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RESEARCH ARTICLE

Residual effects of integrated nutrient management on the performance of cowpea (*Vigna unguiculata*) in maize-barley-cowpea rotation in northwestern India

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Abstract

Efficient nitrogen management is vital for realising potential crop productivity. Hence, a two-year field experiment (2023–24 and 2024–25) was conducted at the Punjab Agricultural University, Ludhiana, to evaluate the residual effects of sustainable integrated nitrogen management (INM) practices applied to preceding maize and barley on growth, yield and profitability of the succeeding cowpea. Fourteen INM treatments [T_1 [100 % nitrogen (N) from farmyard manure (FYM)], T_2 (100 % N from FYM + residue), T_3 [75 % N from FYM + 25 % from chemical fertilizer (CF)], T_4 (75 % N from FYM + 25 % from CF + residue), T_5 (50 % N from FYM + 50 % from CF), T_6 (50 % N from FYM + 50 % from CF + residue), T_7 (25 % N from FYM + 75 % from CF), T_8 (25 % N from FYM + 75 % from CF + residue), T_9 (100 % from CF + 25 % N extra from FYM), T_{10} (100 % from CF + 25 % N extra from FYM + residue), T_{11} (100 % from CF), T_{12} (100 % from CF + residue), T_{13} (Cowpea intercropping in maize without fertilizer + residue retention in barley) and T_{14} (Control)] were applied to previous crops (maize and barley). The results showed that being statistically at par with the treatments (T_1, T_2, T_3, T_4 and T_5), the treatment T_6 recorded significantly higher growth parameters [plant height (95.1 and 95.8 cm), LAI (3.51 and 3.52) and dry matter accumulation (38.2 and 39.0 g/plant)] and yield attributes [pods/plant (21.3 and 22.4), pod length (20.1 and 20.7 cm) and seeds/pod (11.8 and 12.0)] of cowpea over other treatments, consequently resulting in higher productivity (54.56 and 55.76 % more green pod yield over control) and economic benefits.

Keywords: cowpea; integrated nutrient management; maize-barley-cowpea; productivity; profitability; residual effect

Introduction

The conventional rice-wheat cropping pattern has long dominated the Indo-Gangetic Plains (IGP) to ensure food security; however, its continuous practice has raised significant sustainability concerns, viz., depletion of groundwater resources, formation of hard plough pans, deterioration of soil properties, waterlogging, stagnant productivity, increased global warming potential and declining factor productivity (1). To mitigate these challenges, diversification through legume-based rotations has proven to be a suitable strategy as a sustainable strategy to restore soil health, enhance system productivity and improve overall profitability (2). Moreover, intensive agricultural practices have led to declining productivity and nutrient depletion in soils, limiting crops' ability to achieve their full yield potential. Integrating short-duration legumes into cropping systems can provide multiple ecological and agronomic benefits through biological nitrogen fixation, organic matter addition, and efficient nutrient use (3, 4). The addition of short-duration legumes to cropping systems enhances productivity, profitability and soil health, contributing to long-term sustainability (5). Recent studies emphasise the importance of managing nutrients at the system level rather than for individual crops, as inputs applied in one season substantially influence the performance of subsequent crops (6, 7). Inputs applied to preceding crops in a cropping system have a significant impact on the growth and yield of the crops succeeding in the cropping sequence (8). Intensive reliance on chemical fertilisers in cereal-based systems has further aggravated nutrient imbalances and environmental footprints, contributing to declines in soil health and yield stagnation (1). Integrated nutrient management (INM) has been recognised as a sustainable approach for maintaining cropping system productivity by creating a carryover effect that enhances soil fertility and benefits succeeding crops (6–8). Assessing the residual impact of nutrient management from preceding cereals to succeeding legumes is vital for optimising inputs and ensuring sustained productivity and profitability for successful diversifying the conventional rice-wheat cropping system. Despite extensive research on INM in cereal-based systems, the maize-barley-cowpea cropping system remains largely unexplored, particularly regarding the residual effects of INM from preceding cereals (maize and barley) on the succeeding legume (cowpea). It was hypothesised that INM strategies applied to maize and barley would exert positive residual effects on the growth and productivity of the succeeding cowpea. Accordingly, the present study was undertaken to evaluate the residual effects of INM practices in maize and barley on the growth, productivity and profitability of cowpea grown in a maize-barley-cowpea rotation under the Indo-Gangetic Plains.

Materials and methods

Study area

A field investigation was undertaken at the Punjab Agricultural University (PAU) in Ludhiana, Punjab, India. This location is characterised by the coordinates 30°56′ N and 75°52′ E with an elevation of 247 m, representing the northwestern Indo-Gangetic Plains (IGP), during two consecutive years (2023–24 and 2024–25). The area has a sub-tropical and semi-arid climate marked by distinct seasonal variation. The summers (April to June), are typically hot and dry, with temperatures frequently surpassing 38 °C and sometimes rising to around 45 °C. The southwest monsoon, occurring from July to September, brings most of the annual rainfall (500–750 mm) with warm and humid conditions. The post-monsoon months of October and November are mild, followed by cool to cold winters from December to February. Seasonal transitions are often accompanied by occasional cyclonic showers and significant temperature fluctuations, particularly during winter.

Experimental site description

The soil of the study area was classified as sandy loam using the international pipette method (9). Soil pH (7.65) and electrical conductivity (0.214 dS/m) were measured in a 1:2.5 soil-water suspension using a digital pH meter and conductivity meter, respectively (10). Soil organic carbon (0.37 %) was low and determined by the Walkley and Black wet oxidation method (11). Similarly, the available nitrogen content of the soil was 183.9 kg/ha (low), estimated using the alkaline $KMnO_4$ method (12). Available phosphorus (21.0 kg/ha) was determined by Olsen's method using spectrophotometry, while available potassium (137.5 kg/ha) was extracted with neutral normal ammonium acetate and measured using a flame photometer (10, 13). Three replications of the experiment were carried out using the randomized complete block design (RCBD), comprising 14 INM treatments viz., [T_1 [100 % nitrogen (N) from farmyard manure (FYM)], T_2 (100 % N from FYM + residue), T_3 [75 % N from FYM + 25 % from chemical fertilizer (CF)], T_4 (75 % N from FYM + 25 % from CF + residue), T_5 (50 % N from FYM + 50 % from CF), T_6 (50 % N from FYM + 50 % from CF + residue), T_7 (25 % N from FYM + 75 % from CF), T_8 (25 % N from FYM + 75 % from CF + residue), T_9 (100 % from CF + 25 % N extra from FYM), T_{10} (100 % from CF + 25 % N extra from FYM + residue), T_{11} (100 % from CF), T_{12} (100 % from CF + residue), T_{13} (Cowpea intercropping in maize without fertilizer + residue retention in barley) and T_{14} (Control)] applied to the previous crops and the succeeding cowpea was cultivated under the residual effects on inputs in maize-barley-cowpea rotation. The entire residue of the maize and barley crops was retained in the respective plots treatment-wise. Cowpea cv. Cowpea 263 was sown at a spacing of 45 cm × 15 cm (row-to-row × plant-to-plant) using a seed rate of 20 kg/ha, following the Pora method. The NPK content (%) of FYM applied was 0.87:0.24:0.55 %, respectively, whereas the NPK composition (%) of maize and barley residues was 0.63:0.17:1.00 and 0.45:0.12:0.84, respectively. Nitrogen content was determined using the Kjeldahl digestion method (9). Phosphorus was estimated by the vanadomolybdate yellow colour method using spectrophotometry, while potassium was determined using flame photometry after di-acid digestion of the samples (10). Nitrogen (N), phosphorus (P) and potassium (K) were supplied through synthetic fertilisers as urea, single superphosphate (SSP) and muriate of potash (MOP), respectively. The recommendations as per the package of practices developed by PAU for maize and barley were 125 kg N/ha, 60 kg P_2O_5/ha and 30 kg K_2O/ha and 62.5 kg N/ha and 30 kg P_2O_5/ha, respectively. The FYM was incorporated 15 days before sowing in the pre-marked plots as per the treatments and the inorganic fertilizer were applied in three splits as per the PAU recommendations treatment-wise. The succeeding cowpea was sown in the same plots (5 m × 6 m) after the harvest of barley.

Observations and computation

The data from five tagged plants per plot were averaged to assess the growth characteristics of cowpea (plant height in cm, LAI and dry matter accumulation in g/plant), yield attributing characters (number of pods/plants, number of seeds/pods, pod length in cm and 100-seed weight in grams). The root characteristics, viz., total nodules per plant, effective nodules per plant, root fresh weight (g/plant) and nodule fresh weight (mg/plant) of cowpea were recorded at harvest. The tagged plants were uprooted to maintain intact root systems, gently washed to remove adhering soil and blotted to remove excess moisture. The root and nodule fresh weights were determined using an electronic balance. All nodules were detached and counted to determine the total number of nodules per plant and nodule fresh weight was expressed as mg/plant. For assessing effective nodules, the individual nodules were sliced with a sharp blade, and those with the pink colouration were classified as effective nodules per plant (14). The green pods were harvested at regular intervals from each plot and weighed with an electronic balance. The green pod yield was determined by adding the weights of green pods from the net area of the plot and expressed in kg/ha. Similarly, the haulm yield was also measured from the net plot area and presented on a per-hectare basis. The Biological yield (kg/ha) was calculated by adding the total green pod yield (kg/ha) and the total haulm yield (kg/ha). The total cost of cultivation (₹/ha) was computed by adding all expenses incurred for all field operations and input use under each treatment on a ha^{-1} basis. Gross returns (₹/ha) were estimated by multiplying the economic yield (green pod yield) by the prevailing market prices for the years 2024 and 2025, respectively. The net returns (₹/ha) were then calculated by subtracting the entire cost of cultivation from the gross returns. The ratio of benefit to cost (B:C) was calculated by dividing the net returns (₹/ha) by the total cost of cultivation (₹/ha).

Statistical data analysis

The recorded data on growth, yield determinants and yield of cowpea in maize-barley-cowpea rotation were statistically examined using analysis of variance (ANOVA) as per the standard methodology employing SPSS software (Version 20.0; SPSS Inc., Chicago, IL, USA) (15). The means of treatment were compared through the F-test at a 5 % level of significance (*P=0.05*), and significant variations among treatments were identified using the least significant difference (LSD) test.

Results and Discussions

Root characteristics

The root parameters (number of nodules/plant, number of effective nodules/plant, fresh weight of root and fresh weight of nodules) of cowpea grown under residual effect differ significantly among the different INM treatments applied to previous maize and barley in maize-barley-cowpea rotation during 2024 and 2025 (Table 1). It was revealed that the treatment of 50 % N from FYM + 50 % N from CF + residue (T_6) recorded significantly higher number of nodules/plant (30.1), number of effective nodules/plant (25.2), fresh weight of root (10.42 g/plant) and fresh weight of nodules (862 mg/plant) in cowpea at harvest in 2024 over other INM treatments but was statistically at par with the INM treatment, viz., T_5 (50 % N from FYM + 50 % CF), T_4 (75 % N from FYM + 25 % CF + residue), T_3 (75 % N from FYM + 25 % CF), T_2 (100 % N from FYM + residue) and T_1 (100 % N from FYM). Furthermore, in 2025, the significantly higher number of nodules/ plant (30.7), number of effective nodules/plant (25.4), fresh weight of root (10.54 g/plant) and fresh weight of nodules (891.67 mg/plant) of cowpea were observed under the treatment T_2 (100 % N from FYM + residue), which was statistically at par with the INM treatments (T_1, T_3, T_4, T_5 and T_6) but higher than the other treatments at harvest. The improved root and nodule parameters under organic and INM treatments is due to enhanced soil structure, sustained nutrient availability and stimulated microbial and rhizobia activity through residue incorporation and organic matter buildup, consequently favouring root proliferation, effective nodulation and enhanced biological nitrogen fixation in legumes (16). The improved root characteristics of legumes have also been reported in earlier research, attributing to the balanced fertilization through INM (17).

Growth characteristics

The growth parameters (plant height, LAI and dry matter accumulation) of cowpea showed significant differences among the different INM treatments applied to maize and barley in maize-barley-cowpea rotation during 2024 and 2025, as given in Table 2. It revealed that the treatment of 50 % N from FYM + 50 % N from CF + residue (T_6) resulted in substantially higher plant height (95.1 cm) and LAI (3.51) in cowpea at harvest in 2024 in comparison to other treatments but was statistically at par with the INM treatment, viz., T_5 (50 % N from FYM + 50 % CF), T_4 (75 % N from FYM + 25 % CF + residue), T_3 (75 % N from FYM + 25 % CF), T_2 (100 % N from FYM + residue) and T_1 (100 % N from FYM). In the year 2025, the significantly higher plant height (97.0 cm) and LAI (3.56) of cowpea were observed under the treatment T_2 (100 % N from FYM + residue), which was statistically comparable with treatments (T_1, T_3, T_4, T_5 and T_6) but higher than the other treatments at harvest. Furthermore, the treatment of 50 % N from FYM + 50 % from CF + residue (T_6) in the preceding crops (maize and barley) resulted in 54 % higher dry matter accumulation in cowpea over the control but was statistically at par with the INM treatments (T_1, T_2, T_3, T_4 and T_5). In the year 2025, treatment T_2, being statistically comparable with the treatments (T_1, T_3, T_4, T_5 and T_6) recorded 52.7 % higher dry matter accumulation over the control. These results indicate that treatments where a larger proportion of nitrogen was supplied through FYM (organic source) in the maize and barley enhanced the growth performance of the succeeding cowpea. This is due to the improved residual nutrient availability (macronutrients and micronutrients) from the organic amendments and residue retention, which in turn facilitated the cowpea to better convert carbohydrates into protoplasmic and cell-wall materials, thereby promoting cell expansion, consequently resulting in better plant height and biomass accumulation (1, 6).

Table 1. Residual effect of INM on the root characteristics of cowpea in the maize-barley-cowpea cropping system.

Treatment	No. of nodules/plant		No. of effective nodules/plant		Fresh weight of root (g/plant)		Fresh weight of nodules (mg/plant)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
T_1	27.9 ± 0.81a	28.7 ± 0.85a	23.7 ± 0.29a	23.9 ± 0.58a	9.83 ± 0.21a	9.99 ± 0.11a	797 ± 22.8a	826 ± 21.7a
T_2	28.7 ± 0.87a	30.7 ± 0.67a	24.7 ± 0.60a	25.4 ± 0.65a	10.21 ± 0.23a	10.54 ± 0.09a	838 ± 25.7a	892 ± 27.4a
T_3	28.0 ± 0.81a	29.3 ± 0.72a	23.9 ± 0.64a	24.9 ± 0.38a	9.88 ± 0.20a	10.12 ± 0.20a	801 ± 26.3a	840 ± 23.1a
T_4	29.3 ± 0.90a	30.5 ± 0.79a	25.0 ± 0.99a	25.3 ± 0.57a	10.34 ± 0.20a	10.51 ± 0.20a	855 ± 24.9a	881 ± 31.8a
T_5	28.4 ± 0.76a	28.9 ± 0.84a	24.3 ± 0.58a	24.4 ± 0.61a	9.94 ± 0.18a	10.05 ± 0.21a	817 ± 22.8a	835 ± 24.7a
T_6	30.1 ± 0.69a	30.3 ± 0.67a	25.2 ± 0.91a	25.2 ± 0.67a	10.42 ± 0.16a	10.47 ± 0.23a	862 ± 26.1a	876 ± 24.1a
T_7	22.7 ± 0.69bc	23.0 ± 0.66bc	18.7 ± 0.49cd	19.2 ± 0.55cd	8.06 ± 0.18bc	8.13 ± 0.18bc	621 ± 26.1bc	637 ± 29.7bc
T_8	23.6 ± 0.79b	24.1 ± 0.76b	19.5 ± 0.85bc	20.5 ± 0.72bc	8.35 ± 0.20b	8.42 ± 0.14b	648 ± 24.9bc	668 ± 28.3bc
T_9	23.1 ± 0.52bc	23.5 ± 0.58bc	19.0 ± 0.55bc	19.8 ± 0.38bc	8.20 ± 0.27b	8.30 ± 0.18b	633 ± 23.2bc	650 ± 28.3bc
T_{10}	24.3 ± 0.64b	25.0 ± 0.61b	20.6 ± 0.55b	21.2 ± 0.43b	8.53 ± 0.25b	8.65 ± 0.23b	680 ± 20.2b	700 ± 24.7b
T_{11}	20.3 ± 0.73d	20.8 ± 0.70de	16.3 ± 0.38e	16.7 ± 0.70ef	7.27 ± 0.19d	7.32 ± 0.24d	539 ± 20.8de	557 ± 23.3de
T_{12}	21.1 ± 0.78cd	21.8 ± 0.62cd	17.0 ± 0.61de	17.6 ± 0.64de	7.51 ± 0.19cd	7.59 ± 0.16cd	584 ± 24.8cd	597 ± 27.2cd
T_{13}	19.2 ± 0.81de	19.7 ± 0.71ef	15.7 ± 0.44ef	15.9 ± 0.61fg	6.96 ± 0.14de	7.04 ± 0.22de	532 ± 24.8de	550 ± 20.6de
T_{14}	18.0 ± 0.72e	18.5 ± 0.52f	13.9 ± 0.52f	14.3 ± 0.38g	6.60 ± 0.22e	6.71 ± 0.21e	507 ± 21.7e	513 ± 21.5e

T_1 – 100% nitrogen (N) through farmyard manure (FYM), **T_2** – 100% N through FYM + residue, **T_3** – 75% N through FYM + 25% N through chemical fertilizer (CF), **T_4** – 75% N through FYM + 25% N through CF + residue, **T_5** – 50% N through FYM + 50% N through CF, **T_6** – 50% N through FYM + 50% N through CF + residue, **T_7** – 25% N through FYM + 75% N through CF, **T_8** – 25% N through FYM + 75% N through CF + residue, **T_9** – 100% N through CF + 25% additional N through FYM, **T_{10}** – 100% N through CF + 25% additional N through FYM + residue, **T_{11}** – 100% N through CF, **T_{12}** – 100% N through CF + residue, **T_{13}** – Cowpea intercropping in maize without fertilizer + residue retention in barley, **T_{14}** – Control (no fertilizer application).

Table 2. Residual effect of INM on growth parameters of cowpea in maize-barley-cowpea cropping system.

Treatment	Plant height (cm)		Leaf area index		Dry matter accumulation (g/plant)	
	2023-24	2024-25	2023-24	2024-25	2023-24	2024-25
T_1	91.4 ± 1.60abc	92.9 ± 1.92ab	3.29 ± 0.07ab	3.36 ± 0.08a	35.5 ± 1.16a	36.9 ± 0.91a
T_2	92.3 ± 1.86ab	97.0 ± 1.73a	3.42 ± 0.07a	3.56 ± 0.06a	37.0 ± 1.15a	39.4 ± 0.70a
T_3	93.1 ± 2.02ab	94.3 ± 2.77ab	3.33 ± 0.08a	3.43 ± 0.09a	35.7 ± 0.91a	37.7 ± 0.81a
T_4	93.8 ± 2.34a	96.1 ± 2.10a	3.48 ± 0.06a	3.53 ± 0.08a	37.5 ± 0.82a	39.2 ± 1.27a
T_5	91.6 ± 1.81abc	93.3 ± 1.76ab	3.37 ± 0.07a	3.40 ± 0.06a	36.2 ± 0.91a	37.1 ± 0.87a
T_6	95.1 ± 1.73a	95.8 ± 1.54a	3.51 ± 0.07a	3.52 ± 0.05a	38.2 ± 0.79a	39.0 ± 1.19a
T_7	85.0 ± 2.10de	85.8 ± 1.41cde	2.81 ± 0.07def	2.86 ± 0.07cde	30.5 ± 1.06bc	31.4 ± 0.98bc
T_8	87.7 ± 1.64bcd	89.0 ± 1.34bc	3.00 ± 0.07cd	3.05 ± 0.09bc	31.3 ± 0.96b	32.5 ± 0.79b
T_9	85.2 ± 1.39de	86.2 ± 1.32cde	2.91 ± 0.08cde	2.98 ± 0.05bcd	30.8 ± 0.91bc	31.6 ± 0.90b
T_{10}	86.2 ± 1.95cd	87.2 ± 1.25cd	3.06 ± 0.07bc	3.12 ± 0.07b	32.1 ± 1.13b	33.1 ± 0.70b
T_{11}	80.3 ± 1.76ef	80.9 ± 1.49ef	2.70 ± 0.06efg	2.72 ± 0.06ef	27.4 ± 1.01de	28.0 ± 0.61de
T_{12}	82.3 ± 1.76def	83.1 ± 1.53def	2.79 ± 0.10def	2.80 ± 0.06de	28.0 ± 0.85cd	28.9 ± 0.78cd
T_{13}	79.5 ± 2.46ef	80.2 ± 2.06f	2.63 ± 0.09fg	2.65 ± 0.04ef	26.0 ± 0.95de	26.7 ± 0.70de
T_{14}	78.1 ± 2.05f	79.5 ± 1.92f	2.55 ± 0.09g	2.51 ± 0.05f	24.8 ± 0.99e	25.8 ± 0.64e

$\mathbf{T_1}$ – 100% nitrogen (N) through farmyard manure (FYM), $\mathbf{T_2}$ – 100% N through FYM + residue, $\mathbf{T_3}$ – 75% N through FYM + 25% N through chemical fertilizer (CF), $\mathbf{T_4}$ – 75% N through FYM + 25% N through CF + residue, $\mathbf{T_5}$ – 50% N through FYM + 50% N through CF, $\mathbf{T_6}$ – 50% N through FYM + 50% N through CF + residue, $\mathbf{T_7}$ – 25% N through FYM + 75% N through CF, $\mathbf{T_8}$ – 25% N through FYM + 75% N through CF + residue, $\mathbf{T_9}$ – 100% N through CF + 25% additional N through FYM, $\mathbf{T_{10}}$ – 100% N through CF + 25% additional N through FYM + residue, $\mathbf{T_{11}}$ – 100% N through CF, $\mathbf{T_{12}}$ – 100% N through CF + residue, $\mathbf{T_{13}}$ – Cowpea intercropping in maize without fertilizer + residue retention in barley, $\mathbf{T_{14}}$ – Control (no fertilizer application).

Research have demonstrated that higher application of FYM to the preceding crops leads to superior growth performance of the succeeding crop in a cropping system (7, 8, 18).

Yield attributing characters

The significant differences were also observed in the yield attributing characters of cowpea under the different INM treatments applied to the preceding crops (maize and barley) in maize-barley-cowpea rotation during both years (Table 3). The results indicated that the INM treatment T_6 (50 % N from FYM + 50 % from CF + residue) produced substantially higher number of pods/plant (21.3), length of pod (20.1 cm) and number of seeds/pod (11.8) over the other treatments, but found statistically comparable with T_5, T_4, T_3, T_2 and T_1 during 2024. Similarly, in the year 2025, the treatment T_2 recorded significantly higher number of pods/plant (22.4), length of pod (20.7 cm) and seeds/pod (12.0) over other treatments, but was statistically comparable with T_1, T_3, T_4, T_5 and T_6. The enhanced performance of cowpea under these treatments can be attributed to the residual fertility effects arising from the preceding crops due to the carry-over effect. The high cellulose content in FYM and residues slowed mineralization, ensuring a steady nutrient release throughout cowpea growth, which improved source-sink balance and reproductive efficiency (6). Organic amendments enrich the soil, improve its structure and moisture balance, and stimulate microbial activity, supporting efficient assimilate translocation and better pod and seed development in the succeeding crop (1). Similar results have also been reported in the previous studies (7, 8).

Productivity and profitability

The green pod yield, haulm yield and biological yield of cowpea in maize-barley-cowpea rotation obtained under various treatments of INM are given in Table 3 and the economic analysis is given in Table 4. The findings indicated that in 2024, the application of 50 % N from FYM + 50 % from CF + residue (T_6), being statistically at par with the treatments, *i.e.,* T_1, T_2, T_3, T_4 and T_5 produced significantly higher green pod yield of 7467 kg/ha, haulm yield of 9360 kg/ha and biological yield of 16827 kg/ha in comparison to other treatments. Moreover, treatment T_2 recorded significantly greater green pod yield (7704 kg/ha), haulm yield (9646 kg/ha) and biological yield (17350 kg/ha) over the other treatments but was statistically comparable with T_1, T_3, T_4, T_5 and T_6 in 2025. The higher cowpea productivity under treatments with higher FYM application in the preceding crops can be linked to an increased availability of nutrients and better soil health. The slow and steady nutrient release from FYM enhances soil organic carbon, supporting the mineralization process and creating a favourable environment for soil microbes and fauna that aid nitrogen fixation. Residue retention further enriches soil organic matter, moisture and cation exchange capacity, facilitating vigorous growth and productivity. Similar residual benefits of INM on succeeding legumes have been reported in earlier research (7, 18). These results highlight that balanced use of organic and inorganic (chemical) sources in preceding crops exerts a positive effect on succeeding legumes through improved nutrient cycling, ensuring agroecosystem sustainability. The findings in Table 4 show that in 2023-24, the application of 50 % N from FYM + 50 % from CF + residue generated the highest net returns of ₹76312/ha, leading to a superior BC ratio of 2.14 due to increased economic yields. In the year 2024-25, the treatment with 100 % N from FYM + residue produced the highest net returns (₹79865/ha) and a BC ratio of 2.24.

Conclusion

The present investigation showed that integrating higher doses of FYM with chemical fertilizers in the preceding maize and barley crops exerts a strong positive residual effect on the succeeding cowpea in the maize-barley-cowpea rotation. The integrated nutrient management (T_1, T_2, T_3, T_4, T_5 and T_6) significantly enhanced growth characters and yield attributes of cowpea, consequently resulting in

Table 3. Residual effect of INM on yield attributes and yield of cowpea in maize-barley-cowpea cropping system **.**

Treatment	2023-24							2024-25						
	No. of pods/ plant	Length of pod (cm)	No. of seeds/ pod	100-seed weight (g)	Green pod yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)	No. of pods/ plant	Length of pod (cm)	No. of seeds/ pod	100-seed weight (g)	Green pod yield (kg/ha)	Haulm yield (kg/ha)	Biological yield (kg/ha)
T_1	18.9 ± 1.09ab	18.5 ± 0.58abc	11.1 ± 0.29a	11.6 ± 0.79a	7085 ± 143a	8891 ± 221a	15976 ± 364a	20.2 ± 1.06ab	19.5 ± 0.57ab	11.6 ± 0.35abc	12.2 ± 0.41a	7249 ± 131a	9181 ± 147a	16430 ± 278a
T_2	19.9 ± 0.84a	19.3 ± 0.45a	11.4 ± 0.31a	12.1 ± 0.68a	7257 ± 196a	9070 ± 234a	16327 ± 430a	22.8 ± 0.68a	20.9 ± 0.45a	12.4 ± 0.30a	12.7 ± 0.66a	7704 ± 142a	9646 ± 131a	17350 ± 268a
T_3	19.2 ± 1.26a	18.8 ± 0.60a	11.3 ± 0.32a	11.8 ± 1.03a	7101 ± 150a	9034 ± 205a	16135 ± 351a	20.4 ± 0.87a	20.1 ± 0.64a	11.7 ± 0.38ab	11.9 ± 0.37a	7417 ± 228a	9304 ± 187a	16721 ± 414a
T_4	20.8 ± 0.81a	19.6 ± 1.02a	11.6 ± 0.36a	12.4 ± 0.99a	7312 ± 193a	9274 ± 185a	16586 ± 377a	22.7 ± 1.09a	20.8 ± 0.57a	12.1 ± 0.65a	12.3 ± 0.69a	7676 ± 147a	9537 ± 198a	17213 ± 343a
T_5	19.9 ± 0.90a	18.7 ± 0.91ab	11.3 ± 0.41a	12.1 ± 0.55a	7188 ± 191a	9057 ± 185a	16245 ± 376a	20.4 ± 0.81a	19.9 ± 0.54a	11.6 ± 0.35abc	12.3 ± 0.55a	7337 ± 174a	9262 ± 201a	16600 ± 375a
T_6	21.3 ± 0.72a	20.1 ± 0.82a	11.8 ± 0.29a	12.6 ± 0.51a	7467 ± 154a	9360 ± 190a	16827 ± 344a	22.4 ± 0.67a	20.7 ± 0.41a	12.0 ± 0.43a	12.6 ± 0.50a	7632 ± 128a	9476 ± 153a	17108 ± 280a
T_7	15.0 ± 0.77cd	16.2 ± 0.44de	9.4 ± 0.23bcd	11.9 ± 0.62a	5799 ± 129bc	7342 ± 170bc	13141 ± 299bc	16.0 ± 0.81cdef	16.9 ± 0.36cd	10.2 ± 0.23def	11.9 ± 0.52a	5992 ± 115bc	7439 ± 168bc	13431 ± 283bc
T_8	16.6 ± 0.67bc	17.0 ± 0.51bcd	9.8 ± 0.25b	12.0 ± 0.48a	6129 ± 131b	7522 ± 172b	13651 ± 303b	17.6 ± 1.30bc	18.1 ± 0.57bc	10.8 ± 0.26bcd	12.1 ± 0.38a	6378 ± 187b	7615 ± 145b	13993 ± 331b
T_9	15.5 ± 0.75cd	16.3 ± 0.60de	9.6 ± 0.20bc	11.7 ± 0.59a	5887 ± 101b	7372 ± 169bc	13260 ± 244b	16.3 ± 0.92cde	16.9 ± 0.47cd	10.1 ± 0.23def	11.6 ± 0.81a	6107 ± 222b	7538 ± 181bc	13645 ± 352b
T_{10}	16.1 ± 0.78cd	16.9 ± 0.50cde	10.1 ± 0.34b	11.8 ± 1.13a	6237 ± 196b	7727 ± 169b	13964 ± 365b	17.0 ± 1.30cd	17.7 ± 0.52c	10.6 ± 0.35cde	11.9 ± 0.45a	6503 ± 151b	7845 ± 176b	14348 ± 327b
T_{11}	13.7 ± 0.52de	15.2 ± 0.34efg	8.6 ± 0.24de	11.1 ± 0.47a	5208 ± 168de	6633 ± 174de	11841 ± 337de	14.0 ± 0.77efg	15.5 ± 0.34de	9.2 ± 0.26fg	11.0 ± 0.35a	5367 ± 237de	6739 ± 150de	12106 ± 385de
T_{12}	14.0 ± 0.93de	15.6 ± 0.35def	8.9 ± 0.29cd	11.3 ± 1.11a	5337 ± 110cd	6896 ± 204cd	12233 ± 313cd	14.7 ± 0.75def	16.0 ± 0.40de	9.6 ± 0.29ef	11.4 ± 1.05a	5572 ± 241cd	7079 ± 166cd	12651 ± 406cd
T_{13}	12.1 ± 0.26ef	14.3 ± 0.31fg	7.9 ± 0.25ef	10.7 ± 0.44a	5067 ± 173de	6474 ± 131de	11541 ± 266de	13.5 ± 0.76fg	14.9 ± 0.47ef	8.4 ± 0.23gh	10.8 ± 0.77a	5186 ± 148de	6514 ± 124e	11700 ± 237de
T_{14}	11.2 ± 0.58f	13.7 ± 0.29g	7.6 ± 0.30f	10.2 ± 0.51a	4831 ± 133e	6255 ± 155e	11086 ± 287e	11.6 ± 0.66g	14.0 ± 0.29f	8.0 ± 0.29h	10.6 ± 0.68a	4900 ± 119e	6379 ± 133e	11279 ± 252e

T_1 – 100% nitrogen (N) through farmyard manure (FYM), **T_2** – 100% N through FYM + residue, **T_3** – 75% N through FYM + 25% N through chemical fertilizer (CF), **T_4** – 75% N through FYM + 25% N through CF + residue, **T_5** – 50% N through FYM + 50% N through CF, **T_6** – 50% N through FYM + 50% N through CF + residue, **T_7** – 25% N through FYM + 75% N through CF, **T_8** – 25% N through FYM + 75% N through CF + residue, **T_9** – 100% N through CF + 25% additional N through FYM, **T_{10}** – 100% N through CF + 25% additional N through FYM + residue, **T_{11}** – 100% N through CF, **T_{12}** – 100% N through CF + residue, **T_{13}** – Cowpea intercropping in maize without fertilizer + residue retention in barley, **T_{14}** – Control (no fertilizer application).

Table 4. Residual effect of INM on the profitability of cowpea in the maize-barley-cowpea cropping system.

Treatment	2023-24				2024-25			
	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	BC ratio	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	BC ratio
T_1	35695	106274	70579	1.98	35695	108735	73040	2.05
T_2	35695	108859	73164	2.05	35695	115560	79865	2.24
T_3	35695	106515	70820	1.98	35695	111255	75560	2.12
T_4	35695	109681	73986	2.07	35695	115138	79443	2.23
T_5	35695	107818	72123	2.02	35695	110060	74365	2.08
T_6	35695	112007	76312	2.14	35695	114480	78785	2.21
T_7	35695	86985	51290	1.44	35695	89885	54190	1.52
T_8	35695	91937	56242	1.58	35695	95670	59975	1.68
T_9	35695	88306	52611	1.47	35695	91605	55910	1.57
T_{10}	35695	93555	57860	1.62	35695	97540	61845	1.73
T_{11}	35695	78117	42422	1.19	35695	80505	44810	1.26
T_{12}	35695	80057	44362	1.24	35695	83579	47884	1.34
T_{13}	35695	76004	40309	1.13	35695	77783	42088	1.18
T_{14}	35695	72469	36774	1.03	35695	73501	37806	1.06

$\mathbf{T_1}$ – 100% nitrogen (N) through farmyard manure (FYM), $\mathbf{T_2}$ – 100% N through FYM + residue, $\mathbf{T_3}$ – 75% N through FYM + 25% N through chemical fertilizer (CF), $\mathbf{T_4}$ – 75% N through FYM + 25% N through CF + residue, $\mathbf{T_5}$ – 50% N through FYM + 50% N through CF, $\mathbf{T_6}$ – 50% N through FYM + 50% N through CF + residue, $\mathbf{T_7}$ – 25% N through FYM + 75% N through CF, $\mathbf{T_8}$ – 25% N through FYM + 75% N through CF + residue, $\mathbf{T_9}$ – 100% N through CF + 25% additional N through FYM, $\mathbf{T_{10}}$ – 100% N through CF + 25% additional N through FYM + residue, $\mathbf{T_{11}}$ – 100% N through CF, $\mathbf{T_{12}}$ – 100% N through CF + residue, $\mathbf{T_{13}}$ – Cowpea intercropping in maize without fertilizer + residue retention in barley, $\mathbf{T_{14}}$ – Control (no fertilizer application).

higher productivity and profitability due to the carry-over effect of organic amendments. Hence, these treatments can be recommended for the adoption in preceding maize and barley crops to enhance the performance and profitability of the succeeding cowpea, thereby promoting long-term sustainability of the maize-barley-cowpea rotation in the trans-Gangetic plains.

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Authors' contributions

GS contributed to the conception and design of the study; performed material preparation, data collection, and analysis; wrote the first draft of the manuscript. SSW, SPS, SK and KS contributed to the conception and design of the study, assisted in material preparation, data collection, and analysis. RB contributed to the conception and design of the study, assisted in material preparation, data collection and analysis and reviewed the manuscript. All authors read and approved the final manuscript.

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During the preparation of this work, the authors used ChatGPT in order to improve the language and correct the grammar. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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