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Nutrient management approach to improve productivity and profitability of pigeonpea (*Cajanus cajan*) in north east hill zones of India

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ABSTRACT

The low yields of pigeonpea [*Cajanus cajan* (L.) Millsp] in the valleys of north eastern hill zones may be attributed to inadequate, unbalanced fertilization practices, and costly synthetic fertilizers application. These factors have had a negative impact on productivity, sustainability and soil health. The study was carried out during rainy (*kharif*) seasons 2022 and 2023 at the College of Agriculture, Lembucherra, West Tripura, Tripura to investigate effectiveness of organic matter in improving soil fertility while lowering reliance on synthetic fertilizers. A study was designed with eight treatments, viz. T_1, 100% recommended dose of fertilizer (RDF) @20:60:40 kg/ha; T_2, 50% RDF + phosphate solubilizing bacteria (PSB) @30 kg/ha; T_3, 50% RDF + PSB @30kg/ha + *Trichoderma* @2.5 kg/ha; T_4, 50% RDF + PSB @30 kg/ha + vermicompost (VC) @2.5 t/ha; T_5, 50% RDF + PSB @30 kg/ha + *Trichoderma* @2.5 kg/ha + VC @2.5 t/ha; T_6, 50% RDF + PSB @30 kg/ha + VC @5 t/ha; T_7, 50% RDF + PSB @30 kg/ha + *Trichoderma* @2.5 kg/ha + VC @5 t/ha; T_8, Control (farmers practice). The pigeon pea variety chosen for this study was PA-421. The experiment was laid out in a randomized block design (RBD) in three replications. Results indicated that applying vermicompost @5 t/ha and phosphorus-solubilizing bacteria @30 kg/ha markedly increased number of nodules (17.38) and leaf area index (5.54) at 90 and 120 days after sowing, respectively, with highest seed yield (1.90 t/ha) and stover yield (7.93 t/ha), when 50% of recommended doses had been replaced. Nutrient uptake, soil availability and microbial populations also showed the same trends. The greatest net return (80.43×10^3 ₹/ha) in the mentioned treatment also proves its economic viability. Hence, north-eastern hill farmers must adopt vermicompost and biofertilizers to substitute costly fertilizers for a higher return, while preserving soil health for future generations.

Keywords: Economics, North-eastern, Nutrient management, Nutrient uptake, Pigeonpea, Yield

Underutilized and neglected crops such as pigeonpea [*Cajanus cajan* (L.) Millsp] could boost food and protein requirements and improve the nutritional status and quality of life of impoverished rural people. Within legume family, pigeonpea plays a vital role in rain-fed agriculture. Rice (*Oryza sativa* L.) is the primary crop in the valley sections of the north-eastern hill (NEH) region, whereas pulses are mostly grown in rainfed uplands with few or no inputs (Bhadana *et al.* 2013). NEH area offers significant opportunities for pulse production, which farmers capitalize on, to achieve improved economic outcomes (De *et al.* 2023). Inadequate and unbalanced fertilizer application, especially concerning nitrogen and phosphorus, is the primary cause of inadequate or stagnant pigeonpea production in the NEH region (De *et al.* 2019). Singh (2007) posited that the inadequate and inconsistent use of fertilizers, together with utilization of costly synthetic fertilizers, might be potential factors contributing to the low productivity of pigeonpea crops. The use of ecologically friendly management practices has the potential to reduce the need for fertilizer application in agricultural areas (Kumar Rao 1990). Investigating that organic matter could increase soil fertility and reduce dependency on synthetic fertilizers is essential. In the north-eastern hill area of India, the goal is to develop an ecologically friendly and sustainable pigeonpea production system while reducing expenses through the application of nutrient management techniques.

MATERIALS AND METHODS

The study was carried out during rainy (*kharif*) seasons 2022 and 2023 at the College of Agriculture, Lembucherra, West Tripura (23°90'N, 91°31'E, 52 m amsl), Tripura. The soil of experimental site was sandy loam (Inceptisols) in texture having *p*H 5.3, organic carbon of 1.8, available nitrogen of 219.6 kg/ha, available phosphorus 0.43 kg/ha and available potassium of 152.4 kg/ha; with its characteristic high annual rainfall, high humidity and long winter, climate

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is subtropical. Treatments used for the study were, T_1, 100% recommended dose of fertilizer (RDF) @20:60:40 kg/ha; T_2, 50% RDF + phosphate solubilizing bacteria (PSB) @30 kg/ha; T_3, 50% RDF + PSB @30kg/ha + *Trichoderma* @2.5 kg/ha; T_4, 50% RDF + PSB @30 kg/ha + vermicompost (VC) @2.5 t/ha; T_5, 50% RDF + PSB @30 kg/ha + *Trichoderma* @2.5 kg/ha + VC @2.5 t/ha; T_6, 50% RDF + PSB @30 kg/ha + VC @5 t/ha; T_7, 50% RDF + PSB @30 kg/ha + *Trichoderma* @2.5 kg/ha + VC @5 t/ha; T_8, Control (farmers practice). The land preparation was done by two runs of power tiller, and the treatments were replicated thrice in a randomized block design (RBD) with a plot size of 3.6 m × 4 m. According to the treatment schedule, urea, SSP and MOP were administered at 20, 60 and 40 kg/ha N, P and K, respectively, during land preparation. Biofertilizers utilized had been *T. viride* and *Pseudomonas fluorescens* brought from State Agricultural Research Station, Arundhatinagar, Agartala. The pigeon pea variety chosen for this study was PA-421. Seeds were treated with carbendazim, followed by chlorpyriphos and *Rhizobium* at 2 g/kg. Sowing was done on 24th and 26th June and harvesting on 24th and 28th November, respectively during 2022 and 2023. To observe growth and yield parameters, 10 plants were selected at random from each plot. Dry matter and nutrient absorption analyses were performed on destructive samples.

Soil samples have been obtained prior to and after harvest to examine the nutrients which are readily available in the soil. Amount of nitrogen available in soil samples, measured in kg/ha, determined employing Subbiah and Asija (1956) alkaline permanganate procedure. According to Olsen *et al.* (1954), the available phosphorus content in kg/ha has been calculated employing Olsen's method. By applying flame photometer and a neutral NH_4OAC solution, the available potassium content in kg/ha was calculated following Hanway and Heidal (1952) methodology.

A 10 ml combination of diacids (H_2SO_4 and $HClO_4$ in a 9:1 ratio for N, P and K) was mixed with 0.2 g dried powdered plant sample in a 50 ml conical flask and the mixture was allowed to sit overnight. Afterwards, the mixture was heated until it transformed into a transparent and colorless solution of approximately 3–4 ml. Subsequently, solution was filtered by filter paper (Whatman No. 1).

Total nitrogen content (%) was determined using Lindner's colorimetric technique. The Vanado-molybdophosphoric yellow colour technique, was employed for determining total phosphorus content (%) of plant samples (Koenig and Johnson 1942). Potassium content (%) was determined in acid digest of plant samples applying flame photometer.

Total general cost of cultivation is ₹31.41 × 10^3/ha and cost of fertilizers and manures were added as per the treatment. Statistical package (Indostat services, Hyderabad) had been employed to analyze data gathered from field and laboratory experiments, subjecting them to statistical analysis suitable for design. Version 16 of SPSS Inc. has been employed to conduct Duncan's multiple range test (DMRT) and Pearson's correlation.

RESULTS AND DISCUSSION

Crop growth attributes: Over the assessment years, integrated nutrition treatments have impact substantially the plant height, number of nodules, primary branches and leaf area index (LAI). Tallest plants (362 cm) and highest primary branches (25.67) were found in the T_6 treatment (50% RDF + PSB @30 kg/ha vermicompost at 5 t/ha) and T_7 performed *at par* with T_5 for most of the cases during both the years (Table 1). This may be due to the judicious release of nutrients from chemical fertilizers and vermicompost, resulting in the development of new primary and secondary branches and slow height increase after flower-bud initiation (De *et al.* 2020). Majority of nodules had been larger and better developed during 90 DAS, which may be caused by adequate phosphorus availability, improved aeration (from addition of organic matter) and adequate soil moisture for microbial growth in light soils. The incorporation of organic materials augmented germination, stimulated shoot and root development and improved nodulation in legumes (Reddy *et al.* 2011), however, number varied during vegetative and reproductive phases, only discernible trend was declining trend in later stages before harvest (Ahamad *et al.* 2017). Again, leaf area index (5.54) is found to be highest at 120 DAS, where the possible reason might be due to the abundant release of nutrients which in turn affected the aeration and nodulation of the soil better than the later stages, leading to good growth of plants and put forth more foliage. Again, inorganic, organic and nutrient-solubilizing biofertilizers release abundant nutrients, boosting soil aeration and nodulation and promoting plant growth and foliage (Babu *et al.* 2014 and Verma *et al.* 2018).

Yield and yield attributing characters: Except for seed index (100-seed weight), yield attributes across integrated nutrition treatments varied significantly, whereas seed yield, stover yield and harvest index varied substantially. T_6 produced greatest seed yield (1.90 t/ha) and stover yield (7.93 t/ha), number of pods/plant (156), no. of seeds/pod (4.82) and seed index (10.73), followed by T_7 and T_5 treatments as adding *Trichoderma* to the treatments increased nutrient availability and reduced disease-causing pests, which boosted yield (Singh *et al.* 2017) (Table 1 and Table 2). Thus, the increased supply of critical elements increases their availability, acquisition, mobilization and influx into plant tissues. This, in turn, enhanced the growth properties, yield components and ultimately the seed yield. The stover yield increased due to stem development even during reproductive period, owing to the plentiful release of nutrients via various integrated nutrition treatments which accumulate and distribute dry matter in the shoot system and continue stem growth during the reproductive phase (Pandey *et al.* 2015 and Kumawat 2015). The harvest index (HI) was calculated through economic by biological yield, and T_6 had the lowest HI (17.45%) because of its higher biological yield of 11.17 t/ha (Sharma *et al.* 2012, Pandey *et al.* 2015). Thus, yield and yield-attributing characteristics satisfy one of primary aim in improving productivity of pigeonpea in NEH region by combining inorganic, organic

Table 1 Effect of integrated nutrient management (INM) approaches on crop growth and yield attributes of pigeonpea (2 years pooled data)

Treatment	Plant height (cm)	Primary branches (nos.)	Effective nodules/plant				LAI					No. of pods/ plant	No. of seeds/pod	Seed index (g)	Pod yield (t/ha)
			30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS	150 DAS (harvest)				
T_1	224^{bc}	18.66^{cd}	3.85^{b}	9.14^{c}	11.27^{d}	3.04^{c}	0.12^{ab}	1.61^{bcd}	3.48^{c}	4.20^{d}	0.48^{c}	76^{b}	4.26^{bc}	10.22^{a}	1.65^{c}
T_2	223^{bc}	18.70^{cd}	3.05^{d}	10.87^{b}	12.48^{cd}	2.90^{c}	0.12^{ab}	1.47^{cde}	3.55^{c}	4.32^{cd}	0.30^{d}	77^{b}	4.19^{cd}	10.08^{a}	1.48^{c}
T_3	214^{bc}	17.73^{d}	3.18^{cd}	7.60^{de}	12.28^{cd}	4.01^{b}	0.12^{ab}	1.46^{de}	3.53^{c}	4.29^{cd}	0.30^{d}	73^{b}	4.09^{cd}	10.02^{a}	1.65^{c}
T_4	309^{ab}	19.95^{bc}	3.46^{bcd}	7.64^{de}	11.17^{d}	4.26^{b}	0.12^{bc}	1.61^{bcd}	3.76^{bc}	4.69^{bc}	0.49^{c}	96^{b}	4.26^{bc}	10.25^{a}	2.04^{b}
T_5	33^{6}a	21.6^{7}b	3.61^{bc}	7.91^{d}	13.2^{5b}c	4.03^{b}	0.12^{bc}	1.63^{bc}	3.85^{b}	4.7^{1b}c	0.49^{c}	143^{a}	4.59^{ab}	10.28^{a}	2.22^{b}
T_6	36^{2}a	25.6^{7}a	4.95^{a}	11.66^{b}	17.3^{8}a	5.83^{a}	0.12^{a}	1.85^{a}	4.27^{a}	5.54^{a}	0.70^{a}	156^{a}	4.82^{a}	10.73^{a}	2.47^{a}
T_7	349^{a}	24.4^{2}a	5.05^{a}	13.18^{a}	14.2^{9}b	4.43^{b}	0.12^{ab}	1.65^{b}	3.87^{b}	5.0^{2}b	0.62^{b}	147^{a}	4.82^{a}	10.31^{a}	2.46^{a}
T_8	19^{5}c	13.0^{0}e	2.21^{e}	6.70^{e}	9.1^{2}e	2.92^{c}	0.11^{c}	1.42^{e}	3.11^{d}	3.6^{3}e	0.28^{d}	49^{c}	3.82^{d}	9.97^{a}	1.17^{d}
LSD (*P*=0.05)	101.55	1.97	0.52	0.99	1.48	0.69	0.01	0.16	0.29	0.45	0.08	32.29	0.38	0.83	0.21

LAI, Leaf area index; DAS, Days after sowing; T_1, 100% RDF (20:60:40 kg/ha); T_2, 50% RDF + PSB @30 kg/ha; T_3, T_2 + *Trichoderma* @2.5 kg/ha; T_4, T_2 + Vermicompost @2.5 t/ha; T_5, T_3 + Vermicompost @2.5 t/ha; T_6, T_2 + Vermicompost @5 t/ha; T_7, T_3 + Vermicompost @5 t/ha and T_8, Control (farmers practices). Means followed by the same letters (a,b,c,d and e) in a column are not significantly different at 0.05.

Table 2 Effect of integrated nutrient management (INM) approaches on yield, nutrient status, microbial count and economics after pigeonpea (2 years pooled data)

Treatment	Seed yield (t/ha)	STY (t/ha)	BY (t/ha)	HI (%)	Nutrient concentration (%)			Soil available (kg/ha)			Microbial population ($\times 10^5$ CFU/g)		Cost of cultivation ($\times 10^3$₹/ ha)	Gross return ($\times 10^3$₹/ ha)	Net return ($\times 10^3$₹/ ha)	B:C
					N	P	K	N	P	K	Bacteria	Fungi				
T_1	1.31^{c}	1.72^{c}	3.52^{c}	37.88^{a}	0.97^{c}	0.06^{d}	0.99^{cd}	265.8^{cd}	1.012^{d}	158.10^{de}	0.34^{e}	0.40^{e}	37.48^{b}	91.70^{c}	54.22^{c}	2.45^{a}
T_2	1.02^{d}	1.45^{c}	3.24^{c}	32.12^{ab}	0.90^{c}	0.30^{c}	1.00^{cd}	248.3^{de}	1.084^{cd}	155.88^{de}	0.59^{d}	0.58^{d}	35.43^{b}	71.72^{d}	36.28^{d}	2.02^{b}
T_3	1.28^{c}	1.92^{c}	3.43^{c}	39.56^{a}	0.87^{cd}	0.31^{c}	0.97^{cd}	223.0^{de}	1.142^{cd}	154.50^{e}	0.63^{d}	0.92^{b}	35.52^{b}	90.09^{c}	54.57^{c}	2.54^{a}
T_4	1.60^{b}	4.69^{b}	6.39^{b}	25.86^{b}	0.97^{c}	0.26^{c}	1.19^{bc}	309.4^{bc}	1.138^{cd}	162.40^{cd}	1.56^{c}	0.73^{c}	44.05^{ab}	112.24^{b}	68.19^{b}	2.57^{a}
T_5	1.73^{b}	3.98^{b}	6.86^{b}	26.31^{b}	1.31^{b}	0.31^{c}	1.39^{b}	349.3^{b}	1.237^{bc}	166.60^{bc}	1.65^{c}	0.91^{b}	44.14^{ab}	120.58^{b}	76.44^{ab}	2.75^{a}
T_6	1.90^{a}	7.93^{a}	11.17^{a}	17.45^{c}	1.75^{a}	0.68^{a}	2.05^{a}	413.3^{a}	2.438^{a}	171.36^{b}	2.52^{a}	0.93^{b}	52.68^{a}	133.11^{a}	80.43^{a}	2.58^{a}
T_7	1.89^{a}	4.34^{b}	7.97^{b}	25.59^{b}	1.66^{a}	0.50^{b}	1.44^{b}	356.8^{b}	1.415^{b}	185.17^{a}	2.17^{b}	1.36^{a}	52.77^{a}	132.15^{a}	79.38^{a}	2.56^{a}
T_8	0.91^{d}	1.68^{c}	2.85^{c}	32.82^{ab}	0.71^{d}	0.04^{d}	0.84^{d}	210.5^{e}	0.339^{e}	143.52^{f}	0.31^{e}	0.54^{de}	31.41^{b}	63.68^{d}	32.27^{d}	2.03^{b}
LSD (*P*=0.05)	0.14	0.99	1.77	7.88	0.18	0.08	0.28	51.45	0.19	7.54	0.25	0.14	5.29	9.88	10.65	0.35

T_1, 100% RDF (20:60:40 kg/ha); T_2, 50% RDF + PSB @30 kg/ha; T_3, T_2 + *Trichoderma* @2.5 kg/ha; T_4, T_2 + Vermicompost @2.5 t/ha; T_5, T_3 + Vermicompost @2.5 t/ha; T_6, T_2 + Vermicompost @5 t/ha; T_7, T_3 + Vermicompost @5t/ha and T_8, Control (farmers practices). STY, Stover yield; BY, Biological yield and HI, Harvest index. Means followed by the same letters (a,b,c,d,e and f) in a column are not significantly different at 0.05. *MSP of pigeonpea seeds is ₹7000/qt. #Price of vermicompost is ₹5/kg, and ₹2/kg for 2022 and 2023, respectively, as it is taken as produced by the farmer itself.

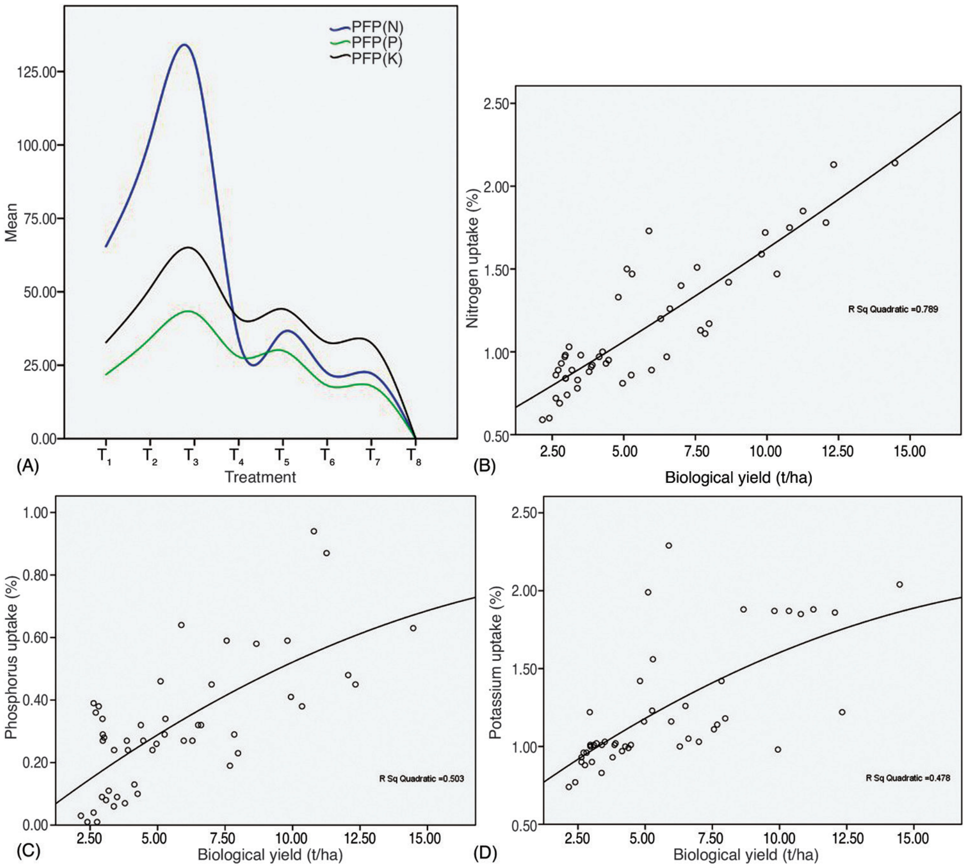

Fig. 1 (A) Partial factor productivity (PFP) of primary nutrients (nitrogen, phosphorus and potassium); (B), (C) and (D) Quadratic curve fitting of biological yield (t/ha) to primary nutrients (nitrogen, phosphorus, and potassium) uptake in percentage.
Treatment details are given under Materials and Methods.

and nutrient-solubilizing biofertilizers.

Plant nutrient uptake: Maximum plant nutrient uptake of nitrogen (1.75%), phosphorus (0.68%) and potassium (2.05%) had been observed with treatments T_6, followed by T_7 and T_5, according to pooled data (Table 2). However, these treatments differed significantly than 100% RDF (T_1) and control (T_8). The primary factors were enhanced biological production and strong root systems with higher root activity. Soil organic matter (SOM) also stores nitrogen and phosphorus, helping plants obtain these nutrients with PSB to solubilize fixed phosphorus (Ahamad *et al.* 2017). Singh *et al.* (2017) reported that enhanced growth, nutrient input and photosynthetic rate may boost nutrient absorption and translocation to the seed and stover (Cai *et al.* 2015). The analysis revealed that as the applied dose of nutrients increased, the partial factor productivity (PFP) decreased (Fig. 1A). The overall PFP for the entire experiment reached its peak at T_2 on replacing half of the recommended dose. However, it declined at T_7 when doses exceeded the replacement of the recommended dose with organic matter. This phenomenon exemplifies that with the increased application of nutrient doses the factor productivity decreases and vice versa (Dua *et al.* 2007), which again expresses lower productivity concerning nutrients applied, but maintains long-term soil health and fertility. A quadratic curve fitting study showed that biological yield of pigeonpea increases with nutrient uptake (Fig. 1 B, C and D). However, the yield plateaus or declines as the nutrient uptake increases. T_8 and T_1 treatments may decrease soil nutrient release during subsequent periods.

Soil available nutrients: T_6 had highest soil available nitrogen (413 kg/ha) and phosphorus (2.44 kg/ha) but T_7 treatment had the highest potassium (185.17 kg/ha), that is been comparable to T_6 and significantly higher than T_8 and T_1 (Table 2). This could be because inorganic fertilizers have been employed, that could minimize soil organic matter by encouraging decomposition, root growth and recycling of plant residue. Adding organic materials directly to soil, enhanced root development and increased recycling of plant wastes in soil led to higher organic matter content in treatments that acquired organic materials with chemical fertilizers (Sharma *et al.* 2000). This may be due to the addition of vermicompost, which enhanced the soil's organic carbon content, transformed organically bound nitrogen into mineralizable nitrogen, decreased the soil's capacity to fix phosphorus, dissolved inorganic P minerals, mineralized organic P and stored significant amounts of P in biomass and non-exchangeable K that were released from the soil (Singh *et al.* 2017). While increasing soil K, this released and applied K-matched crop needs. During the experimental year, there were additionally considerable variations in combination of in-organics and organics i.e. the impact of prescribed fertilizer and VC on available nutrients (Shivran and Ahlawat 2000, Singh *et al.* 2017). Additionally, by elevating soil organic carbon, pigeonpea biomass (leaves, roots etc.) enhances soil nutrition (Tolanur and Badanur 2003). According to Das *et al.* (2010), application of organics significantly enhanced the fertility status of the soil. This could be considering addition of N, P_2O_5 and K_2O recommended doses, followed by the addition of VC or their various combinations, favoured higher phosphorus availability in soil.

Microbial population: With an increase in available soil nutrients, proofs of improved microbial populations were observed in treatments with organic matter and biofertilizers. The pooled data showed that integrated nutrient management

Table 3 Pearson correlation among the growth, yield and plant uptake to improve productivity of pigeonpea through INM approaches (2 years pooled data)

	Plant height (cm)	Primary branches (no.s)	Pods/plant (no.s)	Seed index (g)	Pod yield (t/ha)	Seed yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Net return (× 10^3 ₹/ha)	Nitrogen uptake (%)	Phosphorus uptake (%)	Potassium uptake (%)
Plant height (cm)	1	0.537**	0.826**	0.169	0.585**	0.620**	0.607**	-0.526**	0.585**	0.544**	0.528**	0.375**
Primary branches (no.s)		1	0.752**	0.204	0.888**	0.865**	0.700**	-0.529**	0.812**	0.893**	0.829**	0.793**
Pods/plant (no.s)			1	0.083	0.763**	0.779**	0.655**	-0.433**	0.727**	0.719**	0.728**	0.569**
Seed index (g)				1	0.245	0.227	0.205	-0.192	0.196	0.245	0.279	0.248
Pod yield (t/ha)					1	0.974**	0.750**	-0.518**	0.929**	0.853**	0.739**	0.749**
Seed yield (t/ha)						1	0.754**	-0.475**	0.966**	0.833**	0.712**	0.737**
Stover yield (t/ha)							1	-0.781**	0.702**	0.761**	0.709**	0.693**
Harvest index (%)								1	-0.396**	-0.641**	-0.470**	-0.460**
Net return (× 10^3 ₹/ha)									1	0.760**	0.667**	0.676**
Nitrogen uptake (%)										1	0.777**	0.765**
Phosphorus uptake (%)											1	0.734**
Potassium uptake (%)												1

**, Correlation is significant at the 0.01 level (1-tailed), *, Correlation is significant at the 0.05 level (1-tailed); INM, Integrated nutrient management.

strategies affected the soil microbial community after pigeonpea harvest for both years. Under treatment T_6, the soil bacterial colony peaked at 2.52 × 10^5 CFU/g (Khan *et al.* 2005) (Table 2). Treatment T_7 had the greatest fungal colony count of 1.36 × 10^5 CFU/g over the trial years as Trichoderma increased fungal population in rhizosphere zone (Khan *et al.* 2004). Organic matter, recommended fertilizer, PSB, *Trichoderma*, adequate water supply, temperature, *p*H, moisture and clay concentration affect soil microbial biomass (Carter 1986, Almeida *et al.* 2011). Organic supplies create a favourable environment for microbial biomass expansion (Sharma *et al.* 2011, Kulkarni *et al.* 2020).

Economics: Pigeonpea management of nutrients had the greatest gross return (133.11 × 10^3 ₹/ha) and net return (80.43 × 10^3 ₹/ha) for T_6, followed by T_7 and T_5 (Table 2). For the benefit-cost ratio, T_5 (2.75) achieved the highest, which is followed by T_6 and T_7, according to the pooled data. This may be since among T_5 and T_6, the net return is higher in T_6 though B:C ratio is lesser comparatively, indicating T_6 is providing lower return per unit cost but it is better for generating more sum of money (Rana *et al.* 2014). Greater input costs through organic matter incorporation (vermicompost) would increase net return along with soil physical and chemical properties improvement over time. Household-made vermicompost may lower pigeonpea cultivation expenses and stabilize earnings. Furthermore, the expense of producing vermicompost decreased in the subsequent year, resulting in increased earnings and improved soil quality. This led to greater profitability for farmers in the NEH area who were able to maintain consistent output.

Pearson correlation of different parameters: Positive association was found between growth and yield metrics, except harvest index, which was negatively linked. The highest correlation was observed between pod yield (t/ha) and seed yield (t/ha). The net return exhibits a strong positive correlation with pod and seed yield, while demonstrating a negative correlation with harvest index (Table 3). This may be attributed to greater revenue associated with better seed output and reduced cultivation costs (Reddy *et al.* 2011, Kumawat *et al.* 2015). A positive correlation was discovered between net return and nutritional intake. Research has suggested replacing half of the chemical fertilizers with vermicompost and bio-fertilizers to boost primary branching, pods, yield and economics, thus improving soil fertility, structure, crop canopy and production (Das *et al.* 2010).

Pigeonpea growth in the north-eastern hill zone could be improved by utilizing a balanced nutrition system of chemical, organic and biofertilizers. Substituting 50% of chemical fertilizer with vermicompost and adding PSB, farmers can enhance soil microbiota and microbes, resulting in higher gross return and preservation of soil health for future generations.

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