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Effect of irrigation stress and phosphorus levels on growth, yield and economics of Wheat (*Triticum aestivum* L.)

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Abstract

A field experiment was conducted during *rabi* 2025-26 at the Agronomy Research Farm, Guru Kashi University, Talwandi Sabo, Bathinda, Punjab, India (29°57'N, 75°7'E; altitude 213 m ASL) to study the effect of irrigation stress and phosphorus (P) levels on growth, yield and economics of wheat cv. 'DBW 222'. The experiment was laid out in a split plot design with three replications. Main plots comprised four P levels (0, 30, 60 and 90 kg P₂O₅ ha⁻¹) and sub-plots three critical irrigation timings [Crown Root Initiation (CRI-I₁), Booting (I₂) and Anthesis (I₃)]. Results revealed that both P levels and irrigation timing significantly influenced all growth, yield and economic parameters. Application of 90 kg P₂O₅ ha⁻¹ combined with irrigation at CRI (P₉₀I₁) recorded significantly maximum plant height (103.2 cm), effective tillers (447 m⁻²), dry matter accumulation (1762 g m⁻²), spike length (13.9 cm), 1000-grain weight (45.9 g) and grain yield (56.4 q ha⁻¹). The P₉₀ treatment yielded the highest net returns (₹89,350 ha⁻¹) and benefit-cost ratio (2.91). Moisture deficit at early growth stages severely curtailed P diffusion, root development and nutrient uptake, while adequate P supply mitigated terminal drought effects. It is concluded that 90 kg P₂O₅ ha⁻¹ with CRI irrigation is the most productive and economically viable management strategy for wheat in semi-arid regions of the Indo-Gangetic plain.

Keywords: Benefit-cost ratio, crown root initiation, DBW 222, phosphorus levels, split plot design, *Triticum aestivum*, water stress, wheat yield

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important *rabi* cereal crops in India, occupying more than 33 million ha and contributing substantially to national food security (1). Punjab, Haryana and Uttar Pradesh together account for a major share of production, with wheat forming the dietary staple for millions of people in the form of chapati and bread (2). Inadequate phosphorus (P) nutrition and unscheduled irrigation are considered the two most critical constraints limiting wheat productivity in the Indo-Gangetic plain. Phosphorus is an essential macronutrient involved in energy transfer (ATP), photosynthesis, cell division and root development. Its diffusion in soil is strongly dependent on soil moisture, so moisture deficit directly reduces P availability to plant roots (3, 4). Timely irrigation at critical phenological stages, Crown Root Initiation (CRI), Booting and Anthesis is indispensable because water stress at these stages reduces tiller number, spike fertility and grain weight, leading to severe yield penalties (5, 6).

In Punjab, rapid depletion of groundwater tables has intensified the need for water-efficient irrigation schedules. Research has repeatedly demonstrated a synergistic interaction between P supply and soil moisture: adequate P promotes deeper root systems that exploit residual soil moisture, while sufficient moisture enhances P diffusion and uptake (7, 8). Despite this, farmers often apply P fertilizers without matching irrigation, resulting in poor fertilizer-use efficiency (9). The high-yielding variety DBW 222, released for the North-Western Plain Zone, shows a strong positive response to both P nutrition and timely irrigation (10). A systematic evaluation of P × irrigation interactions for this variety under semi-arid Punjab conditions has not been reported. The present study was therefore undertaken with the following objectives: (i) to evaluate the effect

of P levels (0, 30, 60 and 90 kg P₂O₅ ha⁻¹) on growth and yield of wheat; (ii) to assess the influence of irrigation timing (CRI, Booting, Anthesis) on yield attributes; (iii) to quantify P and N uptake under different P × irrigation combinations; and (iv) to identify the most economically viable P × irrigation combination for semi-arid wheat production.

Materials and Methods

Experimental site

The field experiment was conducted during rabi 2025–26 at the Agronomy Research Farm, Guru Kashi University, Talwandi

Sabo, Bathinda, Punjab, India (lat. 29°57'N; long. 75°7'E; altitude 213 m asl). The climate is semi-arid with extreme summers and cold winters. The experimental period (November 2025 to April 2026) recorded a maximum temperature of 35.0°C in April (maturity stage) and a minimum of 6.0°C in January (tillering–jointing stage). Total rainfall during the crop season was only 3 mm; all crop water requirements were therefore met through scheduled irrigation. Optimum photosynthetic temperatures (20–25 °C) occurred in February–March, coinciding with spikelet development and anthesis.

Table 1: Meteorological data during rabi 2025-26 at Talwandi Sabo

Month	Max temp (°C)	Min temp (°C)	Relative humidity (%)	Rainfall (mm)
November	27.5	13.5	66	2
December	23.0	9.0	71	0
January	19.0	6.0	76	0
February	26.0	11.0	64	1
March	30.5	15.5	55	0
April	35.0	20.0	48	0

Soil properties

Composite soil samples were collected from the 0–15 cm layer before sowing and analyzed for physico-chemical properties

(Table 2). The soil was sandy loam with neutral to slightly alkaline pH (7.6), low organic carbon (0.42%) and low available P (18.2 kg ha⁻¹).

Table 2: Initial physico-chemical properties of the experimental soil (0–15 cm depth)

Property	Value	Method
pH (1:2.5)	7.6	Glass-electrode (Jackson 1967)
EC (dS m ⁻¹)	0.34	Conductivity meter 1:2 (Jackson 1967)
Organic carbon (%)	0.42	Walkley–Black rapid titration (Jackson 1967)
Available N (kg ha ⁻¹)	235.0	Alkaline KMnO ₄ (Subbiah and Asija 1956)
Available P ₂ O ₅ (kg ha ⁻¹)	18.2	Olsen <i>et al</i> (1954)
Available K ₂ O (kg ha ⁻¹)	275.5	NH ₄ OAc extraction (Jackson 1967)
Available Zn (mg kg ⁻¹)	0.55	DTPA – AAS (Lindsay and Norvell 1978)

Experimental design and treatments

The experiment was laid out in a split plot design (SPD) with three replications. Main plots consisted of four P levels (P₀: 0, P₃₀: 30, P₆₀: 60 and P₉₀: 90 kg P₂O₅ ha⁻¹ as single superphosphate) and sub-plots of three irrigation timings [I₁: CRI (20–25 DAS); I₂: Booting; I₃: Anthesis], giving 12 treatment combinations and 36 plots. Each net plot measured 3.0 m × 3.0 m (9.0 m²) with intervening bunds to prevent inter-plot water movement.

Crop management

Wheat cv. 'DBW 222' was sown on 15 November 2025 at 100 kg seed ha⁻¹ in rows 22.5 cm apart at 4-5 cm depth. Nitrogen was applied uniformly at 150 kg ha⁻¹ (urea): half as basal + two equal splits at 24 December 2025 and 14 February 2026. Potassium was applied as muriate of potash at 40 kg K₂O ha⁻¹ basal. Phosphorus was applied as full basal dose as per treatment and incorporated to 10 cm depth. Weeds were controlled by pre-emergence pendimethalin @ 1.0 kg a.i. ha⁻¹ within 48 h of sowing and supplemented by hand weeding at 35 DAS. The crop was harvested with hand sickles in April 2026 at physiological maturity; grain and straw were threshed separately, sun-dried for three days and recorded at approximately 12% moisture content.

Observations

Growth observations (plant height, dry matter accumulation and number of effective tillers m⁻²) were recorded on five tagged plants per net plot at 30, 60, 90 DAS and at harvest. Plant height was measured from ground level to spike tip (awns excluded). Dry matter was determined by oven-drying at 65 °C to constant

weight and expressed as g m⁻². Yield attributes (spike length cm and 1000-grain weight g) were recorded at harvest. Grain and straw yield were recorded plot-wise and converted to q ha⁻¹. Phosphorus and nitrogen contents in grain and straw were determined by standard analytical methods and uptake calculated as (content × yield).

Economic analysis

Gross returns were calculated as: (grain yield × MSP 2025–26) + (straw yield × market price). Net returns = gross returns – cost of cultivation. Benefit-cost (B:C) ratio = net returns ÷ cost of cultivation.

Statistical analysis

Data were subjected to analysis of variance (ANOVA) for split plot design following Cochran and Cox (1967) and Gomez and Gomez (1984). Treatment means were compared at the 5% level of significance (P = 0.05) using critical difference (CD) values. All statistical computations were done using standard ANOVA procedures.

Results and Discussion

Plant height

Plant height increased progressively and significantly with increasing P levels at all growth stages and at harvest (Table 3). Maximum plant height at harvest was recorded under P₉₀ (99.4 cm) compared with P₀ control (88.2 cm). Among irrigation timings, I₁ (CRI irrigation) recorded significantly greater plant height (98.1 cm at harvest) than I₂ (94.2 cm) and I₃ (90.4 cm). The

interaction $P \times I$ was significant; the tallest plants (103.2 cm) were produced under the $P_{90}I_1$ combination. Water application at CRI enhanced P ion diffusion in the soil solution, promoting cellular elongation and internode extension through adequate ATP supply (11, 12). Conversely, moisture deficit at CRI and booting (I_2 and I_3) reduced turgor pressure, restricting cell expansion in actively growing meristematic zones (13). These findings are consistent with Kumar *et al* (23) and Singh *et al* (44) who reported that phosphorus promotes intermodal elongation through enhanced metabolic activity.

Table 3: Effect of phosphorus levels and irrigation timing on plant height (cm) of wheat cv. 'DBW 222'

Treatment	30 DAS	60 DAS	90 DAS	At harvest
Phosphorus levels (kg P₂O₅ ha⁻¹)				
P ₀ (Control)	18.5	42.1	78.4	88.2
P ₃₀	20.2	45.6	82.3	92.5
P ₆₀	22.4	48.9	86.7	96.8
P ₉₀	23.8	51.2	89.5	99.4
S.Em ±	0.82	1.15	1.45	1.60
CD (P = 0.05)	2.45	3.42	4.30	4.75
Irrigation timing				
I ₁ (CRI)	24.1	50.5	88.2	98.1
I ₂ (Booting)	18.2	43.4	84.6	94.2
I ₃ (Anthesis)	17.5	41.2	80.1	90.4
S.Em ±	0.75	1.02	1.30	1.45
CD (P = 0.05)	2.10	2.85	3.65	4.05
Interaction P × I (at harvest)				
I ₁ × P ₀ / P ₃₀ / P ₆₀ / P ₉₀	92.1	96.4	100.7	103.2
I ₂ × P ₀ / P ₃₀ / P ₆₀ / P ₉₀	88.2	92.5	96.8	99.3
I ₃ × P ₀ / P ₃₀ / P ₆₀ / P ₉₀	84.3	88.6	92.9	95.7
S.Em ± (P × I)	—	—	—	1.05
CD (P = 0.05)	—	—	—	3.15

Number of effective tillers (m⁻²)

Phosphorus application significantly increased the number of effective tillers m⁻² at all observation dates (Table 4). At harvest, P₉₀ produced 402 tillers m⁻² compared with 302 tillers m⁻² in P₀. I₁ irrigation produced significantly more tillers (398 m⁻²) than I₂

(332 m⁻²) or I₃ (312 m⁻²). Maximum tiller number (447 m⁻²) was recorded under P₉₀I₁. Phosphorus stimulates early root growth and tiller initiation by supplying metabolic energy (ATP) and supporting meristematic activity at the CRI stage (14). Moisture stress at this critical stage prevented adventitious root development and primary tiller differentiation, an injury not fully recoverable in subsequent growth stages (15).

Table 4: Effect of phosphorus levels and irrigation timing on effective tillers (m⁻²) of wheat cv. 'DBW 222'

Treatment	60 DAS	90 DAS	At harvest
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	285	310	302
P ₃₀	312	345	338
P ₆₀	348	382	375
P ₉₀	372	410	402
S.Em ±	12.4	14.1	13.8
CD (P = 0.05)	37.5	42.5	41.2
Irrigation timing			
I ₁ (CRI)	365	405	398
I ₂ (Booting)	310	340	332
I ₃ (Anthesis)	290	320	312
S.Em ±	10.5	11.8	11.5
CD (P = 0.05)	30.2	34.1	33.2
Interaction P ₉₀ I ₁ / P ₉₀ I ₂ / P ₉₀ I ₃ (harvest)	—	—	447 / 386 / 373
S.Em ± (P × I)	—	—	16.1
CD (P = 0.05)	—	—	48.5

Dry matter accumulation (g m⁻²)

Dry matter accumulation increased steadily from 60 DAS to harvest across all treatments (Table 5). At harvest, P₉₀ recorded 1560 g m⁻², which was 35.6% higher than P₀ (1150 g m⁻²). I₁ recorded 1520 g m⁻² against 1220 g m⁻² under I₃. The interaction P₉₀I₁ produced the highest dry matter (1762 g m⁻²). Higher P availability improved leaf area index (LAI) through greater cell division, thereby enhancing light interception and photosynthetic efficiency. Drought-induced stomatal closure under I₂ and I₃ restricted CO₂ assimilation and reduced overall biomass accumulation (16, 17).

Table 5: Effect of phosphorus levels and irrigation timing on dry matter accumulation (g m⁻²) of wheat cv. 'DBW 222'

Treatment	60 DAS	90 DAS	At harvest
Phosphorus levels (kg P₂O₅ ha⁻¹)			
P ₀	340	710	1150
P ₃₀	385	820	1280
P ₆₀	425	940	1410
P ₉₀	460	1050	1560
S.Em ±	15.2	32.4	45.6
CD (P = 0.05)	46.1	98.2	138.5
Irrigation timing			
I ₁ (CRI)	440	1020	1520
I ₂ (Booting)	380	850	1310
I ₃ (Anthesis)	350	780	1220
S.Em ±	14.1	28.6	40.2
CD (P = 0.05)	41.2	82.5	116.4
Interaction P ₉₀ I ₁ (harvest)	—	—	1762
S.Em ± (P × I)	—	—	50.8
CD (P = 0.05)	—	—	152.4

Yield attributes: spike length and 1000-grain weight

Both spike length and 1000-grain weight (test weight) increased significantly with increasing P levels and were highest under I₁ irrigation (Table 6). Maximum spike length (11.8 cm) and test weight (43.5 g) were recorded under P₉₀, while minimum values (8.4 cm and 36.5 g) were observed in P₀. Irrigation at CRI (I₁)

produced the longest spikes (11.2 cm) and heaviest grain (42.1 g); delayed irrigation to anthesis (I₃) reduced 1000-grain weight to 37.8 g. The interaction P₉₀I₁ produced the longest spike (13.9 cm) and heaviest grain (45.9 g). Phosphorus is integral to nucleic acids and phospholipids required during rapid cell division at the spikelet differentiation phase. High P at 90 kg ha⁻¹ enhanced

translocation of photo assimilates to reproductive sinks, reducing spikelet abortion (18, 19). Even under terminal drought stress (I_3), application of 90 kg P_2O_5 ha⁻¹ improved 1000-grain weight (41.7 g) above the irrigated control (38.2 g), indicating that P acts as a physiological buffer against terminal drought, consistent with findings of Si *et al* (41) and Mumtaz *et al* (28).

Table 6: Effect of phosphorus levels and irrigation timing on spike length (cm) and 1000-grain weight (g) of wheat cv. 'DBW 222'

Treatment	Spike length (cm)	1000-grain weight (g)
Phosphorus levels (kg P_2O_5 ha⁻¹)		
P_0	8.4	36.5
P_{30}	9.2	38.2
P_{60}	10.5	40.8
P_{90}	11.8	43.5
S.E.m $\pm$	0.28	0.81
CD (P = 0.05)	0.85	2.42
Irrigation timing		
I_1 (CRI)	11.2	42.1
I_2 (Booting)	9.8	39.5
I_3 (Anthesis)	9.1	37.8
S.E.m $\pm$	0.24	0.70
CD (P = 0.05)	0.72	2.10
Interaction $P_{90}I_1$	13.9	45.9
S.E.m $\pm$ (P $\times$ I)	1.15 / 0.38*	0.83
CD (P = 0.05)	—	2.50

Grain and straw yield

Grain and straw yield increased significantly with increasing P levels and were maximum under I_1 irrigation (Table 7). The highest grain yield (51.8 q ha⁻¹) and straw yield (70.4 q ha⁻¹) were recorded under P_{90} , while P_0 produced 32.5 and 48.2 q ha⁻¹, respectively. Among irrigation timings, I_1 produced significantly greater grain (48.6 q ha⁻¹) and straw yield (66.5 q ha⁻¹) than I_2 or I_3 . Maximum grain yield (56.4 q ha⁻¹) was obtained under $P_{90}I_1$. Harvest index was not significantly affected by either P or irrigation, indicating that while total biomass increased, the

partitioning ratio (grain: straw) in cv. 'DBW 222' was genetically stable. This is in agreement with Noonari *et al* (30) who reported a linear increase in grain yield with P application up to 90 kg ha⁻¹, and Kumar *et al* (22) who documented significant yield losses following delayed early irrigation in northwest India.

Table 7: Effect of phosphorus levels and irrigation timing on grain yield (q ha⁻¹), straw yield (q ha⁻¹) and harvest index (%) of wheat cv. 'DBW 222'

Treatment	Grain yield (q ha ⁻¹)	Straw yield (q ha ⁻¹)	Harvest index (%)
Phosphorus levels (kg P_2O_5 ha⁻¹)			
P_0	32.5	48.2	40.2
P_{30}	38.4	54.5	41.3
P_{60}	45.2	62.8	41.8
P_{90}	51.8	70.4	42.4
S.E.m $\pm$	1.28	1.71	NS
CD (P = 0.05)	3.85	5.12	NS
Irrigation timing			
I_1 (CRI)	48.6	66.5	42.2
I_2 (Booting)	41.2	58.4	41.3
I_3 (Anthesis)	36.8	52.1	41.3
S.E.m $\pm$	1.03	1.42	NS
CD (P = 0.05)	3.10	4.25	NS
Interaction $P_{90}I_1$	56.4	75.7	—
S.E.m $\pm$ (P $\times$ I)	1.80	2.15	—
CD (P = 0.05)	5.40	6.45	—

Post-harvest soil properties

Soil pH, EC and organic carbon did not differ significantly among treatments (Table 8). Available soil P increased significantly with P level, ranging from 10.5 (P_0) to 24.1 kg ha⁻¹, with irrigation timing also showing a significant effect. Higher residual soil P under I_3 (18.8 kg ha⁻¹) compared to I_1 (15.5 kg ha⁻¹) reflected reduced crop uptake caused by moisture-limited P diffusion and lower biomass production under stressed conditions. Available K was unaffected by treatments.

Table 8: Effect of phosphorus levels and irrigation timing on post-harvest soil properties

Treatment	pH	EC (dS m ⁻¹)	OC (%)	Avail. N (kg ha ⁻¹)	Avail. P (kg ha ⁻¹)	Avail. K (kg ha ⁻¹)
Phosphorus levels						
P_0	7.62	0.34	0.41	142.5	10.5	212.4
P_{30}	7.60	0.35	0.42	144.1	14.2	214.5
P_{60}	7.61	0.36	0.42	145.8	18.6	211.8
P_{90}	7.59	0.35	0.43	147.2	24.1	215.2
CD (P = 0.05)	NS	NS	NS	NS	2.55	NS
Irrigation timing						
I_1 (CRI)	7.60	0.34	0.42	143.2	15.5	212.1
I_2 (Booting)	7.61	0.35	0.42	145.4	17.2	214.3
I_3 (Anthesis)	7.60	0.36	0.41	146.1	18.8	213.9
CD (P = 0.05)	NS	NS	NS	NS	1.95	NS

Phosphorus and nitrogen uptake

Total P uptake increased significantly from 11.00 kg ha⁻¹ (P_0) to 27.13 kg ha⁻¹ (P_{90}) and was highest under I_1 (23.22 kg ha⁻¹; Table 9). The interaction $P_{90}I_1$ yielded maximum total P uptake (36.08 kg ha⁻¹). Soil moisture at CRI provided a diffusion pathway for basal-applied SSP, delivering P ions to developing crown roots. Under drought conditions (I_2 , I_3), diffusion was limited by low soil water potential, effectively starving roots even where fertilizer P was adequate (20). High P application (90 kg ha⁻¹) compensated partially under stress by stimulating root elongation

and lateral root formation, enabling $P_{90}I_3$ plants (21.24 kg ha⁻¹ P uptake) to outperform well-irrigated P_0 plots (12.50 kg ha⁻¹), consistent with Kang *et al* (19).

Total N uptake followed a similar trend, rising from 76.9 kg ha⁻¹ (P_0) to 134.0 kg ha⁻¹ (P_{90} ; Table 10). This synergistic effect of P on N uptake reflects the role of a well-developed root system in mining greater soil volume for nitrate. The interaction $P_{90}I_1$ produced the highest N uptake (175.4 kg ha⁻¹), demonstrating that adequate P and timely moisture together maximize nutrient-use efficiency.

Table 9: Main effects of phosphorus levels and irrigation timing on phosphorus uptake (kg ha⁻¹) by wheat cv. 'DBW 222'

Treatment	P content grain (%)	P content straw (%)	P uptake grain (kg ha ⁻¹)	P uptake straw (kg ha ⁻¹)	Total P uptake (kg ha ⁻¹)
Phosphorus levels					
P ₀	0.22	0.08	7.15	3.85	11.30
P ₃₀	0.25	0.10	9.60	5.45	15.40
P ₆₀	0.29	0.13	13.10	8.16	21.68
P ₉₀	0.32	0.15	16.57	10.56	27.60
CD (P = 0.05)	0.03	0.02	1.35	1.05	2.45
Irrigation timing					
I ₁ (CRI)	0.30	0.13	14.58	8.64	23.65
I ₂ (Booting)	0.26	0.11	10.71	6.42	17.50
I ₃ (Anthesis)	0.24	0.09	8.83	4.68	13.84
CD (P = 0.05)	0.03	0.03	1.22	0.80	2.08

Table 10: Main effects of phosphorus levels and irrigation timing on nitrogen uptake (kg ha⁻¹) by wheat cv. 'DBW 222'

Treatment	N uptake grain (kg ha ⁻¹)	N uptake straw (kg ha ⁻¹)	Total N uptake (kg ha ⁻¹)
Phosphorus levels			
P ₀	52.8	24.1	76.9
P ₃₀	65.2	28.3	93.5
P ₆₀	79.5	34.5	114.0
P ₉₀	93.2	40.8	134.0
CD (P = 0.05)	4.10	2.85	6.50
Irrigation timing			
I ₁ (CRI)	88.5	38.4	126.9
I ₂ (Booting)	74.2	32.1	106.3
I ₃ (Anthesis)	65.1	25.2	90.3
CD (P = 0.05)	3.85	2.50	5.45
Interaction P ₉₀ I ₁	—	—	175.4
CD (P = 0.05)	—	—	9.25

Economics of wheat production

Economic analysis (Table 11) showed that although cost of cultivation increased marginally with P level (₹41,500 ha⁻¹ for P₀ to ₹46,600 ha⁻¹ for P₉₀), the additional expenditure (~₹5,100 ha⁻¹) was far outweighed by the increase in net returns (₹89,350 ha⁻¹ for P₉₀ vs ₹43,750 ha⁻¹). P₉₀ recorded the highest B:C ratio (2.91), compared with 2.05 for P₀. Among irrigation timings, I₁ yielded maximum net returns (₹79,500 ha⁻¹) and B:C ratio (2.76), while I₃ reduced net returns to ₹53,100 ha⁻¹. The results emphasize that every rupee invested in basal P and timely CRI irrigation generates significantly higher profit, an observation corroborated by Patidar *et al* (33) and Tiwari *et al* (48).

Table 11: Effect of phosphorus levels and irrigation timing on economics of wheat production (₹ ha⁻¹)

Treatment	Cost of cultivation (₹ ha ⁻¹)	Gross returns (₹ ha ⁻¹)	Net returns (₹ ha ⁻¹)	B:C ratio
Phosphorus levels				
P ₀	41,500	85,250	43,750	2.05
P ₃₀	43,200	1,00,800	57,600	2.33
P ₆₀	44,900	1,18,650	73,750	2.64
P ₉₀	46,600	1,35,950	89,350	2.91
CD (P = 0.05)	—	5,420	4,650	0.16
Irrigation timing				
I ₁ (CRI)	45,000	1,24,500	79,500	2.76
I ₂ (Booting)	44,200	1,08,150	63,950	2.44
I ₃ (Anthesis)	43,500	96,600	53,100	2.22
CD (P = 0.05)	—	4,850	3,950	0.13

Conclusion

Application of 90 kg P₂O₅ ha⁻¹ combined with irrigation at the CRI stage (P₉₀I₁) consistently gave the highest values for all growth parameters (plant height 103.2 cm, effective tillers 447 m⁻², dry matter 1762 g m⁻²), yield attributes (spike length 13.9

cm, 1000-grain weight 45.9 g) and grain yield (56.4 q ha⁻¹) of wheat cv. 'DBW 222' under the semi-arid conditions of Punjab. The interaction between P and irrigation timing was significant for all parameters, confirming that moisture at CRI is essential for effective P diffusion and root development. Even under terminal drought stress (I₃), 90 kg P₂O₅ ha⁻¹ maintained higher yields and nutrient uptake than well-irrigated control plots, demonstrating the buffering role of adequate P nutrition. On economic grounds, P₉₀ with CRI irrigation gave a B:C ratio of 2.91 and net returns of ₹89,350 ha⁻¹, making it the most viable and recommended agronomic practice for semi-arid wheat production in the Indo-Gangetic plain.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. Abbas T, Ali S, Rizwan M, *et al*. Integrated phosphorus nutrient sources improve wheat yield and phosphorus use efficiency under sub-humid conditions. *PLoS One*. 2021;16(10):e0258285.
2. Abdelraouf RE, El-Habbasha SF, Taha MH, Refaie KM. Effect of irrigation water requirements and fertigation levels on growth, yield and water use efficiency in wheat. *Middle East J Sci Res*. 2013;16(4):441-450.
3. Alam MS, Jahan I. Yield and yield components of wheat as affected by phosphorus fertilization. *Rajshahi Univ J Life Earth Agric Sci*. 2013;41:21-27.

4. Ali A, Asif M, Adnan M, Aziz A, Hayyat MS, Saleem MW, Ali SM. Effect of different levels of phosphorus on growth, yield and quality of wheat (*Triticum aestivum* L.). Int J Bot Stud. 2020;5:64-68.
5. Arya KC, Singh SN. Effect of different levels of phosphorus and zinc on yield and nutrient uptake of wheat (*Triticum aestivum* L.) with and without irrigation. Indian J Agron. 2000;45(4):717-721.
6. Bashir MA, Rehim A, Ali A. Phosphorus placement's influence on yield, yield components, and P uptake in wheat. J Agric Sci. 2015;25(3):112-118.
7. Bashir S, Anwar S, Ahmad B, Sarfraz Q, Khatak W, Islam M. Response of wheat crop to phosphorus levels and application methods. J Environ Earth Sci. 2015;5(9):151-155.
8. Behera SK, Panda RK. Effect of fertilization and irrigation schedule on water and fertilizer solute transport for wheat crop in a sub-humid sub-tropical region. Agric Ecosyst Environ. 2009;130(3-4):141-155.
9. Dar EA, Brar AS, Poonia T, Bhat MA. Influence of sowing dates and irrigation schedules on growth and yield of drip-irrigated wheat (*Triticum aestivum*) under semi-arid conditions of Punjab. Indian J Agron. 2019;64(2):218-225.
10. Devi KN, Singh MS, Singh NG, Athokpam HS. Effect of integrated nutrient management on growth and yield of wheat (*Triticum aestivum* L.). J Crop Weed. 2011;7(2):23-27.
11. Dubey Y, Sharma SK. Effect of irrigation and fertilizers on growth, yield and nutrient uptake by wheat (*Triticum aestivum*). Indian J Agron. 1996;41(1):41.
12. Grant CA, Flaten DN, Tomasiewicz DJ, Sheppard SC. The importance of early season phosphorus nutrition. Can J Plant Sci. 2001;81:211-224.
13. Holford ICR. Soil phosphorus: Its measurement, and its uptake by plants. Aust J Soil Res. 1997;35:227-239.
14. Hussain MI, Shah SH, Hussain SAJ, Iqbal K. Growth, yield and quality response of three wheat (*Triticum aestivum* L.) varieties to different levels of N, P and K. Int J Agric Biol. 2002;4(3):362-364.
15. Ishfaq M, Akbar N, Anjum SA, Anwar-ul-Haq M. Optimizing irrigation and nitrogen requirements for cereals through empirical modeling in semi-arid environment. Environ Sci Pollut Res. 2019;26:1227-1237.
16. Jamil M. Effect of different phosphorus levels on growth and yield of wheat under water stress conditions. J Environ Earth Sci. 2014;4(19):23-30.
17. Jing J, Zhang F, Rengel Z, Shen J. Morphological responses of wheat (*Triticum aestivum* L.) roots to phosphorus supply in two contrasting soils. J Agric Sci. 2012;153(4):1-12.
18. Jogawat A. Osmolytes and their role in abiotic stress tolerance in plants. In: Molecular plant abiotic stress: Biology and biotechnology. 2019. p. 91-104.
19. Kang LY, Shen YF, Yue SC, Li SQ. Effect of phosphorus application in different soil depths on root distribution and grain yield of winter wheat under different water conditions. J Plant Nutr. 2014;37:1870-1881.
20. Kaur G, Sanwal SK, Kumar A, Pundir RK, Yadav M, Sehrawat N. Role of osmolytes dynamics in plant metabolism to cope with salinity-induced osmotic stress. Discov Agric. 2024;2(1):59.
21. Korav SB, Patil SR, Sujatha HT, Sharma V. Performance of wheat (*Triticum aestivum* L.) as influenced by phosphorus levels and drip irrigation regimes. Plant Sci Today; 2025.
22. Kumar P, Pannu RK. Effect of different sources of nutrition and irrigation levels on yield, nutrient uptake and nutrient use efficiency of wheat. Int J Life Sci Bot Pharma Res. 2012;1(4):187-192.
23. Kumar P, Singh Y, Singh R, et al. Effect of irrigation schedule and organic fertilizer on wheat yield, nutrient uptake, and soil moisture in northwest India. Sustainability. 2023;15(13):10204.
24. Lazaro L, Abbate PE, Cogliatti DH, Andrade FH. Relationship between yield, growth and spike weight in wheat under phosphorus deficiency and shading. J Agric Sci. 2010;148(1):83-93.
25. Li F, Guo L, Jin L, Zhang S, Han L, Xiao K. Effects of P fertilization level on phosphorus uptake and agronomic traits under deficit irrigation in winter wheat (*Triticum aestivum* L.). J Plant Nutr. 2020;43(2):214-226.
26. Mahawar AK. Effect of phosphorus levels and biofertilizers on growth, yield and quality of pea (*Pisum sativum* L.) [MSc thesis]. Bikaner: Swami Keshwanand Rajasthan Agricultural University; 2013.
27. Malav JK, Jat AL. Yield, nutrient content and uptake by wheat (*Triticum aestivum* L.) as influenced by FYM and sources of irrigation water. Ann Arid Zone. 2024;63(4):153-158.
28. Mumtaz MZ, Aslam M, Jamil M, Ahmad M. Effect of different phosphorus levels on growth and yield of wheat under water stress conditions. J Environ Earth Sci. 2014;4(19):23-30.
29. Nawaz F, Ahmad R, Waraich EA, Naeem MS, Shabbir RN. Nutrient uptake, physiological responses, and yield attributes of wheat (*Triticum aestivum* L.) exposed to early and late drought stress. J Plant Nutr. 2012;35(6):961-974.
30. Noonari S, Kalhor SA, Ali A, Mahar A, Raza S, Ahmed M, Baloch SU. Effect of different levels of phosphorus and method of application on the growth and yield of wheat. Nat

- Sci. 2016;8(7):305-314.
31. Pal S, Singh D, Kumar R. Effect of moisture regime on IW/CPE ratio on soil properties, yield and water use efficiency of wheat crop. *Int J Curr Microbiol Appl Sci*. 2020;9(3):2499-2506.
 32. Patel RM, Upadhyay PN. Response of wheat (*Triticum aestivum*) to irrigation under varying levels of nitrogen and phosphorus. *Indian J Agron*. 1993;38:530-534.
 33. Patidar M, Singh S, Meena RN. Effect of irrigation scheduling and nutrient management on productivity, profitability and nutrient uptake of wheat (*Triticum aestivum*) grown under zero-tilled condition in south-eastern Rajasthan. *Indian J Agron*. 2016;61(1):53-58.
 34. Prihar SS, Sandhu BS. Irrigating wheat using the IW/PAN-E approach: Water saving and yield maintenance. *Field Crops Res*. 1987;16(2):145-152.
 35. Protich R, Todorovich G, Protich N. Grain weight per spike of wheat using different ways of seed protection. *Bulg J Agric Sci*. 2012;18(2):185-190.
 36. Raghothama KG. Phosphate acquisition. *Annu Rev Plant Physiol Plant Mol Biol*. 1999;50:665-693.
 37. Rahim A, Ranjha AM, Rahamatullah, Waseem M. Effect of phosphorus application and irrigation scheduling on wheat yield and phosphorus use efficiency. *Soil Environ*. 2010;29(1):15-22.
 38. Ram H, Singh G, Aggarwal N. Growth and yield of wheat (*Triticum aestivum*) as influenced by irrigation scheduling and organic manures. *Indian J Agron*. 2017;62(1):74-79.
 39. Reddy KS, *et al*. Enhancing wheat productivity and economics through microbe-mediated phosphorus fertilization in wheat (*Triticum aestivum*) + mustard intercropping systems. *Front Sustain Food Syst*. 2025;9:1-15.
 40. Sepat S, Rai RK. Effect of phosphorus levels and sources on productivity, nutrient uptake and soil fertility of maize-wheat cropping system. *Indian J Agron*. 2013;58(1):294-298.
 41. Si Z, Zain M, Li S, Liu J, Liang Y, Gao Y, *et al*. Optimizing nitrogen application for drip-irrigated winter wheat in the North China Plain. *Agric Water Manag*. 2023;271:107723.
 42. Singh BR, Singh RV, Rajput OP. Effect of nitrogen, phosphorus and zinc on growth, yield and nutrient uptake of wheat (*Triticum aestivum*). *Curr Adv Agric Sci*. 2009;1(2):133-134.
 43. Singh R, Ahlawat IPS. Response of wheat to carry-over effect of P applied to the preceding crop. *Indian J Agric Sci*. 2006;76(2):112-115.
 44. Singh R, Kumar P, Singh Y, *et al*. Effect of irrigation schedule and organic fertilizer on wheat yield, nutrient uptake, and soil moisture in northwest India. *Sustainability*. 2023;15(13):10204.
 45. Sillo F, Salon C, Lamboeuf M, *et al*. A novel P indicator to evaluate bread wheat (*Triticum aestivum*) genotypes for tolerance to phosphorus deficiency. *Plant Sci*. 2023.
 46. Tari AF. The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. *Agric Water Manag*. 2016;167:1-10.
 47. Tariq M, *et al*. Effect of phosphorus and sulfur on the yield and nutrients uptake of wheat. *Int J Sci Basic Appl Res*. 2018;37(1):125-135.
 48. Tiwari A, Singh V, Kumar A. Response of phosphorus and zinc on yield and economics of wheat (*Triticum aestivum*). *Int J Plant Soil Sci*. 2023;35(18):403-411.
 49. Waraich EA, Ahmad R, Saifullah, Ashraf MY. Improving agricultural water use efficiency by nutrient management in crop plants. *Acta Agric Scand B Soil Plant Sci*. 2011;61:291-304.