897	2.567	1.463	F	
2.774	4.160	3.283	2.193	1.460	M	
Mean of Cultivars						
2.479	3.684	3.059	1.782	1.392	Babel	Cultivars* Levels
2.751	3.926	3.443	2.191	1.444	Baghdad	
Mean of Methods						
2.303	3.142	2.878	1.770	1.422	S	Application Methods* Levels
2.874	4.163	3.687	2.228	1.418	F	
2.669	4.110	3.188	1.961	1.415	M	
	3.805	3.251	1.987	1.418	Average of Levels	
P*A*V	P*A	P*V	A*V	P	A	V
0.2389	0.1602	0.1589	0.1446	0.0992	0.0705	0.1875



Table 6: Effect of wheat cultivars, phosphate fertilizer application methods, levels, and their interactions on harvest index of wheat plants (%).

Application Methods* Cultivars					Application Methods	Cultivars
	P ₄	P ₃	P ₂	P ₁		
25.3	29.4	25.8	24.1	21.9	S	Babel
27.9	34.9	32.8	22.7	20.9	F	
26.5	33.3	27.6	23.5	21.7	M	
25.9	30.4	29.9	22.4	21.0	S	Baghdad
27.8	34.4	32.0	23.4	21.3	F	
26.4	33.3	27.1	24.0	21.0	M	
Mean of Cultivars						
26.6	32.5	28.8	23.4	21.5	Babel	Cultivars* Levels
26.7	32.7	29.7	23.3	21.1	Baghdad	
Mean of Methods						
25.6	29.9	27.8	23.3	21.4	S	Application Methods* Levels
27.8	34.7	32.4	23.1	21.1	F	
26.4	33.3	27.4	23.7	21.4	M	
	32.6	29.2	23.3	21.3		
P*A*V	P*A	P*V	A*V	P	A	V
N.S	1.77	N.S	N.S	1.11	0.72	N.S



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