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Long-term assessment of organic nutrient management on the productivity, resilience, and profitability of pigeonpea (*Cajanus cajan)* in the North Eastern Region, India

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ABSTRACT

Pigeonpea (*Cajanus cajan* L. Millsp.) is a protein-rich crop that provides food, fuel, and income for smallholders in the Northeast Hill (NEH) region, where resources are limited. However, its low yield necessitates an effective organic nutrient management strategy to improve productivity in light-textured, acidic soils. To address this issue, an experiment was conducted at the College of Agriculture, Lembucherra, Tripura, over five consecutive *kharif* seasons (2019–2023). The study comprised six treatments, including four combinations of farmyard manure (FYM) at 4 t/ha and vermicompost at 2 t/ha, supplemented with *Trichoderma* and *Pseudomonas* at 2.5 kg/ha each. These were compared against a recommended dose of fertilizer and an untreated control. The highest yield (1.15 t/ha) and benefit-cost ratio (2.65) were observed in the treatment combining FYM at 4 t/ha with *Pseudomonas* at 2.5 kg/ha, while the lowest yield was recorded in the untreated control. The study indicated that treatments with organic manure significantly improved residual organic carbon and primary nutrient levels compared to the control. FYM enriched with biofertilizers proved economically viable, offering a sustainable solution for marginal pigeonpea farmers in the NEH region to enhance crop growth and yield.

Key words: Economics, Long-term, Northeast, Nutrients, Organics, Pigeonpea, Yield

Pigeonpea (*Cajanus cajan* L. Millsp.) is a significant pulse crop in India, accounting for 91% of global production. It is the fifth most important pulse crop worldwide and the second most important in India after chickpea. Pigeonpea is a vital source of protein, firewood, and income for resource-limited smallholders in the Northeast Hill (NEH) region, where it is cultivated with minimal inputs under challenging conditions (Kumar and Paslawar, 2017). Poor farmers of the NEH region rarely use synthetic fertilizers due to their high costs and concerns about food quality. Additionally, the excessive use of chemicals in modern agriculture has contributed to soil and water degradation. Organic farming, on the other hand, works in harmony with nature rather than against it. Currently, there is growing awareness across India regarding the adoption of organic farming as a sustainable alternative to address the challenges posed by chemical-based agriculture.

The northeast region is susceptible to the effects of climate change owing to its geo-ecological vulnerability and socio-economic circumstances. The rising temperatures and declining rainfall over the years will undoubtedly impact the water balance and concurrently alter the region's farming patterns (Lairenjam *et al.,* 2017). It is possible to use more organic matter to improve soil fertility and water retention in light soils instead of using fewer synthetic fertilizers. Consequently, all these approaches are inherently organic, with farmers using farmyard manure, green manure, composts, and locally created goods and methods for pest management in both crops and veg-

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etables (Das *et al.,* 2018a). Again, plant growth requires the absorption of macro and micronutrients from the soil (Qi *et al.,* 2012) where, *Trichoderma* increased plant tissue macro and micronutrient absorption (Huang *et al.,* 2011). Whereas, *Pseudomonas* are known as plant growth-promoting bacteria. Numerous PSBs, including *Pseudomonas*, *Bacilli*, *Rhizobia*, and *Azotobacter*, have significant industrial importance (Verma *et al.,* 2019b) and they are present in the rhizospheric region contributing to plant growth-promoting activities, therefore, used as biofertilizers for sustainable agriculture practices (Pattnaik *et al.,* 2019). Moreover, the NEH region has significant prospects for organic agriculture owing to the little use of synthetic fertilizers (< 12.0 kg/ha), with the abundant supply of biomass and animal dung (Das *et al.,* 2017). However, the existing exhaustive agriculture production system, mostly reliant on cereal-based clean farming with little organic inputs, poses a significant danger to the sustainability of food grain production in the area (Babu *et al.,* 2020). Hence, the study was conducted to examine the long-term impact of organic nutrient sources on the development and yield of pigeonpea, as well as to assess the influence of biofertilizer inoculation on these parameters, aiming to enhance economic viability in the virgin soils of the North Eastern hill zones.

MATERIALS AND METHODS

The field experiments was conducted at the research farm of College of Agriculture, Tripura continuously for five years during the *kharif* seasons from 2019 to 2023. The soil of the experimental site was sandy loam (Inceptisols) having a pH of 5.3, organic carbon (0.67), available nitrogen of 110.84 kg/ha, available phosphorus of 25.27 kg/ha, and available potassium of 90.40 kg/ha. The climate is subtropical, with distinctive characteristics of high annual rainfall with elevated humidity and a prolonged winter. The treatments are T_1=FYM @ 4 t/ha + *Trichoderma* @ 2.5 kg/ha, T_2=Vermicompost @ 2 t/ha + *Trichoderma* @ 2.5 kg/ha, T_3=FYM @ 4 t/ha + *Pseudomonas* @ 2.5 kg/ha, T_4=Vermicompost @ 2 t/ha + *Pseudomonas* @ 2.5 kg/ha), T_5=Untreated control, T_6=Recommended dose of fertilizer (RDF) @ 25:60:40 NPK kg/ha. The land preparation was done by two runs of power tiller, and the treatments were replicated four times in a randomized block design with a plot size of 3.6 x 4 m^2. The variety chosen for this study was PA-421. The seed was treated with *Rhizobium* at 2 g/kg. Sowing was done between the 19th to 26th of June and harvesting between the 29th of November and to 11th of December, respectively during the 2019 to 2023 experiments. Ten (10) nos. plants were randomly selected from each plot to observe growth and yield parameters. Destructive samples were used for growth attributes analyses, whereas soil samples, were used for available soil nutrient analyses.

Soil samples were collected at both the beginning and end of the experiment from all four cardinal directions and subsequently combined. The soil samples underwent air-drying in a shaded environment for a duration of 3 to 4 days. The material was subsequently crushed with a mortar and pestle and filtered through a 2 mm sieve to eliminate larger fragments. Only the remaining fine soil samples were utilized for the analysis, excluding the coarse pieces that were discarded. The alkaline permanganate technique (Subbiah and Asija, 1956) was employed to quantify the nitrogen content in soil samples, reported in kilograms per hectare. The content of available phosphorus, measured in kilograms per hectare, was assessed using Olsen's method, (Olsen *et al.*, 1954). The potassium content was assessed using a flame photometer and a neutral NH_4OAC solution (Hanway and Heidal, 1952).

The total general cost of cultivation is ₹25.72 × 10^3/ha and the cost of fertilizers and manures were added as per the treatment. The price of the produce is taken as per the minimum support price (MSP) of ₹7000/q or ₹70/kg for pigeonpea. The data collected from the field and laboratory experiments were subjected to statistical analysis appropriate to the design and analyzed using a statistical package (Indostat Services, Hyderabad). Pearson's correlation and Duncan's Multiple Range test (DMRT) were performed using SPSS Inc. Version 16.

RESULTS AND DISCUSSION

Plant Growth characters

The highest plant height (176.67 cm) was recorded under T_3 followed by T_1 (172.79 cm) and the lowest being at T_5 (134.82 cm), but T_2 (157.59 cm) and T_6 (159.61 cm) led to significant at par results, as depicted from the five years pooled values (Table 1). Plant height gradually increased up to the age of 120 DAS and thereafter, it decreased which may be due to genetic variation (Varatharajan *et al.,* 2019). In the case of primary branches (Table 1), pooled values showed that the T_3 (15.66) treatment was significantly superior to other treatments followed by T_1 and T_2. Treatment T_3 recorded the highest leaf area index (LAI) as measured throughout different days after sowing. At 120 DAS highest LAI of 4.96 was achieved in T_3 which significantly differed from other treatments but remained at par with T_1. The lowest LAI of 3.11 was achieved in untreated control (T_5). The long-term combined use of organic nutrient sources and biofertilizers may have improved the height, primary branches, and LAI by increasing nutrient availability. This could be the consequence of increased photosynthetic activity followed by

Table 1. Long-term assessment of growth characteristics of pigeonpea cultivation (5 years pooled)

Treatments	Plant Height (cm)	Primary branches (nos.)	Leaf area index			
			60 DAS	90 DAS	120 DAS	At Harvest
T_1 = (FYM @ 4 t/ha + Trichoderma @ 2.5 kg/ha)	172.79^{ab}	14.01^{b}	1.70^{ab}	3.24^{ab}	4.62^{ab}	0.60^{ab}
T_2= (Vermicompost @ 2 t/ha + Trichoderma @ 2.5 kg/ha)	157.59^{bc}	13.96^{b}	1.62^{b}	3.09^{b}	4.40^{b}	0.57^{b}
T_3 = (FYM @ 4 t/ha + Pseudomonas @ 2.5 kg/ha)	176.67^{a}	15.66^{a}	1.83^{a}	3.48^{a}	4.96^{a}	0.64^{a}
T_4 = (Vermicompost @ 2 t/ha + Pseudomonas @ 2.5 kg/ha)	155.66^{c}	12.05^{c}	1.45^{c}	2.78^{c}	3.93^{c}	0.51^{c}
T_5 = (Untreated control)	134.82^{d}	9.49^{d}	1.14^{d}	2.18^{d}	3.11^{d}	0.40^{d}
T_6 = (Recommended dose of fertilizer -RDF)	159.61^{bc}	11.74^{c}	1.34^{c}	2.56^{c}	3.63^{c}	0.47^{c}

Means followed by the same letters (a,b,c) in a column are not different at 0.05 probability level.

effective metabolite transfer (Ade *et al.,* 2018). The improvement brought about by the addition of bulky organic materials may be the consequence of a healthy nutrition supply (Ansari and Mahmood, 2017; Pathak *et al.,* 2023).

Yield attributes and yield

Pooled data (Table 2) expressed the highest pods per plant (144.06) by T_3 which was followed by T_1 and T_2 treatment. T_3 treatment (with farm yard manure addition) increased 37.35% pods per plant over untreated control. There was no significant difference between the T_5 and T_6 treatments and were statistically at par. But in the case of seed index the highest result (8.39g) was recorded under T_2 treatment (with vermicompost addition) and the lowest (7.79g) under T_6 treatment, showing significant differences from the latter whereas T_3 treatment remained statistically at par with the other treatments. The highest pod and seed yield from the pooled data was recorded by T_3 treatment (1.50 and 1.15 t/ha) and the lowest by untreated control treatment. T_3 treatment gave the highest pod and seed yield which was significantly superior than the other treatment but statistically at par with T_1. T_3 treatment enhanced seed output by 86.6% compared to the untreated control. The increase of pods per plant and higher seed yield might be likely owing to a sufficient supply of nutrients through FYM and *Pseudomonas* facilitating the conversion of plenty of nutrients into a soluble state for plant absorption (Yadav *et al.,* 2019; Pradeep *et al.,* 2018). Consequently, over time, pigeonpea might improve productivity and restore the physical health of the soil. The current investigation revealed that pigeonpea has the potential to rehabilitate the soil's physical, chemical, and biological health over time (Prasadrao, 2020). The fixation of atmospheric N_2 via root nodule symbiosis, together with the gradual release of nitrogen from roots, promotes the development and yields of subsequent crops (Nath *et al.,* 2023).

A graphical depiction (Fig. 1) illustrated the percentage change in the yield of seeds during the study, indicating that the application of FYM and vermicompost consistently resulted in positive changes, in contrast to the negative changes seen in the untreated control and RDF treat-

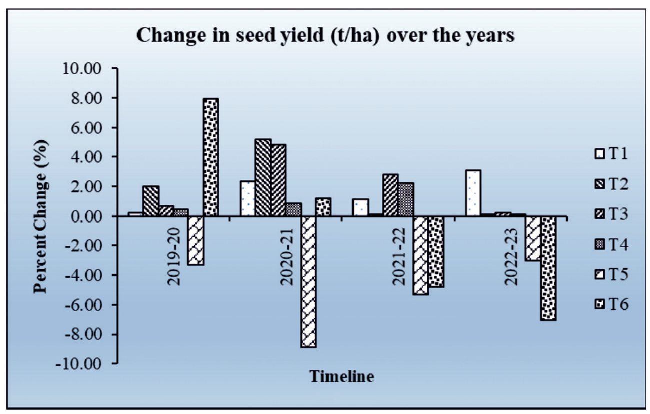

Fig. 1. Percent change in seed yield against treatments applied over the years of study.

Table 2. Long-term assessment of yield attributes and yield of pigeonpea cultivation (5 years pooled)

Treatments	Pods/plant (nos.)	100 seed wt. (g)	Seed yield/ plot (kg)	Pod yield (t/ha)	Seed yield (t/ha)
T_1 = (FYM @ 4 t/ha + Trichoderma @ 2.5 kg/ha)	132.36^{b}	8.12^{ab}	11.82^{b}	1.37^{b}	1.06^{b}
T_2= (Vermicompost @ 2 t/ha + Trichoderma @ 2.5 kg/ha)	109.91^{c}	8.39^{a}	9.88^{c}	1.33^{b}	1.02^{bc}
T_3 = (FYM @ 4 t/ha + Pseudomonas @ 2.5 kg/ha)	144.06^{a}	8.07^{ab}	12.77^{a}	1.50^{a}	1.15^{a}
T_4 = (Vermicompost @ 2 t/ha + Pseudomonas @ 2.5 kg/ha)	111.88^{c}	8.21^{ab}	10.31^{c}	1.32^{b}	1.01^{c}
T_5 = (Untreated control)	90.25^{d}	8.19^{ab}	7.60^{e}	0.778^{d}	0.616^{e}
T_6 = (Recommended dose of fertilizer -RDF)	91.68^{d}	7.79^{b}	8.44^{d}	1.05^{c}	0.819^{d}

Means followed by the same letters (a,b,c) in a column are not different at 0.05 probability level.

ment. However, farmyard manure overtook vermicompost owing to much higher application rates.

Soil available nutrient

The pooled data (Table 3) showed that organically manured plots were statistically comparable but significantly different from the untreated control and RDF. T_3 observed the highest soil available nitrogen content (226.22 kg/ha), while T_6 recorded the lowest nitrogen accumulation (155.21 kg/ha), followed by T_5. Adding farmyard manure @ 4 t/ha and *Pseudomonas* @ 2.5 kg/ha (T_3) increased the amount of available nitrogen by 20.23 % compared to the untreated control and by 40.75 % compared to using only the RDF. Soil-available phosphorus showed the same trend of increase as appeared from pooled values in the long-term study. T_3 recorded the highest soil phosphorus content, followed by T_1 and T_2, but both farmyard manure-treated plots remained at par and significantly differed from vermicompost-applied treatments. The T_3 treatment resulted in a 40.91% increase in soil-available phosphorus compared to the untreated control. Throughout the study, a distinct pattern in soil available potassium emerged. The T_1 treatment achieved the highest soil-available potassium, followed by T_3 and T_2, but the pooled values revealed that farmyard-manured treatments performed the best in maintaining the soil-available potassium. Soil Organic carbon (SOC) content increased with the application of biofertilizers and showed statistically at par with organic-applied treatments but differed significantly for untreated control and RDF incorporation. T_3 treatment attained higher SOC content (0.90) over the years as evident from the pooled study (Table 3), followed by T_1, T_2, and T_4.

The average soil nutrient levels following the harvest of pigeonpea demonstrate an enhancement in the residual nutrient status compared to the initial soil condition. This improvement is attributed to organic amendments, such as farmyard manure and vermicompost, which release nutrients gradually, necessitating more time for nutrient availability to plants. Additionally, biofertilizers like *Trichoderma and Pseudomonas*, enhance macro and micronutrient availability, and phosphorus solubility, thereby increasing nutrient availability in the soil (Prasadrao, 2020). Furthermore, the pigeonpea crop itself contributes to nitrogen fixation. Polynomial curve fitting (Fig. 2) of SOC, available nitrogen, phosphorus, and potassium against years of experimentation, clearly indicates that during the five-year study, there was an overall steady sequestration of carbon and an increase in residual nutrients. This proves that the addition of organics can enhance soil health and ecology (Gurmu, 2019).

Again, in the long run, enhanced absorption of macro and micro-nutrients in plant tissues by the treatment of *Trichoderma* may be attributed to the fact that *Trichoderma* possesses a cysteine-rich cell wall protein that has a major role in lateral root growth along with hair formation and elongation which results in the enhancement of total absorptive surface (Singh *et al.,* 2019).

Quadratic curve fitting (Fig. 3) between SOC and available soil nutrients indicates that nitrogen and potassium increase with rising SOC, whereas phosphorus exhibits an inverse relationship, potentially due to the fixation of released phosphorus in conjunction with the increased acidity resulting from organic matter decomposition over time (Gächter and Meyer, 1993).

Economics

Pooled data from Table 4 showed that the T_3 treatment gave the highest monetary benefit in terms of gross monetary return, net monetary return, and benefit-cost ratio. T_3 treatment was significantly differed from other treatments and followed by T_1 treatment. Hence, FYM 4 t/ha combined with *Pseudomonas* 2.5 kg/ha (T_3) gave the highest net monetary return which was 63.09% higher than the untreated control and 46.71% higher than the RDF application, respectively. Treatments T_2 and T_4 are statistically at par in case gross monetary return, net monetary return, and benefit cost. The lowest monetary return

Table 3. Long-term assessment of soil nutrient and organic carbon availability during pigeonpea cultivation (5 years pooled)

Treatments	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)	Soil organic carbon (%)
T_1 = (FYM @ 4 t/ha + Trichoderma @ 2.5 kg/ha)	221.70^a	32.33^b	149.80^a	0.91^a
T_2 = (Vermicompost @ 2 t/ha + Trichoderma @ 2.5 kg/ha)	224.72^a	29.35^c	124.35^c	0.91^a
T_3 = (FYM @ 4 t/ha + Pseudomonas @ 2.5 kg/ha)	226.22^a	35.61^a	140.44^b	0.92^a
T_4 = (Vermicompost @ 2 t/ha + Pseudomonas @ 2.5 kg/ha)	220.32^a	28.79^c	122.27^c	0.90^a
T_5 = (Untreated control)	188.15^b	25.27^d	91.51^e	0.67^b
T_6 = (Recommended dose of fertilizer -RDF)	155.21^c	26.38^d	106.86^d	0.61^b

Means followed by the same letters (a, b, c) in a column are not different at 0.05 probability level.

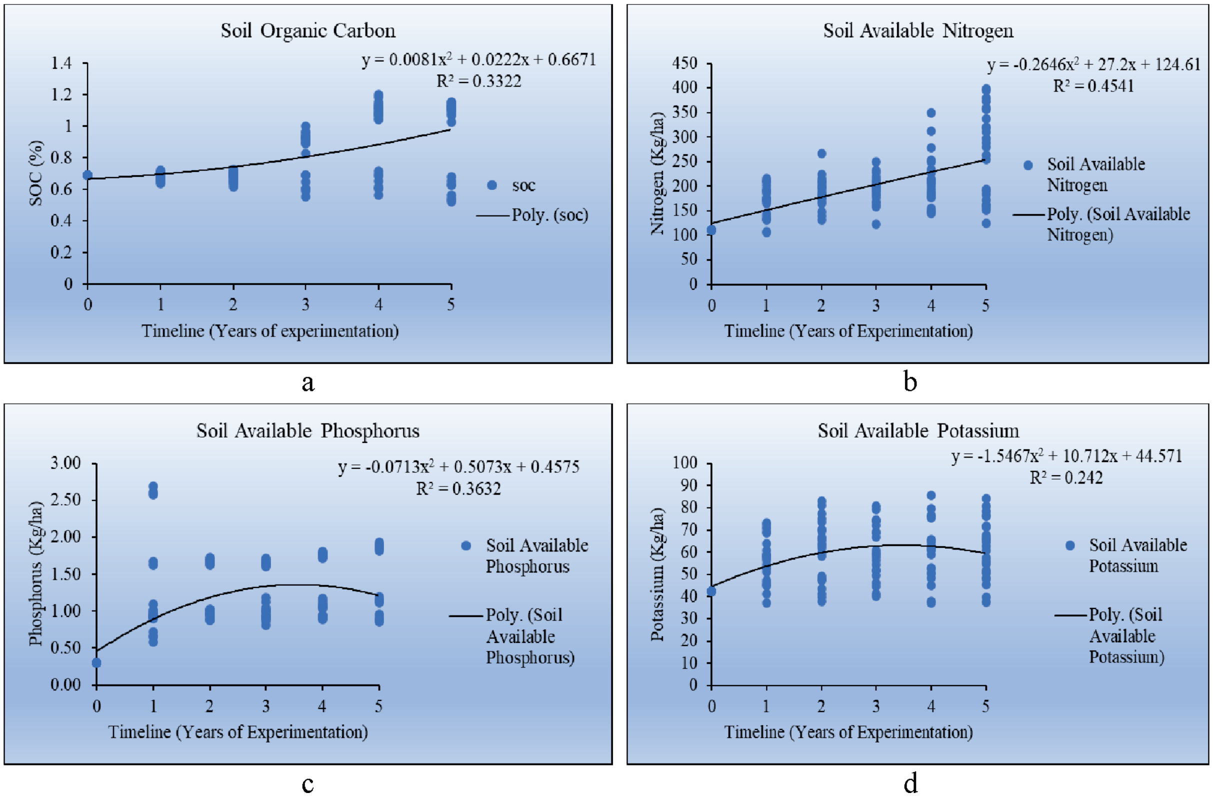

Fig. 2. Polynomial curve fitting of Soil organic carbon (a) available nitrogen (b); available phosphorus (c) and available potassium (d) over the years of study

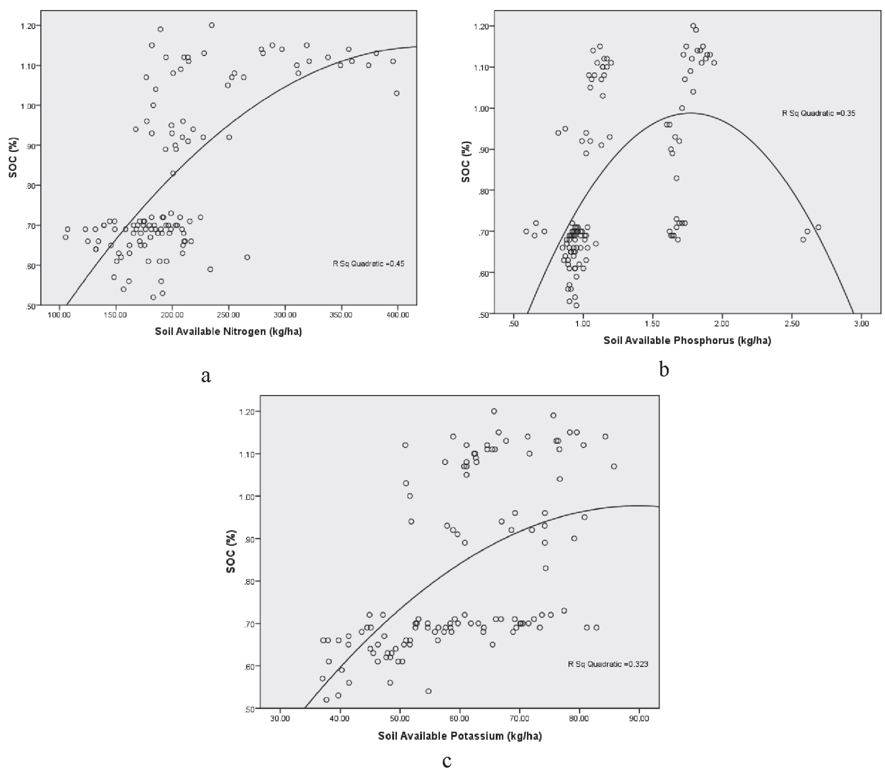

Fig. 3. Quadratic curve fitting of soil organic carbon with available nitrogen (a); available phosphorus (b) and available potassium (c) over the years of study.

Table 4. Long-term assessment of the economics of pigeonpea cultivation (5 years pooled)

Treatments	Cost of cultivation (₹ x 10^3/ha)	Gross return (₹ x 10^3/ha)	Net return (₹ x 10^3/ha)	B:C
T_1 = (FYM @ 4 t/ha + Trichoderma @ 2.5 kg/ha)	30.23	72.83^b	39.06^b	2.22^b
T_2 = (Vermicompost @ 2 t/ha + Trichoderma @ 2.5 kg/ha)	47.19	64.84^c	18.58^d	1.40^d
T_3 = (FYM @ 4 t/ha + Pseudomonas @ 2.5 kg/ha)	30.24	79.41^a	49.50^a	2.65^a
T_4 = (Vermicompost @ 2 t/ha + Pseudomonas @ 2.5 kg/ha)	47.20	67.79^c	20.44^d	1.43^d
T_5 = (Untreated control)	25.72	44.45^e	18.27^d	1.70^c
T_6 = (Recommended dose of fertilizer -RDF)	31.51	57.89^d	26.37^c	1.84^c

Means followed by the same letters (a,b,c) in a column are not different at 0.05 probability level.

Table 5. Correlation of application of organic manure and biofertilizers on pigeonpea cultivation (5 years pooled)

	Plant Height (cms)	Primary branch (nos.)	Pods/ plant (nos.)	Pod Yield (t/ha)	Seed Yield (t/ha)	Available Nitrogen (kg/ha)	Available Phosphorus (kg/ha)	Available Potassium (kg/ha)	SOC (%)	Net Return (₹/ha)
Plant Height (cms)	1	0.111	0.349**	0.336**	0.338**	0.244**	0.231*	0.327**	0.131	0.294**
Primary branch (nos.)		1	0.332**	0.427**	0.430**	0.152	0.146	0.361**	0.286**	0.389**
Pods/plant (nos.)			1	0.629**	0.616**	0.290**	0.512**	0.551**	0.511**	0.629**
Pod Yield (t/ha)				1	0.998**	0.453**	0.562**	0.744**	0.601**	0.568**
Seed Yield (t/ha)					1	0.449**	0.556**	0.750**	0.600**	0.576**
Available Nitrogen (kg/ha)						1	0.418**	0.333**	0.664**	0.188*
Available Phosphorus (kg/ha)							1	0.533**	0.489**	0.474**
Available Potassium (kg/ha)								1	0.500**	0.539**
SOC (%)									1	0.294**
Net Return (₹/ha)										1

**Correlation is significant at the 0.01 level (1-tailed), *Correlation is significant at the 0.05 level (1-tailed).

was recorded under untreated control. Vermicompost owing to higher unit price, resulted in increased input costs and lower net revenue. If possible, NEH farmers are advised to use homemade vermicompost for growing pigeonpea, as it may help cut expenses and stabilize overall profits (De *et al*., 2020; Kumawat *et al*., 2015).

Pearson Correlation

The correlations among growth, yield, and nutrient metrics indicated that all parameters had a firmly positive correlation with one another. However, all except seed and pod yield (0.998), showed low correlation. Once again, seed yield and net returns were shown to positively correlate with pod yield (Table 5). The available soil nutrients, particularly phosphorus, potassium, and soil organic carbon, exhibited a significant association with pod and seed output (De *et al.,* 2023; Manjappa *et al.,* 2023).

The research provided modest suggestions indicating that the application of extensive organic matter significantly enhances pod and yield development, as well as crop canopy and productivity in the natural (untreated control) condition, and the exclusive application of RDF adversely impacts the total yield of pigeonpea. Consequently, the long-term impacts of organic manure combined with biofertilizers may serve as an alternative agricultural strategy for marginal pigeonpea producers seeking to improve economic viability in the virgin soils of the NEH regions.

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