Indian Journal of Agricultural Sciences **95** (8): 904–910, August 2025/Article
https://doi.org/10.56093/ijas.v95i8.166750

# Comparative assessment of integrated phosphorus management practices on growth attributes, productivity and nutrient utilisation under pigeon pea (*Cajanus cajan*)–wheat (*Triticum aestivum*) system

ASIK DUTTA[1]*, KALI KRISHNA HAZRA[1], CHAITANYA P NATH[1], NARENDRA KUMAR[1], RAGHAVENDRA SINGH[2], C S PRAHARAJ[3] and ABHIK PATRA[4]

*ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh 208 024, India*

Received: 16 May 2025; Accepted: 10 July 2025

ABSTRACT

The present experiment was conducted during 2019–2022 at ICAR–Indian Institute of Pulses Research, Kanpur, Uttar Pradesh for assessing integrated phosphorus management strategies on growth attributes, yield and nutrient utilisation in pigeon pea [*Cajanus cajan* (L.) Millsp.]-wheat (*Triticum aestivum* L.) system. The experiment was laid out in a randomised block design (RBD) with four replication having treatments $T_1$, Pi $_{\text{No-RDP (recommended dose of phosphorus)}}$ –$W_{\text{No-RDP}}$ (only N and K); $T_2$, Pi $_{\text{100\% RDP}}$ –$W_{\text{100\% RDP}}$; $T_3$, Pi $_{\text{60\% of RDP}}$ + FYM (5 t/ha)- $W_{\text{60\% of RDP}}$; $T_4$, $Pi_{\text{60\% of RDP}}$ + PM (1 t/ha) -$W_{\text{60\% of RDP}}$; $T_5$, Pi $_{\text{60\% of RDP}}$ + CR (50%) –$W_{\text{60\% of RDP}}$; $T_6$, $Pi_{\text{60\% of RDP}}$ + CR (50%) + PSB–$W_{\text{60\% of RDP}}$. Findings showed, nitrate reductase, chlorophyll-A and RGR impacted positively by integrated P-management practices in both the crops. Respective gain in yield under pigeon pea and wheat was 18% and 5% under $T_4$ than $T_1$ and on par with $T_2$. Progressive release of nutrients along with improvement in soil physio-chemical condition have resulted higher P-uptake in $T_4$ (26% and 11% in pigeon pea and wheat, respectively) than $T_1$. Physiological efficiency impacted significantly under nutrient management strategies and showed much variability in wheat due to residual fertiliser impact and leaf fall of previous pigeon pea crop specifically in $T_1$. In nutshell, application of 60% RDP in association with 1 t/ha poultry manure have proved a suitable alternative against conventional practice in pigeon pea-wheat system.

**Keywords**: Integrated phosphorus management, Nutrient harvest index, Pigeon pea-wheat, Poultry manure, Uptake

Pigeon pea [*Cajanus cajan* (L.) Millsp.]-wheat (*Triticum aestivum* L.) system (PiWS) is the best substitute of exhaustive rice-wheat system covering an area of ~3.9 Mha in the Indo-Gangetic plains (IGP) with advantages like nutritional and economic security, resilient to abiotic and biotic stresses, sustaining nitrogen economy, higher system productivity with low carbon (C) and water footprint and conserving natural resources vis-a-vis improving soil health (Praharaj *et al.* 2021). Remarkable jump in area and system productivity under PiWS particularly in the non-traditional niches can be witnessed with the development of short to medium duration (150–160 days) high yielding determinate type pigeon pea varieties (Singh *et al.* 2010). But, one of the major bottleneck of achieving targeted yield is judicious nutrient management specifically phosphorus (P) as the use of efficacy of the same hardly exceeds 20% (Paramesh *et al.* 2020). Di-ammonium phosphate (DAP) is the primary source for P in India but, over relies on the same was burdensome as India imports a lion share of DAP (53.18 lakh tonnes on 2022–23) every year (Open Government Data 2024). Therefore, emphasis must be given on sustainable phosphorus management (IPsM) strategies by replacing a part of DAP with P-containing organic sources like poultry manure (PM), farm yard manure (FYM) or crop residues (CR) posing win-win impact on system productivity as well as on nutrient utilisation (Ansari and Mahmood 2017). Unlike FYM and CR, information of application of PM was scarce even it contains more than 13 essential elements (Amanullah *et al.* 2007). Besides organic manures, application of PGPR like phosphate solubilising bacteria (PSB) along with crop residue is really effective in solubilising bio-available P (Ansari and Mahmood 2017). Hence, based on the above facts it is present need to identify suitable P-management practices which can curtail the requirement of DAP without any yield penalty under

[1]ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh; [2]ICAR-Indian Institute of Farming System Research, Modipuram, Meerut, Uttar Pradesh; [3]ICAR-Directorate of Groundnut Research, Junagadh, Gujarat; [4]Krishi Vigyan Kendra, Narkatiaganj, West Champaran, Bihar. *Corresponding author email: asikdutta975@gmail.com

legume-cereal system especially in IGP. Therefore, a three years field experiment has been taken up to evaluate the diverse IPsM strategies on growth, productivity and nutrient utilisation under pigeon pea (Pi)-wheat (W) system (PiWS).

## MATERIALS AND METHODS

The present experiment was conducted during 2019–2022 at ICAR-Indian Institute of Pulses Research, Kanpur, Uttar Pradesh. The annual average rainfall and ambient temperature of the study region was 750 mm and 27˚C, respectively. The experimental site was moderately alkaline (*p*H: 8.1), non-saline (EC, 0.25 ds/m) with low organic carbon (0.35%). Available N (180.5 kg/ha) and olsen-P (15.2 kg/ha) was medium in experimental plot whereas, available K content (210.2 kg/ha) was low (Jackson 1973). The experiment consisted of six treatments, viz. $T_1$, $Pi_{\text{No-RDP [(recommended dose of phosphorus (RDP)]}}$–$W_{\text{No-RDP}}$ (only N and K); $T_2$, $Pi_{\text{100\% RDP}}$–$W_{\text{100\%RDP}}$; $T_3$, $Pi_{\text{60\% of RDP}}$ + FYM (5 t/ha)–$W_{\text{60\% of RDP}}$; $T_4$, $Pi_{\text{60\% of RDP}}$ + PM (1 t/ha)–$W_{\text{60\% of RDP}}$; $T_5$, $Pi_{\text{60\% of RDP}}$ + CR (50%)–$W_{\text{60\% of RDP}}$; $T_6$, $Pi_{\text{60\% of RDP}}$ + CR (50%) + PSB–$W_{\text{60\% of RDP}}$. The size of every experimental plot was 5.5 m × 8 m. Every year, recommended ($T_2$) and calculated ($T_3$ to $T_6$) dose of fertiliser-P (as DAP) was applied as basal in wheat (N: $P_2O_5$: $K_2O$:: 120:60:40 in kg/ha) and pigeon pea (N: $P_2O_5$: $K_2O$:: 20:60:40 in kg/ha). For pigeon pea, all amount of urea (for N) and muriate of potash (for K) were applied as basal whereas; in wheat, urea was applied in splits. The experiment was laid out in randomised block design (RBD) having four replications.

Ridge sowing of pigeon pea cv. 'UPAS-120' was done annually in the second week of June at 50 cm × 25 cm spacing (seed rate, 15 kg/ha). Late sown wheat cv. 'Unnat Halna' was sown at 100 kg/ha just after harvesting pigeon pea which accord mostly in the second week of December every year in flat beds in continuous way with a inter row spacing of 22.5 cm. Weeding and irrigation practices were followed as per standard package of practices in both the crops. Need based spray of broad spectrum fungicide (Matco$^{TM}$ by Indofil industries) was carried out to control Phytophthora stem blight in pigeon pea whereas; no plant protection measures were taken for wheat. Organic manures (PM and FYM) were thoroughly applied 15 days before sowing of *kharif* crop only (pigeon pea) in the respective treatments. Wheat residue was applied based on 50% of the stover yield (3 t/ha) in $T_5$ and $T_6$ alike organic manures. Every year irrespective of treatment all the pigeon pea seeds were treated with *Rhizobium* and a subsection was also treated with PSB (*Bacillus polymyxa* L.) for $T_6$ at 20 g/kg of seed. In both the crops leaf samples were collected at peak vegetative stage just before flowering in pigeon pea (90 DAS) and in active tillering stage (65 DAS) in wheat for measuring growth attributes. While, in maturity 5 plants from each of pigeon pea and wheat were collected from two rows in every plot for measuring yield attributing characters like height, grains/pod, pod length, tillers/hill, 1000-seed weight etc. Finally, plant and grain samples were processed and stored after attaining constant weight in paper packets for analysis of nutrients. Plot wise manual threshing was followed in case of pigeon pea whereas, wheat was threshed mechanically and yield was recorded in t/ha at 14% moisture content.

Chlorophyll in the fresh leaf was extracted by dimethyl sulfoxide and optical density (OD) of the supernatant was measured at 645 nm and 663 nm using 80% acetone as a reference in spectrophotometer (Hiscox and Israelstam 1979) and final calculation by Arnon (1949) (eqn. 1 and 2) (V, Volume of extract; W, Weight of sample). For nitrate reductase (NR), 0.1 g leaf sample was incubated with phosphate buffer (*p*H 7.6), potassium nitrate ($KNO_3$) and propanol. Finally, absorbance was measured at 540 nm for sample containing 1 ml of each aliquot, sulphanilamide and 0.025% N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDD) (Cazetta and Villela 2004). Final NR value can be expressed in nanomole $NO_2$/g of fresh weight/hour (nM $NO_2$ g/FW/h) after multiplying OD with 406.8.

$$\text{Chlorophyll A} = (12.21\ OD_{663} - 2.81\ OD_{645}) \times V/W \times 1000 \quad (1)$$

$$\text{Chlorophyll B} = (20.13\ OD_{645} - 5.03\ OD_{663}) \times V/W \times 1000 \quad (2)$$

Relative leaf water content (RLWC) was calculated based on fresh weight ($W_1$), turgid weight ($W_2$) and dry weight ($W_3$) (eqn. 3) differences (Weatherly and Slatyer 1957).

$$\text{Relative leaf water content (\%)} = (W_1\text{-}W_3/W_2\text{-}W_3) \times 100 \quad (3)$$

Total N, P and K was analysed in grain and straw samples by micro-Kjeldahl, vanado-molybdic yellow colour method and flame photometer, respectively (Jackson 1973). Nutrient uptake in the grain and straw was calculated by multiplying the content of individual nutrient (%) with respective yield (Singh *et al.* 2018). Crop growth rate (CGR) and relative growth rate (RGR) was calculated by Briggs *et al.* (1920) method. Nutrient utilisation in both the crops has been expressed by nutrient harvest index (NHI) (eqn. 4), physiological efficiency (PE) (eqn. 5) and internal utilization efficiency (IUE) (eqn. 6) (Singh *et al.* 2018). To test the significant difference among the treatments, experimental datasets were undergone Duncan multiple regression test (DMRT) at $p \leq 0.05$ using SPSS software (version 20).

$$\text{Nutrient harvest index (NHI) (\%)} = \text{Uptake in grain (kg/ha)}/\text{Total uptake (kg/ha)} \times 100 \quad (4)$$

$$\text{Physiological efficiency (PE) (kg/kg)} = \text{Total dry matter}/\text{Total uptake} \quad (5)$$

$$\text{Internal utilization efficiency (IUE) (kg/kg)} = \text{Grain yield}/\text{Total uptake} \quad (6)$$

## RESULTS AND DISCUSSION

*Impact of integrated phosphorus management (IPsM) strategies on pigeon pea*

*Growth attributes*: Integrated phosphorus management (IPsM) have significant impact on growth attributes like plant height, chlorophyll A, NR and RGR. Recorded plant height was highest in $T_5$ by 6% and 3% than No-P ($T_1$) and conventional practices ($T_2$), respectively. Gain in height under IPsM was due to sustained release of nutrients from organic sources resulted better metabolic growth, translocation of photosynthates and synthesis of energy (Idapuganti and Ahlawat 2007) (Table 1). Similarly, chlorophyll A was maximum in $T_5$ (3.16 mg/g of fresh leaf) and order follows: $T_6 > T_3 > T_4 > T_2$ (-11%) >$T_1$ (-15%); with non-significant impact on chlorophyll B. Dodd (2003) also revealed similar findings and apprehended higher K-release from organic residues upregulated stomatal activity inducing higher photosynthetic activity and chlorophyll pigmentation (Table 2). NR is a very crucial enzyme for legumes as biological nitrogen fixation (BNF) plays bigger role in N-metabolism. Results showed, application of FYM ($T_3$), PM ($T_4$) and CR ($T_5$) in association with 60% RDP had surged NR activity in leaves by 11%, 15% and 12% respectively, over $T_2$. Synthesis of biochemical compounds like protein and N-assimilation under IPsM have elevated the overall physiological and biochemical activities prompting better NR activity which were in analogous with experimental findings by Banerjee *et al.* (2024) in urdbean and Ansari and Mahmood (2017) in pigeon pea (Table 2). Two of the most critical growth attributing characteristics such as CGR and RGR changed variably under IPsM in pigeon pea (Table 2). Results showed there was no-significant impact of IPsM on CGR which might be due to efficient nutrient utilisation by pigeon pea plants via deeper roots (Ghosh *et al.* 2006). However, relative growth rate (RGR) affected significantly between P-added plots and P-removed plots. Higher RGR has been recorded in $T_3$ (0.0462) which was at par with other treatments except $T_1$. Higher leaf longevity in P-added plots ($T_2$ to $T_6$) as compared to control ($T_1$) plots ensured higher RGR (Kaur *et al.* 2015) (Table 2).

*Yield attributes and yield*: Yield attributing characteristics like pod length, grains per pod and test weight differ non-significantly between the treatments as reported in other parts of IGP like Delhi (Gangaiah *et al.* 2013), Bihar (Pandey *et al.* 2013) suggesting the need of long term studies in pigeon pea. Among all the treatments highest grains/pod, pod length and test weight can be observed in $T_5$, $T_3$ and $T_2$, respectively (Table 1). Grain and straw yield was recorded highest in $T_4$ by 19% and 18%, respectively

Table 1 Growth attributing characteristics of pigeon pea and wheat under phosphorus management practices (pooled data of two years)

| Treatment | Pigeon pea | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| | Plant height (cm) | Grains/pod | Pod length (cm) | Test weight (gm) | Plant height (cm) | Tillers number/hill | Grains/spike | Test weight (gm) |
| $T_1$ | 1.86b# | 3.2a | 5.05a | 73.75a | 84.33b | 6.5a | 47.5b | 40.08a |
| $T_2$ | 1.93ab | 3.45a | 5.20a | 76.15a | 90.38ab | 7.5a | 51.5ab | 41.81a |
| $T_3$ | 1.86b | 3.5a | 5.30a | 75.60a | 91.28ab | 7a | 51.5ab | 41.52a |
| $T_4$ | 1.93ab | 3.45a | 5.15a | 74.75a | 94.38a | 7.5a | 53.5a | 41.64a |
| $T_5$ | 1.97a | 3.7a | 5.10a | 75.85a | 91.03ab | 7.5a | 52.5ab | 41.55a |
| $T_6$ | 1.88b | 3.65a | 5.20a | 75.60a | 91.08ab | 7a | 52ab | 42.75a |

#Values followed by different upper case letters (a-b) are significantly different between treatments at $p \leq 0.05$.
Treatment details are given under Materials and Methods.

Table 2 Growth attributes, nutrient content, and productivity of pigeon pea under phosphorus management practices (pooled data of three years)

| Treatment | NR (nM $NO_2$ g/ FW/h) | Chl-A (mg/g leaf) | Chl-B (mg/g leaf) | RLWC (%) | Nutrient content in grain (%) | | | Nutrient content in straw (%) | | | Yield (t/ha) | | Growth rate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N | P | K | N | P | K | Grain | Straw | CGR* | RGR** |
| $T_1$ | 46.70c# | 2.68c | 0.54a | 63.46a | 2.92a | 0.52b | 0.72a | 1.17c | 0.12d | 1.53a | 1.29b | 5.59b | 1.69a | 0.0454b |
| $T_2$ | 51.55bc | 2.81bc | 0.61a | 67.94a | 2.97a | 0.63a | 0.73a | 1.27b | 0.15ab | 1.61a | 1.44ab | 6.18ab | 1.75a | 0.0458a |
| $T_3$ | 57.79a | 3.07ab | 0.65a | 67.34a | 3.05a | 0.54b | 0.79a | 1.28b | 0.14abc | 1.57a | 1.44ab | 6.18ab | 1.83a | 0.0462a |
| $T_4$ | 60.62a | 2.94abc | 0.68a | 67a | 2.97a | 0.57ab | 0.77a | 1.38a | 0.14bc | 1.53a | 1.60a | 6.81a | 1.75a | 0.0457a |
| $T_5$ | 58.41a | 3.16a | 0.60a | 67.16a | 2.96a | 0.55ab | 0.74a | 1.34ab | 0.16a | 1.57a | 1.46ab | 6.26ab | 1.76a | 0.0458a |
| $T_6$ | 56.45ab | 3.08ab | 0.61a | 66.62a | 2.98a | 0.54b | 0.74a | 1.36ab | 0.13cd | 1.54a | 1.43ab | 6.08ab | 1.74a | 0.0457a |

*CGR, Crop growth rate ($g/m^2$/day); **RGR, Relative growth rate (g/g/day).
Treatment details are given under Materials and Methods.

as compared to $T_1$. However, other IPsM strategies (FYM, CR and CR+PSB) failed to show statistical difference with $T_2$. Higher productivity in $T_4$ was due to continuous availability of essential nutrients to crop, betterment in soil physio-chemical properties (improvement in OC and water holding capacity, reduction in bulk density) and positive reform in growth attributes (Table 2).

*Nutrient uptake and utilisation*: The impact of IPsM on nutrient content in plant parts (grain and straw) was highly inconsistent as only the grain-P content differs statistically between the treatments. The content of grain-P was highest in $T_2$ (0.62%) by 17% than $T_1$. Unlike grain, highest N and P content in straw can be recorded in $T_4$ (1.38%) and $T_5$ (0.16%), respectively with no statistical difference in K content among the treatments (Table 2). Uptake of N, P and K in grain can be recorded 21%, 26% and 24% higher respectively in $T_4$ by $T_1$, due to increased root cation exchange capacity assisted nutrient uptake under PM (Kumawat *et al.* 2013). Similarly, plots under $T_4$ recorded highest N, P and K uptake in straw due to higher biological yield with efficient rooting system mediated nutrient translocation to the above ground parts (Ahamad *et al.* 2018). Interestingly, the impact of IPsM strategies had no impact on NHI on any nutrient as previous study by Varatharajan *et al.* (2019) also corroborates similar findings but, a slight edge in IPsM plots could be observed over the conventional practice. Pooled data of three years showed non-significant impact of IPsM on physiological efficiency (PE) on major elements except P as P-devoid plots ($T_1$) showed 16% higher in PE as compared to $T_2$ and at par with $T_6$ (Table 3). Babu *et al.* (2013) also find similar results in pigeon pea and highlighted the role of residual P in sustaining the biological yield especially in control plots. As pigeon pea can acquire N through BNF, therefore except N, IPsM modules had significant impact on internal utilisation efficiency (IUE) on P and K. Findings showed, $T_1$ (213.58 kg/kg) recorded maximum IUE (for P) followed by $T_6$ (200 kg/kg), with no statistical difference between $T_2$ and other organic amendment added plots. Higher phosphatase activity in $T_1$ and $T_6$ might have surged mineralisation of organic P resulting higher P- availability vis-à-vis utilisation (Richardson *et al.* 2011) (Table 3).

*Impact of integrated phosphorus management (IPsM) strategies on wheat*

*Growth attributes*: Maximum plant height was

Table 3 Effect of phosphorus management practices on nutrient harvest index, physiological efficiency, internal utilisation efficiency and nutrient uptake of pigeon pea under (pooled data of three years)

| Treatment | NHI | | | PE (kg/kg) | | | IUE (kg/kg) | | | NU in grain (kg/ha) | | | NU in straw (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K | N | P | K |
| $T_1$ | 36.59a# | 48.65a | 9.77a | 66.99a | 515.61a | 72.60a | 48.30a | 213.58a | 48.07a | 37.60b | 6.70c | 9.27b | 65.42c | 6.85c | 85.58c |
| $T_2$ | 35.23a | 49.36a | 9.55a | 63.19a | 416.22c | 69.48a | 45.45a | 186.19c | 38.89b | 42.61ab | 9.03ab | 10.47ab | 78.27bc | 9.27a | 99.15ab |
| $T_3$ | 35.79a | 46.95a | 10.47a | 62.12a | 460.56b | 70.59a | 45.15a | 186.71c | 40.22b | 43.95ab | 7.76bc | 11.31ab | 78.78bc | 8.77ab | 96.72ab |
| $T_4$ | 33.60a | 48.80a | 10.51a | 59.62a | 451.13b | 72.18a | 44.02a | 176.75c | 38.23b | 47.40a | 9.12a | 12.24a | 93.65a | 9.54a | 104.27a |
| $T_5$ | 34.12a | 43.48a | 9.84a | 61.01a | 442.61bc | 70.99a | 45.10a | 182.29c | 40.73b | 43.17ab | 7.58c | 10.71ab | 83.40ab | 9.87a | 98.05ab |
| $T_6$ | 34.07a | 49.46a | 10.12a | 60.11a | 489.81a | 71.98a | 44.30a | 200b | 38.59b | 42.51ab | 7.57c | 10.54ab | 82.37ab | 7.76bc | 93.70bc |

#Values followed by different upper case letters (a-c) are significantly different between treatments at $p \leq 0.05$. NHI, Nutrient harvest index; PE, Physiological efficiency (kg/kg); IUE , Internal utilisation efficiency (kg/kg), NU, Nutrient uptake.

Treatment details are given under Materials and Methods.

Table 4 Growth attributes, nutrient content and productivity of wheat under phosphorus management practices (pooled data of three years)

| Treatment | NR (nM $NO_2^-$ g/FW/h) | Chl-A (mg/g leaf) | Chl-B (mg/g leaf) | RLWC (%) | Nutrient content in grain (%) | | | Nutrient content in straw (%) | | | Yield (t/ha) | | Growth rate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N | P | K | N | P | K | Grain | Straw | CGR* | RGR** |
| $T_1$ | 55.01c# | 2.41c | 0.511d | 64.67a | 1.59b | 0.19a | 0.424b | 0.39b | 0.22d | 1.31b | 3.59b | 4.55b | 8.25b | 0.0966b |
| $T_2$ | 66.66b | 2.62bc | 0.639b | 68.51a | 1.67ab | 0.21a | 0.427b | 0.42a | 0.26bc | 1.60a | 3.83a | 4.86a | 9.43a | 0.0987a |
| $T_3$ | 73.14ab | 2.57c | 0.573c | 64.94a | 1.70ab | 0.21a | 0.500a | 0.42a | 0.27b | 1.61a | 3.66b | 4.53b | 9.36a | 0.0986a |
| $T_4$ | 72.34ab | 2.94a | 0.713a | 68.55a | 1.76a | 0.20a | 0.480a | 0.42a | 0.29a | 1.71a | 3.78a | 4.73ab | 9.34a | 0.0985a |
| $T_5$ | 71.93ab | 2.81ab | 0.597c | 68.38a | 1.71ab | 0.19a | 0.477a | 0.41a | 0.29a | 1.61a | 3.81a | 4.69ab | 9.42a | 0.0987a |
| $T_6$ | 75.87a | 2.89a | 0.571c | 67.93a | 1.74a | 0.19a | 0.474ab | 0.42a | 0.25c | 1.73a | 3.79a | 4.66ab | 9.31a | 0.0985a |

*CGR, Crop growth rate (g/m/day); **RGR, Relative growth rate (g/g/day).

Treatment details are given under Materials and Methods.

recorded in $T_4$ (94.38 cm) but, other integrated practices were statistically at par with 100% RDP ($T_2$) (Table 1). Positive change in NR, chlorophyll A and B content can be documented under IPsM as NR content surged by 27% and 12%, in $T_6$ over $T_1$ and $T_2$, respectively. Whereas, highest value of chlorophyll A and B was recorded in $T_4$ (2.94 and 0.713 mg/g leaf) and no-statistical difference was noticed in case of RLWC between the treatments. Progressive release of essential nutrients like N and manganese (Mn) from decomposing residues and assimilation into chlorophyll structure, stabilisation of soil cation exchange capacity (CEC) and higher nitrogenase activity efficaciously regulated growth attributes (Gorooei *et al.* 2023, Rasool *et al.* 2023) (Table 4). Findings of CGR and RGR were not very promising with non-significant difference between treatments (100% RDP and IPsM plots) except $T_1$ (Table 4). Nutrient supplied in integrated way have resulted better leaf growth, photosynthetic efficiency, assimilation capacity and overall growth rate similar like conventional practices (Zulfiqar *et al.* 2023).

*Yield attributes and yield*: Yield attributing characters like grains/spike recorded 11% hike in $T_4$ as compared to $T_1$ as integration of synthetic and organics had synergistic impact on productive tillers and grains per spike but, non-significant on other parameters (Table 1). The grain yield of wheat ranged from 3.59–3.83 t/ha and 100% RDP ($T_2$) plots were at par with other integrated treatments except $T_3$. On contrary, significant difference on straw yield can be recorded between 100% RDP ($T_2$) and IPsM ($T_3$-$T_6$) modules. Nonetheless, favourable impact of IPsM similar to $T_2$ on wheat yield was due to higher photosynthesis triggered by chlorophyll content, better N-utilisation and dry matter production (Gorooei *et al.* 2023). Also, difference in productivity among treatments with positive impacts of IPsM could be due to varying nutrient concentration in above ground parts (grains and shoot) and gradual availability of residual nutrients from organic sources peculiarly in the later growth stages (Paramesh *et al.* 2020). Also, Paramesh *et al.* (2020) found strong linear correlation with P-uptake and wheat productivity which was evident in this finding too (Table 4 and 5).

*Nutrient uptake and utilisation*: Grain N content was maximum in $T_4$ (+10%) and at par with $T_6$ (+8.6%) as compared to $T_1$; whereas, K-content in grain was almost statistically at par in all the IPsM treatments ($T_3$-$T_6$) but, significantly higher than $T_2$ and $T_1$. The variability in straw N and K content was modest except P which shows contrasting effects between the treatments (Table 4). Like nutrient concentration, the uptake of nutrients in grain and straw did not follow any specific trend. Highest N, P and K-uptake in grain was visible in $T_4$ (66.35 kg/ha), $T_2$ (7.84 kg/ha), $T_3$ (18.30 kg/ha), respectively; although the statistical difference between ($T_3$-$T_6$) treatments was not apparent irrespective of nutrients. Similarly, noticeable impact of IPsM could only be observed in straw P-uptake but, not on others. Straw P-uptake was at par in $T_4$ (13.87 kg/ha) and $T_5$ (13.57 kg/ha) with lowest in P-devoid plots

Table 5 Nutrient harvest index, physiological efficiency, internal utilisation efficiency and nutrient uptake of wheat under phosphorus management practices (pooled data of three years)

| Treatment | NHI | | | PE (kg/kg) | | | IUE (kg/kg) | | | NU in grain (kg/ha) | | | NU in straw (kg/ha) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K | N | P | K | N | P | K |
| $T_1$ | 76.49a# | 40.04a | 20.32a | 109.52a | 484.29a | 108.97a | 12.48a | 96.52a | 13.58a | 56.88b | 6.73b | 15.20c | 17.49b | 10.08d | 59.62b |
| $T_2$ | 75.86a | 38.17a | 16.28b | 103.17ab | 422.69c | 88.29b | 11.91a | 78.44b | 13.09a | 63.85a | 7.84a | 16bc | 20.31a | 12.71b | 82.47a |
| $T_3$ | 76.49a | 38.52a | 20.12a | 100.94b | 417.43cd | 89.91b | 11.74a | 87.06ab | 13.34a | 62.05a | 7.56a | 18.30a | 19.07ab | 12.06bc | 72.81a |
| $T_4$ | 77.17a | 35.16b | 18.33ab | 99.01b | 397.73d | 86.03b | 11.33a | 85.69ab | 13.71a | 66.35a | 7.52a | 18.13ab | 19.66ab | 13.87a | 80.75a |
| $T_5$ | 77.08a | 35.14b | 19.41ab | 100.54b | 406.38cd | 90.84b | 11.52a | 83.67ab | 13.41a | 65.19a | 7.36ab | 18.19ab | 19.39ab | 13.57a | 75.56a |
| $T_6$ | 77.07a | 37.90ab | 18.32ab | 98.77b | 445.92b | 86.05b | 11.45a | 93.31a | 13.71a | 65.97a | 7.18ab | 17.97ab | 19.62ab | 11.77c | 80.53a |

#Values followed by different upper case letters (a-d) are significantly different between treatments at $p \leq 0.05$. NHI, Nutrient harvest index; PE, Physiological efficiency (kg/kg); IUE, Interval utilisation efficiency (kg/kg); NU, Nutrient uptake (kg/ha).

Treatment details are given under Materials and Methods.

($T_1$, 10.08 kg/ha). Applied organic amendments replenish bio-available P in soil inducing higher P-uptake in wheat as reported in former study (Shivay *et al.* 2008) (Table 5). Similar to pigeon pea, NHI for N was non-significant among the treatments but, $T_1$ plots recorded maximum NHI for P (40.04%) and K (20.32%). Gupta *et al.* (2020) proposed higher relative uptake of P and K in grains over total uptake under control might have shoot up the NHI (for P and K) which could be further explained by law of diminishing return. Plots under $T_1$ recorded significantly higher PE of N (9%, 6%), P (18%, 13%) and K (21%, 19%) over $T_4$ and $T_2$, respectively. Findings of Kaur *et al.* (2023) reported similar findings and comprehended higher loss of essential nutrients with increasing fertiliser dose might have resulted poor PE. Lastly, impact of IPsM on IUE can only be noticeable on P where, $T_6$ (+19%) and $T_1$ (+16%) had higher IUE over $T_2$. Variability in wheat biomass due to residual fertility of the preceding pigeon pea and leaf fall greatly affected the IUE of P in wheat (Table 5) (Singh *et al.* 2018). Present experimental findings underline the need of integrated P-management practices (IPsM) practise in pigeon pea-wheat system. Improvement in growth attributes and leaf pigment (chlorophyll-A) and nitrate reductase could be apparent in $T_4$ (60% RDP + PM 1 t/ha) in both the crops. Growth rate analysis showed (CGR and RGR) showed there was not so discernible impacts among the treatments except control. However, concentration vis-à-vis uptake of P was also revamped under integrated condition. Physiological efficiency (PE) and internal utilisation efficiency (IUE) of applied P was highest in control plots in both the crops. Grain and straw yield in pigeon pea was significantly higher in $T_4$ (60% RDP + PM/t/ha) over the conventional practice and on par in wheat.

Finally, based on the findings it could be concluded that, 60% of recommended P-dose along with 1 t/ha poultry manure have the potential to sustain growth, yield and nutrient utilisation in pigeon pea-wheat system. In the present context when global P-reserve is highly limited, these findings signifies the importance of various organic sources as prospective P-sources complementing P-fertilisers.

## REFERENCES

Ahamad A, Kumar N and Yadav D. 2018. Integrated nutrient management in pigeon pea-based intercropping systems. *Indian Journal of Agronomy* **63**(1): 39–44.

Amanullah M M, Somasundaram E, Vaiyapuri K and Sathyamoorthi K. 2007. Poultry manure to crops-A review. *Agricultural Reviews* **28**(3): 216–22.

Ansari R A and Mahmood I. 2017. Optimization of organic and bio-organic fertilizers on soil properties and growth of pigeon pea. *Scientia Horticulturae* **226**: 1–9.

Arnon D I. 1949. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiology* **24**(1): 1.

Babu S, Rana D S, Prasad D and Pal S. 2013. Effect of sunflower stover and nutrients management on productivity, nutrient economy and phosphorus use efficiencies of pigeon pea (*Cajanus cajan*)-sunflower (*Helianthus annuus*) cropping system. *The Indian Journal of Agricultural Sciences* **83**(2): 203–09.

Banerjee P, Venugopalan V K, Nath R, Gaber A and Hossain A. 2024. Dynamics of growth, physiology, radiation interception, production, and quality of autumn black gram [*Vigna mungo* (L.) Hepper] as influenced by nutrient scheduling. *Plos One* **19**(9): e0304466.

Briggs G E, Kidd F and West C. 1920. A quantitative analysis of plant growth: PART II. *Annals of Applied Biology* **7**(2–3): 202–23.

Cazetta J O and Villela L C V. 2004. Nitrate reductase activity in leaves and stems of tanner grass (*Brachiaria radicans* Napper). *Scientia Agricola* **61**: 640–48.

Dodd I C. 2003. Hormonal interactions and stomatal responses. *Journal of Plant Growth Regulation* **22**: 32–46.

Gangaiah B, Ahlawat I P S, Shivakumar B G and Babu M B B. 2013. Impact of organic mode of production on performance of pigeon pea (*Cajanus cajan* L.) during conversion from conventional to organic production. *Indian Journal of Dryland Agricultural Research and Development* **28**(2): 27–31.

Ghosh P K, Mohanty M, Bandyopadhyay K K, Painuli D K and Misra A K. 2006. Growth, competition, yields advantage and economics in soybean/pigeon pea intercropping system in semi-arid tropics of India: II. Effect of nutrient management. *Field Crops Research* **96**(1): 90–97.

Gorooei A, Gaiser T, Aynehband A, Rahnama A and Kamali B. 2023. The effect of farming management and crop rotation systems on chlorophyll content, dry matter translocation, and grain quantity and quality of wheat (*Triticum aestivum* L.) grown in a semi-arid region of Iran. *Agronomy* **13**(4): 1007.

Gupta G, Dhar S, Dass A, Sharma V K, Shukla L, Singh R, Kumar A, Kumar A, Jinger D, Kumar D and S Sannagoudar M. 2020. Assessment of bio-inoculants-mediated nutrient management in terms of productivity, profitability and nutrient harvest index of pigeon pea-wheat cropping system in India. *Journal of Plant Nutrition* **43**(19): 2911–28.

Hiscox J D and Israelstam G F. 1979. A method for the extraction of chlorophyll from leaf tissue without maceration. *Canadian Journal of Botany* **57**(12): 1332–34.

Idapuganti R G and Ahlawat I P S. 2007. Integrated phosphorus management in pigeon pea (*Cajanus cajan*)-wheat (*Triticum aestivum*) cropping system. *Indian Journal of Agronomy* **52**(4): 289–93.

Jackson M L. 1973. *Soil Chemical Analysis*, pp.151–54. Pentice Hall of India Pvt. Ltd., New Delhi.

Kaur G, Ghai N, Kaur J and Singh S. 2015. Growth efficiency and yield of pigeon pea (*Cajanus cajan* L.) as affected by foliar application of mineral nutrients. *Journal of Plant Science and Research* **2**(2): 130.

Kaur P, Saini K S, Sharma S, Kaur J, Bhatt R, Alamri S, Alfagham A T and Hussain S. 2023. Increasing the efficiency of the rice-wheat cropping system through integrated nutrient management. *Sustainability* **15**(17): 12694.

Kumawat N, Singh R P, Kumar R and Om H. 2013. Effect of integrated nutrient management on the performance of sole and intercropped pigeon pea (*Cajanus cajan*) under rainfed conditions. *Indian Journal of Agronomy* **58**(3): 309–15.

Open Government Data 2024. Open Government Data (OGD), platform India, A digital India initiative. https://www.data.gov.in/keywords/DAP (accessed on: 10.1.2025).

Pandey I B, Singh S K and Tiwari S. 2013. Integrated nutrient management for sustaining the productivity of pigeon pea

(*Cajanus cajan*) based intercropping systems under rainfed condition. *Indian Journal of Agronomy* **58**(2): 192–97.

Paramesh V, Dhar S, Dass A, Kumar B, Kumar A, El-Ansary D O and Elansary H O. 2020. Role of integrated nutrient management and agronomic fortification of zinc on yield, nutrient uptake and quality of wheat. *Sustainability* **12**(9): 3513.

Praharaj C S, Ali M, Kumar N, Dutta A, Singh U and Singh R. 2021. Pulses for crop intensification and sustainable livelihood. *Indian Journal of Agronomy* **66**: 60–72.

Rasool A, Ghani A, Nawaz R, Ahmad S, Shahzad K, Rebi A, Ali B, Zhou J, Ahmad M I, Tahir M F and Alwahibi M S. 2023. Effects of poultry manure on the growth, physiology, yield, and yield-related traits of maize varieties. *ACS Omega* **8**(29): 25766–79.

Richardson A E, Lynch J P, Ryan P R, Delhaize E, Smith F A, Smith S E, Harvey P R, Ryan M H, Veneklaas E J, Lambers H and Oberson A. 2011. Plant and microbial strategies to improve the phosphorus efficiency of agriculture. *Plant and Soil* **349**: 121–56.

Shivay Y S, Kumar D and Prasad R. 2008. Relative efficiency of zinc sulfate and zinc oxide-coated urea in rice-wheat cropping system. *Communications in Soil Science and Plant Analysis* **39**(7–8): 1154–67.

Singh U, Praharaj C S, Singh S S, Hazra K K and Kumar N. 2018. Effect of crop establishment practices on the performance of component cultivars under pigeon pea (*Cajanus cajan*)-wheat (*Triticum aestivum*) cropping system in IGP. *The Indian Journal of Agricultural Sciences* **88**(5): 691–7.

Singh V K, Dwivedi B S, Shukla A K and Mishra R P. 2010. Permanent raised bed planting of the pigeon pea-wheat system on a Typic Ustochrept: Effects on soil fertility, yield, and water and nutrient use efficiencies. *Field Crops Research* **116**(1–2): 127–39.

Varatharajan T, Choudhary A K, Pooniya V, Dass A, Rana D S, Rana K S and Harish M N. 2019. Effect of integrated crop management practices on root-shoot characteristics, yield and nutrient harvest index of pigeon pea (*Cajanus cajan*) under irrigated north Indian Plains. *Indian Journal of Agronomy* **64**(2): 270–74.

Weatherley P E and Slatyer R O. 1957. Relationship between relative turgidity and diffusion pressure deficit in leaves. *Nature* **179**(4569): 1085–86.

Zulfiqar U, Ahmad M, Valipour M, Ishfaq M, Maqsood M F, Iqbal R, Ali M F, Roy R and El Sabagh A. 2023. Evaluating optimum limited irrigation and integrated nutrient management strategies for wheat growth, yield and quality. *Hydrology* **10**(3): 56.