



RESEARCH ARTICLE

Performance of pigeon pea in rice-based cropping system and its implications on soil biochemical indicators

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Abstract

The field experiment was conducted during the kharif and rabi seasons of 2022–23 and 2023–24 at the Agronomy Main Research Farm, College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, to identify the performance of pigeon pea in rice-based cropping systems and its implications on soil biochemical indicators. The experiment was laid out in a randomised block design (RBD) with 12 treatments and 3 replications. Recommended dose of fertilisers for rice was 80:40:40 kg N, P₂O₅, K₂O ha⁻¹. N was applied as per treatment; NU spray dose was 2 sprays at 30 and 50 DAT and basal application of P and K at 40 kg each ha⁻¹ and ZnSO₄ at 25 kg ha⁻¹. The pigeon pea variety “PRG-176” was grown under residual nutrient conditions in the rabi season. The soil of the experimental site was sandy loam in texture, acidic in reaction (pH 5.04), medium in available organic carbon (5.23 g kg⁻¹), EC (0.02 dSm⁻¹), low in available nitrogen (213.3 kg ha⁻¹), medium in available phosphorus (16.3 kg ha⁻¹), medium in available potassium (134.4 kg ha⁻¹), low in available sulphur (12.9 kg ha⁻¹) and zinc (0.52 kg ha⁻¹). In pigeon pea grown under residual condition in rabi season, the maximum plant height (145.7 cm), primary branches (14.4 plant⁻¹), secondary branches (19.9 plant⁻¹), dry matter accumulation (99.96 g plant⁻¹) at harvest, number of pods (131.8 plant⁻¹), number of seeds per pod (4.4), seed index (11.5 g), seed yield (1394.1 kg ha⁻¹) and haulm yield (5060.1 kg ha⁻¹) was recorded when 75 % STBN + 25 % VC + ZnSO₄ (T9) was applied to rice and it was at par with 75 % STBN + 25 % FYM + ZnSO₄ (T8), 75 % STBN + 25 % VC (T3) and 75 % STBN + 25 % FYM (T2). After two years of experimentation, the organic carbon content, microbial population (bacteria, fungi and actinomycetes), microbial biomass carbon (MBC), microbial biomass nitrogen (MBN) and activity of soil enzymes like urease, dehydrogenase, acid and alkaline phosphatase improved over the initial value in the rice-pigeon pea system.

Keywords: integrated nutrient management; organic carbon; pigeon pea; residual effect; soil enzymes; soil microbes

Introduction

Pigeon pea (*Cajanus cajan* L. Millsp.), popularly known as arhar, is one of the principal leguminous pulse crops grown predominantly in the rabi season. India is the largest producer of red gram in the world, producing 4.34 million tonnes from an area of 5.05 million hectares, with a productivity of 859 kg ha⁻¹ during 2023–24 (1). Pigeon pea seeds are commonly consumed as dal and its green pods, utilised as vegetables, provide a valuable source of plant-based protein in human diet. Owing to its deep and extensive root system, drought tolerance habit, pigeon pea is well suited for cultivation under water limited residual rainfed conditions, utilising moisture after rice harvest. Pigeon pea, as a soil ameliorant is known to provide multiple benefits to the soil in which it is grown, being a leguminous crop, it fixes atmospheric nitrogen through symbiosis with rhizobium bacteria, thus enriching soil fertility. Despite these benefits, pigeon pea production in eastern India still remains low due to delayed sowing after rice harvest, erratic monsoon rainfall

and prolonged harvesting, compressing the sowing window for rabi pigeon pea by three to four weeks, causing a reduction in vegetative growth, dry matter accumulation and yield potential. Under such circumstances, the selection of short-duration rice varieties is a better solution (2). Additionally, rice–pigeon pea systems improve resource use efficiency, enhance profitability, provides livelihood security and contribute to climate resilience by reducing greenhouse gas emissions compared to rice–rice systems. The performance of integrated nutrient management (INM) and its benefits in rice and rice-based systems, remains a paucity of localised research focused on the residual effect of INM on the rabi pulses. Precise quantification of residual soil fertility and nutrient dynamics after rice cultivation under INM by integrating farmyard manure (FYM), vermicompost (VC), nano urea and zinc sulphate is essential to tailor recommendations that enhance pulse productivity without excessive external inputs. Assessing the residual impact of INM applied to rice on rabi arhar will generate vital insights for designing sustainable and profitable cropping systems for Odisha and similar

agroecologies. Soil microbes play a crucial role in the soil ecosystem by regulating the decomposition of organic matter, the formation of humus and the cycling of nutrient elements, while soil enzymes catalyse most soil biological processes. Thus, soil microbes and enzymes are key components and the main driving force in soil nutrient cycling and energy flow in various cropping systems. The present study evaluates the yield performance and soil biological properties, including microbial activity and enzyme dynamics of pigeon pea under rice-based cropping systems.

Materials and Methods

Site description

The field experiment was conducted at the Agronomy Main Research Farm of the College of Agriculture, Odisha University of Agriculture and Technology, Bhubaneswar, during kharif and rabi seasons of 2022–23 and 2023–24. The farm is situated at the location 20° 15' 53.7" N latitude and 85° 52' 45.78" E longitude, with an altitude of 25.9 m above mean sea level. The study was carried out in a rice–pigeon pea cropping system, with rice cultivated during the kharif season followed by pigeon pea grown in the rabi season with average rainfall of 1362.4 mm and average diurnal temperature of 27 °C during the cropping period.

Experimental design

During the kharif season, a total of 12 treatments with different INM practices in rice were evaluated using a randomised block design (RBD) with three replications, with the plot size 5 m × 4.3 m. The rice variety “Kalinga Dhan 1201” was transplanted in kharif season with the treatments: T1 - 100 % (soil test based nitrogen) STBN, T2 - 75 % STBN + 25 % N through FYM, T3 - 75 % STBN + 25 % N through VC, T4 - 75 % STBN + Nano urea (NU) spray, T5 - 50 % STBN + 25 % N through FYM + NU spray, T6 - 50 % STBN + 25 % N through VC + NU spray, T7 - 100 % STBN + ZnSO₄, T8 - 75 % STBN + 25 % N through FYM + ZnSO₄, T9 - 75 % STBN + 25 % N through VC + ZnSO₄, T10 - 75 % STBN + NU spray + ZnSO₄, T11 - 50 % STBN + 25 % N through FYM + NU spray + ZnSO₄ and T12 - 50 % STBN + 25 % N through VC + NU spray + ZnSO₄. Recommended dose of fertiliser applied to rice was 80 : 40 : 40 kg N, P₂O₅, K₂O ha⁻¹. Nitrogen was applied as per treatment, NU spray dose was 2 sprays at 30 and 50 days after transplanting (DAT) and basal application of P and K at 40 kg ha⁻¹ each and ZnSO₄ at 25 kg ha⁻¹. The pigeon pea variety “PRG-176” was grown under residual nutrient conditions in the rabi

season.

Soil details

The soil of the experimental site was sandy loam in texture, acidic in reaction (pH 5.04), medium in available organic carbon (5.23 g kg⁻¹), electrical conductivity (EC) of 0.02 dSm⁻¹, low in available N (213.3 kg ha⁻¹), medium in available P (16.3 kg ha⁻¹), medium in available K (134.4 kg ha⁻¹), low in available sulphur (12.9 kg ha⁻¹) and low in zinc (0.52 kg ha⁻¹). During the rabi season, pigeon pea was grown in the residual plots of the 12 INM practices previously applied to rice to assess the carry-over impact of these treatments.

Soil microbial and enzyme assay

The population of soil microorganisms (bacteria, fungi and actinomycetes) was estimated in the laboratory by counting the colony-forming units (CFU) with suitable dilution. Microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) content of soil were determined by the chloroform fumigation extraction method. Soil urease, acid phosphatase, alkaline phosphatase and dehydrogenase activities, as well as soil organic carbon content, were determined using standard methods as documented in previous studies (3–6).

Statistical analysis

The pertinent growth, yield and soil microbial load parameters were recorded using standard procedures. All the parameters were then analysed for drawing a conclusion using the analysis of variance (ANOVA) (7).

Results

Effect of integrated nutrient management on plant growth parameters

The plant growth parameters like plant height, number of primary branches, number of secondary branches and dry matter accumulation of pigeon pea were significantly influenced by INM imposed in proceeding rice crop and increased till harvest of the crop. The pooled data of two years of experiments in 2022–23 and 2023–24 are depicted in Table 1. The maximum plant height, number of primary, secondary branches and dry matter accumulation per plant (145.7 cm, 14.4, 19.9 and 99.6, respectively) with the application of 75 % STBN + 25 % VC + ZnSO₄ (T₉) and it was statistically at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈), 75 %

Table 1. Growth parameters of pigeon pea as influenced by integrated nutrient management (INM) in rice-pigeon pea cropping system (pooled data of two years)

Treatments	Plant height at harvest (cm)	No. Primary branches/plant at harvest	Secondary branches/plants at harvest	Effective nodules (75 DAS)	LAI (90 DAS)	Dry matter accumulation (g/plant ⁻¹) at harvest
T1-100 % STBN	120.2	11.8	17.1	31.3	1.72	70.32
T2-75 % STBN + 25 % FYM	142.2	13.7	18.7	40.4	2.91	86.63
T3-75 % STBN + 25 % VC	142.7	13.9	19.4	41.7	2.92	89.03
T4-75 % STBN + NU	118.1	11.4	16.8	29.3	1.69	63.70
T5-50 % STBN + 25 % FYM + NU	122.8	12.5	17.4	34.5	2.10	77.14
T6-50 % STBN + 25 % VC + NU	123.1	12.5	17.5	35.7	2.18	78.40
T7-100 % STBN + ZnSO ₄	122.0	12.2	17.2	33.5	1.89	76.25
T8-75 % STBN + 25 % FYM + ZnSO ₄	144.2	14.1	19.8	41.9	2.94	95.77
T9-75 % STBN + 25 % VC + ZnSO ₄	145.7	14.4	19.9	44.3	2.96	99.96
T10-75 % STBN + NU + ZnSO ₄	120.9	12.1	17.3	33.5	1.83	71.59
T11-50 % STBN + 25 % FYM + NU + ZnSO ₄	123.6	12.6	17.6	36.0	2.47	80.59
T12-50 % STBN + 25 % VC + NU + ZnSO ₄	124.9	12.6	17.6	36.0	2.51	80.82
SEm (±)	3.68	0.39	0.53	1.36	0.087	4.694
CD (0.05)	10.5	1.1	1.5	3.9	0.25	13.38

STBN: Soil test based nutrient application; FYM: Farmyard manure; VC: Vermicompost; NU: Nutrient uptake based nutrient management; ZnSO₄: Zinc sulphate; LAI: Leaf area index; DAS: Days after sowing; SEm (±): Standard error of mean; CD (0.05): Critical difference at 5 % level of significance.

STBN + 25 % VC (T₃) and 75 % STBN + 25 % FYM (T₂). The minimum plant height, number of primary branches, secondary branches and dry matter accumulation were observed with the application of 75 % STBN + NU to rice plants.

Leaf area index (LAI) increased up to 90 DAS and decreased thereafter due to leaf senescence. Application of T₉ recorded the maximum LAI (2.96) per plant, which was statistically at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈), 75 % STBN + 25 % VC (T₃) and 75 % STBN + 25 % FYM (T₂). However, the minimum LAI was observed with the application of 75 % STBN + NU (T₄) to rice plants at all the growth stages.

The number of effective nodules per plant increased up to 75 days after sowing and decreased thereafter due to the degeneration of nodules. Application of T₉ recorded the maximum number of effective nodules per plant (44.3), which was statistically at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈), 75 % STBN + 25 % VC (T₃) and 75 % STBN + 25 % FYM (T₂). However, the minimum number of nodules was observed with the application of 75 % STBN + NU (T₄) to rice plants at all the growth stages.

Effect of integrated nutrient management on yield attributing characters and yield

The yield attributing characters of pigeon pea, viz., the number of pods per plant, seeds per pod and seed index, were significantly influenced by INM followed in the preceding rice crop (Table 2). The pooled data of two years experiment in 2022–23 and 2023–24 at harvest revealed maximum number of pods per plant (131.8), seeds per pod (4.4) and seed index (11.5 g) with the application of T₉ and it was statistically at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈), 75 % STBN + 25 % VC (T₃) and 75 % STBN + 25 % FYM (T₂).

Seed yield and haulm yield of arhar with the application T₉ recorded the maximum (1394.1 kg ha⁻¹ and 5060.1 kg ha⁻¹, respectively), but were statistically at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈), 75 % STBN + 25 % VC (T₃) and 75 % STBN + 25 % FYM (T₂). The lowest seed yield and haulm yield were obtained in 75 % STBN + NU, with values of 933.9 kg ha⁻¹ and 3920.7 kg ha⁻¹, respectively. Harvest index of pigeon pea was not significantly influenced by different treatments imposed on rice. Although a higher harvest index of 21.46 % was recorded in 75 % STBN + 25 % VC + ZnSO₄ (T₉), it was statistically at par with all other treatments.

Effect of integrated nutrient management on soil microbial studies

The population of soil bacteria, fungi and actinomycetes at the end of the experiment increased in various nutrient management treatments over the initial population of 14.2 CFU × 10⁶ g⁻¹ soil, 15.1 CFU × 10⁴ g⁻¹ soil and 10.5 CFU × 10⁶ g⁻¹ soil, respectively (Table 3). Although maximum soil bacterial, soil fungal and soil actinomycetes count was observed with the application of 75 % STBN + 25 % VC + ZnSO₄ (T₉), it did not vary significantly from other treatments. The increase in microbial population over the initial value was minimal with the application of 75 % STBN + NU (T₄). The soil organic carbon at the end of the experiment improved over the initial value in all treatments. However, it did not vary significantly among the various treatments.

Effect of integrated nutrient management on soil biochemical studies

The soil MBC and soil MBN content increased from the initial values of 211.3 µg C g⁻¹ soil and 19.1 µg N g⁻¹ soil, respectively, in all the treatments. Maximum MBC and MBN content were observed in T₉, 75 % STBN + 25 % VC + ZnSO₄ (409.45 µg C g⁻¹ and 41.72 µg N g⁻¹ soil, respectively) and were at par with 75 % STBN + 25 % FYM + ZnSO₄ (T₈).

Effect of integrated nutrient management on soil enzymatic activity

The soil enzyme urease activity and dehydrogenase activity increased in different treatments over the initial value of 55.35 µg NH₄⁺ N g⁻¹ soil hr⁻¹ and 0.21 µg TPF g⁻¹ soil per day, respectively. The urease activity and dehydrogenase activity did not vary significantly among the treatments. Soil enzymatic activity is responsible for farming stable organic molecules that contribute to the permanence of the soil ecosystem. Urease and phosphatase are two important enzymes involved in the N and P cycles, respectively.

The soil enzymes, acid phosphatase activity and alkaline phosphatase activity improved in different treatments over the initial value of 0.135 µg para-nitrophenol (PNP) g⁻¹ soil hr⁻¹ and 0.015 µg PNP g⁻¹ soil hr⁻¹, respectively. The activity of soil enzyme acid phosphatase and alkaline phosphatase was superior in the treatments supplied with an organic source of nutrient and the maximum soil enzyme acid phosphatase and alkaline phosphatase activity was recorded in 75 % STBN + 25 % VC + ZnSO₄ (T₉) with value of 0.187 µg PNP g⁻¹ soil hr⁻¹ and 0.024 µg PNP g⁻¹ soil hr⁻¹, respectively.

Table 2. Yield attributing characters and yield of pigeon pea at harvest as influenced by integrated nutrient management (INM) in rice-pigeon pea cropping system (pooled data of two years)

Treatments	No. of pods plant ⁻¹	Seeds per pod	Seed index (100 seed weight) in g	Seed yield (kg ha ⁻¹)	Haulm yield (kg ha ⁻¹)	Harvest index (%)
T1-100 % STBN	107.3	3.5	10.2	960.9	4045.4	19.2
T2-75 % STBN + 25 % FYM	128.3	4.2	11.0	1253.6	4877.6	20.5
T3-75 % STBN + 25 % VC	129.3	4.2	11.2	1283.7	4919.7	20.6
T4-75 % STBN + NU	103.3	3.3	10.2	933.9	3920.7	19.2
T5-50 % STBN + 25 % FYM + NU	116.8	3.7	10.4	1081.3	4473.9	19.4
T6-50 % STBN + 25 % VC + NU	118.3	3.8	10.4	1121.4	4539.2	19.9
T7-100 % STBN + ZnSO ₄	114.3	3.7	10.3	1002.8	4131.4	19.5
T8-75 % STBN + 25 % FYM + ZnSO ₄	129.8	4.3	11.4	1330.6	4962.7	21.1
T9-75 % STBN + 25 % VC + ZnSO ₄	131.8	4.4	11.5	1394.1	5060.1	21.6
T10-75 % STBN + NU + ZnSO ₄	109.6	3.6	10.3	975.8	4069.1	19.3
T11-50 % STBN + 25 % FYM + NU + ZnSO ₄	119.4	3.9	10.5	1131.0	4617.6	19.7
T12-50 % STBN + 25 % VC + NU + ZnSO ₄	120.7	3.9	10.5	1150.0	4670.1	19.8
SEm (±)	2.42	0.11	0.21	54.07	87.96	0.83
CD (0.05)	6.9	0.3	0.6	154.1	250.7	NS

STBN: Soil test-based nitrogen; FYM: Farmyard manure; VC: Vermicompost; NU: Nutrient uptake-based nutrient management; ZnSO₄: Zinc sulphate; SEm (±): Standard error of mean; CD (0.05): Critical difference at 5 % level of significance; NS: Non-significant.

Table 3. Soil biochemical indicators at the end of two years experiment as influenced by INM in rice-pigeon pea cropping system

Treatment	Microbial studies					Enzymatic activities				
	OC (g kg ⁻¹)	Bacteria (CFU × 10 ⁶ g ⁻¹ soil)	Fungi (CFU × 10 ⁴ g ⁻¹ soil)	Actinomycetes (CFU × 10 ⁶ g ⁻¹ soil)	MBC (µg C g ⁻¹ soil)	MBN (µg N g ⁻¹ soil)	Urease (µg NH ₄ ⁺ N g ⁻¹ soil hr ⁻¹)	Dehydrogenase (µg TPF g ⁻¹ soil day ⁻¹)	Acid phosphatase (µg PNP g ⁻¹ soil hr ⁻¹)	Alkaline phosphatase (µg PNP g ⁻¹ soil hr ⁻¹)
T1-100% STBN	5.13	21.26	19.45	11.17	304.06	29.56	71.23	0.26	0.154	0.018
T2-75% STBN + 25% FYM	5.39	23.92	20.89	11.75	363.39	38.12	75.23	0.30	0.182	0.023
T3-75% STBN + 25% VC	5.43	24.30	21.09	11.83	392.28	38.81	74.98	0.30	0.177	0.022
T4-75% STBN + NU	5.11	21.11	19.20	11.06	293.40	28.38	71.18	0.25	0.153	0.017
T5-50% STBN + 25% FYM + NU	5.25	22.40	20.07	11.41	335.96	33.66	73.67	0.28	0.167	0.021
T6-50% STBN + 25% VC + NU	5.28	22.78	20.27	11.50	341.84	34.74	73.87	0.29	0.170	0.021
T7-100% STBN + ZnSO ₄	5.21	22.02	19.86	11.33	323.07	31.65	73.47	0.27	0.165	0.020
T8-75% STBN + 25% FYM + ZnSO ₄	5.47	24.68	21.30	11.91	401.81	39.35	75.66	0.31	0.185	0.023
T9-75% STBN + 25% VC + ZnSO ₄	5.55	25.06	21.52	12.02	409.45	41.72	76.56	0.31	0.187	0.024
T10-75% STBN + NU + ZnSO ₄	5.19	21.64	19.66	11.25	322.40	30.11	72.86	0.27	0.158	0.019
T11-50% STBN + 25% FYM + NU + ZnSO ₄	5.33	23.16	20.48	11.58	347.16	36.27	74.23	0.29	0.174	0.021
T12-50% STBN + 25% VC + NU + ZnSO ₄	5.36	23.54	20.69	11.66	350.45	37.17	74.45	0.30	0.175	0.022
SEm (±)	0.254	1.353	1.185	0.813	5.836	0.955	4.028	0.016	0.0070	0.0009
CD (0.05)	NS	NS	NS	NS	17.10	2.80	NS	NS	0.021	0.003
Initial	5.23	14.2	15.1	10.5	211.3	19.1	55.35	0.21	0.135	0.015

OC: Organic carbon; CFU: Colony forming units; MBC: Microbial biomass carbon; MBN: Microbial biomass nitrogen; NH₄⁺: Ammonium nitrogen; TPF: Triphenyl formazan; PNP: p-Nitrophenol; STBN: Soil test based nitrogen; FYM: Farmyard manure; VC: Vermicompost; NU: Nutrient uptake-based nutrient management; ZnSO₄: Zinc sulphate; SEm (±): Standard error of mean; CD (0.05): Critical difference at 5 % level of significance; NS: Non-significant.

Discussion

Effect of integrated nutrient management on plant growth parameters

The addition of organic manures, such as VC, improved growth parameters by enhancing soil microbial activity and nutrient release (8). The balanced fertilisation and organic amendments improved root proliferation, thereby increasing nutrient uptake and plant height in pigeon pea (9). Pigeon pea grown under INM recorded a higher number of branches due to improved N assimilation (10). The INM significantly improved secondary branching, resulting in higher biomass production (11).

Higher LAI was measured with VC + microbial inoculant (MI) application at 60 and 90 DAS and at the harvest stage, which was at par with the LAI under FYM + MI and leaf compost (LC) + MI treatment during both years. Among the organic sources of nutrients, VC has resulted in the highest LAI, followed by FYM and LC under both treated and sole application (12).

The application of organic manures will increase the soil physico-chemical as well as biological properties. Soil biological activity mainly depends on the beneficial soil and plant microbial interaction; this will lead to increasing beneficial soil microflora. Treatment which received recommended FYM along with 100 % N equivalent VC (T5) recorded a higher population of actinomycetes, bacteria and fungi as compared to the rest of the treatments. Higher nodulation under INM is attributed to improved microbial activity and enhanced rhizobial population (13).

The efficient utilisation of mineralised N from VC and fertiliser N may have enhanced N availability throughout the crop growth period, thereby increasing the assimilation of photosynthates. This improved source-sink relationship could have contributed to higher yield attributes in the rice-pigeon pea system, corroborating earlier findings reported in the rice-black gram system (14).

Effect of integrated nutrient management on yield attributing characters and yield

The increase in the number of pods, number of seeds per pod and seed index were 28 %, 33 % and 13 % higher over the minimum value recorded in 75 % STBN + NU (T4), respectively. The integrated use of fertilisers with organic manures enhanced seed filling in pigeon pea, thereby increasing the average seeds per pod. The INM practices maintain a better hormonal balance, ensuring proper fertilisation and pod filling in pigeon pea (15) and ensuring better grain filling, resulting in higher seed index (15, 16). The enhanced yield attributes could be linked to increased photosynthetic rates and accumulation of more assimilates, increasing in sink size (17).

According to previous studies, more availability of nutrients leads to more growth, more photosynthesis, more biological yield and finally more partition to grain in mungbean (18). The INM practices enhanced soil fertility status, resulting in improved seed yield. The higher seed and stalk yield of pigeon pea due to the residual effect of INM application to the preceding rice crop is attributed to the higher availability of both macro and micronutrients, facilitating their uptake (19).

Effect of integrated nutrient management on soil microbial studies

The increase in bacterial activity under integrated treatments is linked to the supply of organic substrates and favourable soil

conditions created by manure. Enhanced fungal growth may be linked to increased organic matter availability and better soil aeration in integrated treatments. Organic inputs provide an ideal environment for the growth of actinomycetes, which play a key role in decomposition processes. The maximum population of bacteria, fungi and actinomycetes present in the rice-blackgram soil is due to higher organic carbon content and effective below-ground activities of the legume crop (20). The increase in organic carbon (%) may be due to an increase in plant growth, which in turn increased the plant residues in the soil (21). Inclusion of vermicompost in INM builds up soil organic carbon, improves nutrient status, enhances cation exchange capacity, microbial activities, microbial biomass carbon and enzymatic activities (22).

Effect of integrated nutrient management on soil biochemical studies

Use of FYM and VC alone or in combination with chemical fertilisers significantly increased the soil MBC (SMB-C). It might be due to the supply of additional mineralisable and readily hydrolysable C, which resulted in higher microbial activity and, in return higher MBC. The minimum MBC was recorded under application of inorganic treatments alone (23). The soil microbial activity and biomass were significantly higher in organic management compared to the conventional chemical management system (24).

Effect of integrated nutrient management on soil enzymatic activity

The higher urease activity in the organic farming treatment may be due to enhanced microbial activities, which accelerated the breakdown of organic matter that might have provided a more favourable environment for the accumulation of urease enzyme in the soil matrix (25). The dehydrogenase activity was significantly higher in cropping systems including legumes at all stages, which might be due to the beneficial effects of legumes, such as increased leaf fall and root exudation in leguminous crops. This, in turn, enhances microbial activity by providing more substrates for microbial growth (26).

The addition of organic substances to the soil served as a carbon source that enhanced microbial biomass and phosphatase activity, showing that these enzymes are of microbiological origin and crop growth stage also significantly influenced soil enzyme activities (27). The application of organic sources of nutrients along with inorganic sources resulted in a positive and significant correlation of enzymatic activities.

Correlation analysis of the yield performance of pigeon pea

The correlation analysis revealed strong and highly significant positive associations among seed yield and its contributing traits (Table 4). Seed yield exhibited a very strong positive correlation with

seeds per pod ($r = 0.981^{**}$), number of pods ($r = 0.978^{**}$), primary branches ($r = 0.981^{**}$), dry matter accumulation ($r = 0.978^{**}$), LAI at 90 DAS ($r = 0.973^{**}$), secondary branches ($r = 0.952^{**}$) and plant height ($r = 0.939^{**}$). This indicates that improvement in these traits would directly enhance seed yield.

Among yield components, the number of pods showed an extremely strong association with seeds per pod ($r = 0.989^{**}$), suggesting that reproductive efficiency plays a crucial role in determining final productivity. Primary branches were highly correlated with secondary branches ($r = 0.977^{**}$) and the number of pods ($r = 0.973^{**}$), indicating that better branching architecture contributes substantially to pod formation.

Plant height had significant positive correlations with the number of pods ($r = 0.917^{**}$), primary branches ($r = 0.973^{**}$) and secondary branches ($r = 0.978^{**}$), suggesting that vigorous vegetative growth supports reproductive development. Similarly, LAI at 90 DAS showed strong positive correlations with seed yield ($r = 0.973^{**}$), number of pods ($r = 0.976^{**}$) and primary branches ($r = 0.955^{**}$), highlighting the importance of canopy development and photosynthetic efficiency in yield determination.

Dry matter accumulation was strongly and positively correlated with all major yield attributes, particularly seeds per pod ($r = 0.983^{**}$), primary branches ($r = 0.978^{**}$) and seed yield ($r = 0.978^{**}$). This suggests that higher biomass production increases the availability of assimilates for reproductive growth.

Overall, the results indicate that seed yield is largely governed by an integrated effect of branching traits, pod number, seed setting efficiency, canopy development, LAI and dry matter accumulation. The strong positive interrelationships among these traits suggest the possibility of simultaneous improvement through selection or agronomic management practices.

Conclusion

It can be conducted from the experiment of two consecutive years, growing pigeon pea under residual situation after rice crop grown with the application of 75 % soil test-based nutrient (STBN) along with 25 % vermicompost (VC) and ZnSO_4 proved to be the most effective strategy in the rice-pigeon pea cropping system for achieving higher productivity of pigeon pea. This treatment demonstrated superior performance and remained statistically at par with other integrated nutrient combinations such as 75 % STBN + 25 % farmyard manure (FYM) + ZnSO_4 , 75 % STBN + 25 % VC and 75 % STBN + 25 % FYM. These results indicate that partial substitution of inorganic fertilisers with organic sources can sustain crop productivity without compromising yield.

Furthermore, continuous adoption of INM over the two

Table 4. Correlation analysis between seed yield, yield attributes and growth parameters for pooled data of two years

Treatment	Seed yield	Seeds per pod	No. of pods plant ⁻¹	Plant height	Primary branches/plant	Secondary branches/plant	LAI (90 DAS)	Dry matter accumulation
Seed yield	1							
Seeds per pod	0.981 ^{**}	1						
No. of pods	0.978 ^{**}	0.989 ^{**}	1					
Plant height	0.939 ^{**}	0.937 ^{**}	0.917 ^{**}	1				
Primary branches	0.981 ^{**}	0.985 ^{**}	0.973 ^{**}	0.973 ^{**}	1			
Secondary branches	0.952 ^{**}	0.940 ^{**}	0.913 ^{**}	0.978 ^{**}	0.977 ^{**}	1		
LAI (90 DAS)	0.973 ^{**}	0.971 ^{**}	0.976 ^{**}	0.924 ^{**}	0.955 ^{**}	0.911 ^{**}	1	
Dry matter accumulation	0.978 ^{**}	0.983 ^{**}	0.967 ^{**}	0.921 ^{**}	0.978 ^{**}	0.951 ^{**}	0.933 ^{**}	1

years resulted in noticeable improvements in soil health parameters. Key indicators such as soil organic carbon content, microbial population (including bacteria, fungi and actinomycetes), microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) showed significant enhancement compared to their initial levels. In addition, the activity of important soil enzymes such as urease, dehydrogenase, acid phosphatase and alkaline phosphatase also increased, reflecting improved soil biological activity and nutrient cycling in the pigeon pea.

Despite these positive outcomes, there is a need for further research to explore alternative INM strategies. Future studies should focus on evaluating the effectiveness of different doses of nano urea along with diverse organic nutrient sources such as poultry manure, green manure and oil cakes. Additionally, to ensure efficient utilisation of residual soil nutrients after the kharif rice crop, inclusion of other pulse crops in the cropping sequence may be considered based on the agro-climatic suitability of the region. Such approaches will contribute to enhanced productivity, sustainability and soil fertility in the long term.

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Authors' contributions

Conceptualisation of the research was carried out by SSN and ST. Experimental design was developed by SSN, ST, RKN and BKM. Field and laboratory experiments, along with data collection, were conducted by SSN, ST, GP, BKM and AKP. Data analysis and technical guidance were provided by SSN, ST and GP. The original draft of the manuscript was prepared by SSN, ST, GP and DDP and subsequently revised and coordinated by SS, ST, GP, DDP, AKS, AKD, AB, IK, MR and SKS. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Crop outlook report of Andhra Pradesh: red gram. CARP, ANGRAU; June 2023–May 2024.
2. Nagamani K, Sahoo D, Patra BC. Effect of sowing time on growth and yield of rabi pigeon pea (*Cajanus cajan* L.) in Odisha. *Legume Res.* 2020;43(6):830–835.
3. Tabatabai MA, Bremner JM. Assay of urease activity in soils. *Soil Biol Biochem.* 1972;4(4):479–487. [https://doi.org/10.1016/0038-0717\(72\)90064-8](https://doi.org/10.1016/0038-0717(72)90064-8)
4. Tabatabai MA, Bremner JM. Use of p-nitrophenyl phosphate for assay of soil phosphatase activity. *Soil Biol Biochem.* 1969;1:301–307. [https://doi.org/10.1016/0038-0717\(69\)90012-1](https://doi.org/10.1016/0038-0717(69)90012-1)
5. Casida LE, Klein DA, Santoro T. Soil dehydrogenase activity. *Soil Sci.* 1964;98(6):371–376. <https://doi.org/10.1097/00010694-196412000-00004>
6. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29–38. <https://doi.org/10.1097/00010694-193401000-00003>
7. Gomez KA, Gomez AA. Statistical procedures for agricultural research. New York: Wiley; 1984. p. 76–83.
8. Rathod P, Patel MM, Gohil BS. Influence of organic manures and biofertilizers on growth and yield of pigeon pea. *Int J Curr Microbiol Appl Sci.* 2021;10(2):1150–1158.
9. Rani S, Kapoor D. Vermicompost application in rice–pigeon pea relay intercropping: effects on branching and nutrient uptake. *J Soil Crop Improv.* 2023;38(2):145–154.
10. Sharma R, Jat RS, Meena ML. Effect of integrated nutrient management on growth and yield attributes of pigeon pea (*Cajanus cajan*). *Legume Res.* 2021;44(3):345–350.
11. Kaur H, Singh J, Gill RS. Integrated nutrient management enhances branching and biomass production in pigeon pea under field conditions. *J Food Legumes.* 2022;35(2):90–95.
12. Gupta G, Dhar S, Kumar A, Choudhary AK, Dass A, Sharma VK, et al. Microbes-mediated integrated nutrient management for improved rhizo-modulation, pigeonpea productivity and soil bio-fertility in a semi-arid agro-ecology. *Front Microbiol.* 2022;13:924407. <https://doi.org/10.3389/fmicb.2022.924407>
13. Kumar P, Singh V, Meena RS. Effect of phosphorus and biofertilizers on nodulation of blackgram. *Int J Curr Microbiol Appl Sci.* 2019;8(4):540–546.
14. Balasubramanian A, Stalin P, Saravanaperumal M, Vinoth Kumar SR. Residual effect of integrated nutrient management practices on growth and yield of rice fallow blackgram (*Vigna mungo* L.). *Int J Agric Sci.* 2016;3(5):597–605.
15. Reddy DR, Kumar P, Rao MS. Influence of integrated nutrient management on pod filling and seed development in pigeon pea (*Cajanus cajan* L.). *Indian J Agric Res.* 2023;57(5):610–616.
16. Patel KK, Choudhary R, Sahu D. Effect of integrated nutrient management on branching and yield of pigeon pea (*Cajanus cajan* L.). *Indian J Agric Res.* 2023;57(2):210–216.
17. Garg K, Dhar S, Sharma VK, Meena RP, Bamboriya SD. Effect of enriched FYM and rice residue compost on growth, productivity and economics of pigeonpea (*Cajanus cajan*). *Indian J Agric Sci.* 2023;93(12):1333–1337. <https://doi.org/10.56093/ijas.v93i12.142221>
18. Shivran S. Effect of integrated nutrient management on economics of summer mungbean [*Vigna radiata* (L.) Wilczek]. *Int J Sci Res.* 2023;12:55–59. <https://doi.org/10.21275/SR23427144807>
19. Rani S, Sharma D, Verma P. Effect of integrated nutrient management on root growth and nutrient uptake in pigeon pea (*Cajanus cajan* L.). *J Plant Nutr.* 2023;46(4):655–664.
20. Debata DK, Das LK. Residual effect of integrated green manuring practice on field pea. *Int J Creat Res Thoughts.* 2024;12(2):a335–a339.
21. Senthilvalavan P, Ravichandran M. Post-harvest soil fertility status of rice–blackgram cropping system in typic haplusterts influenced by integrated nutrient management and crop cultivation techniques. *Plant Arch.* 2020;20(1):2644–2649.
22. Kumar AR, Singh V, Meena MC. Effect of integrated nutrient

management on growth and yield of rice under varying fertility conditions. *J Plant Nutr*. 2018;41(12):1650–1658.

23. Verma SN, Sharma M, Urmila. Effect of INM on soil microbial biomass carbon and enzyme activity under soybean of a typical haplustepts. *Int J Curr Microbiol Appl Sci*. 2018;7(1):1312–1318. <https://doi.org/10.20546/ijcmas.2018.701.160>
24. Krishna Kumar S, Meena RS, Singh J. Effect of organic manures on soil microbial biomass and enzyme activities. *J Plant Nutr Soil Sci*. 2005;168(6):735–740.
25. Bhavani R, Srinivas K, Reddy KR. Influence of organic manures and chemical fertilisers on nutrient availability in soil. *Int J Chem Stud*. 2017;5(6):1473–1477.
26. Gupta S, Meena RS, Kumar S, Bohra A. Integrated nutrient management enhances soil enzyme activities and soil fertility under long-term fertilisation. *Soil Sci Plant Nutr*. 2019;65(1):30–38.
27. Sriramachandrasekharan M, Ravichandran K. Effect of organic amendments on phosphatase activity and microbial biomass in soil. *J Plant Nutr Soil Sci*. 2011;174(4):597–603.

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