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Nutrient Management Approaches in Pigeonpea [*Cajanus Cajan* (L.) Millsp.] Cultivation in Acid Soils of North East Hill Regions-A Review

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Abstract

Nutrient management is a strategy that aims to optimize the soil fertility and plant nutrient supply to achieve desired crop productivity. This may be achieved by maximizing the benefits derived from all available plant nutrient sources in an integrated manner. Nutrient management involves balanced utilization of fertilizers, organic substances, and biological sources of plant nutrients to maintain or enhance soil productivity. Sustainable agricultural production along with conservation of soil fertility may be attained by cautious use of integrated nutrient management strategies involving the reasonable use of both inorganic and organic nutrient sources. The comprehensive use of both chemical and organic fertilizers in relation to the yield and yield components is of utmost importance for ensuring food security. Pigeonpea cultivation systems include several types of organic resources, including farmyard manure, vermicompost, animal manure, green manure, crop residue, compost and industrial waste.

Keywords: Inorganic nutrient sources, Nutrient management, Organic nutrient, Yield components

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Introduction

Pigeonpea [*Cajanus cajan* (L.) Millsp.], also known as red gram, arhar and tur in India, is an important pulse crop and accounts for about 20 percent of the total production of pluses in the country. India is the largest producer of Pigeonpea accounting for about 73-80 percent of total production and 63-79 percent of total area of the world. The Pigeonpea production of India is 3.38 million tonnes as per the Third Advance Estimates of Production of Food grains, Oilseeds and other Commercial Crops for the 2023-24 (https://desagri.gov.in/statistics-type/advance-estimates/). Pigeonpea is an important leguminous crop grown in the North East hill regions of India, known for its drought tolerance, nitrogen-fixing ability, and multipurpose use (food, fodder, fuel wood) and plays a pivotal role in cropping system diversification, soil health enhancement, and dietary protein security. It covers nearly 49 million hectares in acidic soil regions (pH <5.5), across states like Odisha, Chhattisgarh, Jharkhand, and the North East hills.

Table 1. The major constraints of pigeonpea cultivation in acidic soils are as follows:

Constraint	Impact on Pigeonpea	Affected States
Al^{3+} Toxicity	Root stunting, reduced nodulation	Odisha, NE Hills, Jharkhand
P Fixation	Low P availability (Fe/Al-P complexes)	Chhattisgarh, West Bengal
Mo Deficiency	Impaired N-fixation (nitrogenase enzyme)	Assam, Meghalaya
Low CEC	Poor nutrient retention	Acidic red soils of Karnataka

The acidic soils in North East regions pose significant challenges to its productivity due to aluminum (Al) toxicity, phosphorus (P) fixation, and micronutrient deficiencies. The productivity of pigeonpea in the North East states is at par with that for India. The state-wise area, production and productivity of pigeonpea in North East India is given in Table 2. The present review examines nutrient management strategies to enhance pigeonpea growth in acidic soils of North East hills.

Table 2. State-wise area, production and productivity of Pigeonpea in North East India (2023-24)

States	Area	Production	Productivity
	(In '000 Hectare)	(In '000 Tonne)	(In Kg. /Hectare)
Arunachal Pradesh	0.89	0.79	891
Assam	6.11	5.26	860
Manipur	0.45	0.38	840
Meghalaya	1.21	1.58	1305
Mizoram	0.19	0.21	1120
Nagaland	0.69	0.66	951
Tripura	4.29	3.42	797
North-East India	13.83	12.3	889
India	4130.59	3416.84	827

Source: Ministry of Agriculture & Farmers Welfare, Govt. of India. (ON3855)

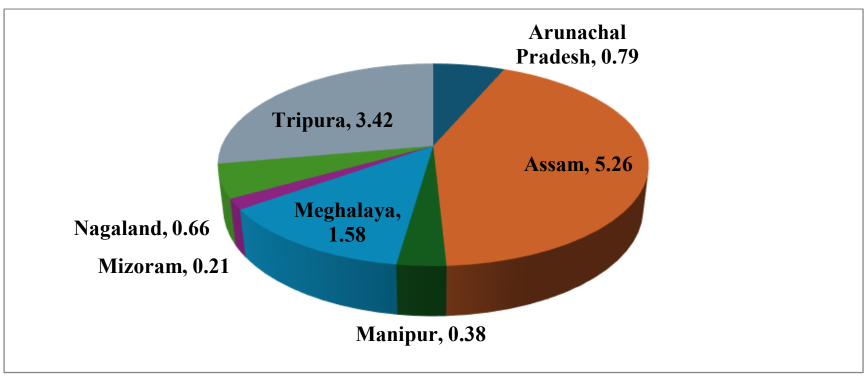

Fig. 1. Production (In '000 Tonne) of Pigeonpea in North East India (2023-24)

Pigeonpea is India's second most important kharif pulse after chickpea, valued for its adaptability to both sole and intercropping systems. Despite its significance, India imports 4.48 million tonnes (MT) of pulses annually to meet its 22 MT domestic demand. Projections by the Indian Institute of Pulses Research indicate a 32 MT pulse requirement by 2030, driven by a 1.68 billion population and 4.2% annual growth in demand. Since 1972, ICAR, ICRISAT, and other national institutes have spearheaded research to improve pigeonpea productivity through breeding, agronomy, and nutrient management innovations.

Nutrient Management Strategies for pigeonpea cultivation in acidic soils

1. **Lime Application (Soil Amendment)**

- **Purpose:** Neutralizes soil acidity, reduces Al toxicity, and improves Ca/Mg supply.
- **Recommended Dose:** 2–4 t/ha of dolomitic lime ($CaMg(CO_3)_2$ (based on soil test).
- **Effect:**

i. Increased Soil pH (to 5.5–6.5).

ii. Increased P availability (reduces Al-P fixation).

iii. Increased Mo solubility (critical for N-fixation).

2. **Phosphorus Management**

- **Use of Rock Phosphate:** Slow-release P source, effective in acidic soils.
- **Soluble P Fertilizers (DAP/SSP):** Apply 30–50 kg P_2O_5/ha in split doses. Band application near roots improves efficiency.
- **Phosphorus-Solubilizing Bacteria (PSB):** Pseudomonas and Bacillus spp. enhance P uptake.

3. **Organic Manures and Biofertilizers**

- **FYM/Compost (5–10 t/ha):** Improves CEC, micronutrient availability.
- **Vermicompost:** Enhances microbial activity and nutrient retention.
- **Rhizobium Inoculation:** Improves N-fixation (strains like Bradyrhizobium spp.).

4. **Micronutrient Supplementation**

- **Molybdenum (Mo):** Foliar spray (0.05% Na_2MoO_4) or seed treatment (1–2 g Mo/kg seed).
- **Boron (B) and Zinc (Zn):** Soil application of borax (10 kg/ha) and $ZnSO_4$ (25 kg/ha).

5. **Integrated Nutrient Management (INM)**

- **Combined Use of Lime + FYM + Chemical Fertilizers**

Pigeonpea responds less to fertilizers than other comparable crops of the semiarid tropics. To produce 1.0 t of pigeonpea grain about 56 N, 12 P_2O_5 and 26 K_2O kg ha^{-1} are required. Since yield of pigeonpea in traditional production systems are low, its nutrient requirement is easily met from nitrogen fixation or from the soil. However, latest short duration varieties, normally grown as sole crops, necessitated the need for fertilizer application for realizing their potential yields. Nitrogen, phosphorus and potassium uptake takes place throughout the vegetative phase and continues during the reproductive phase. Total nitrogen uptake reported for pigeonpea crop in India range from 75 to 215 kg ha^{-1} and phosphorus from 10 to 25 kg ha^{-1}. Several studies indicate that phosphorus is the most frequently limiting nutrient for pigeonpea (Sadaphal, 1988). Higher yields can be obtained with application of 40-60 kg P_2O_5 ha^{-1}. Response to a starter dose of 20 to 25 kg N ha^{-1} to meet the needs of early growth and promote nodulation appears to enhance pigeonpea yield. The deficiency of K, Zn and minor nutrients has also been reported in some soils. Hence, an effective nutrient management is crucial for optimizing the growth and yield of pigeonpea. The optimal crop productivity needs a careful use of organic sources, biofertilizers, and micronutrients. Integrated nutrient management (INM) refers to the strategic use of both organic and inorganic nutrient sources which can help to offer solutions to issues such as the rising costs of inorganic fertilizers and the decline in soil fertility and productivity. INM advocates nutrient application to crop needs and soil conditions to eliminate both excessive applications that degrade water, soil or air quality and insufficient application that results in soil fertility degradation.

Components of Integrated Nutrient Management

Chemical Fertilizer: They are the major contributors for enhancing crop production and maintaining soil productivity and contain nutrients in higher and definite concentrations compared to other sources (Mahajan and Gupta2009).

Organic Manures: The manures which are prepared from plant residues and animal remains are referred to as organic manures and were traditionally and preferentially used in developing countries. Organic manures like FYM, compost, vermicompost; green manures; crop residues; and bio-fertilizers are important inputs for maintaining soil fertility and ensuring yield stability (Mahajan *et al.,* 2002).

The INM approaches in Pigeonpea included application of different levels of recommended dose of fertilizer (RDF), Farmyard manure (FYM), Vermicompost, Phosphate Solubilising Bacteria (PSB), Rhizobium sp., Sulphur, micronutrient mixture, ZnSO4 or Zn-EDTA etc. The Integrated Nutrient Management approaches have significant impact on growth parameters including Leaf Area Index (LAI), Leaf Area Duration (LAD), Crop Growth Rate (CGR), Net assimilation rate (NAR), Dry matter accumulation (DMA) etc.; yield attributes viz. no. of pods per plant, no. of seeds per pod, test weight, stover yield; nutrient availability in soil and its uptake; microbial population; profitability and economics.

Effect of INM Approaches on Growth character

A notable increase in dry matter accumulation (DMA), greater crop growth rate (CGR), and higher leaf area index (LAI) were observed when 30 kg ha^{-1} biofertilizer of PSB were applied, followed by the application of 15 kg ha^{-1} of PSB (Puri, 2020). NM approaches on growth revealed that plant height, primary branches, and nodule number exhibited a statistically significant increase when full doses of fertilizer were applied, compared to when only 50% of the recommended dose of fertilizer (RDF) was used in rain fed conditions for long-duration Pigeonpea (Pandey *et al.,* 2015). observed A substantial increase in nodule formation was observed when using a combination of RDF, PSB, Rhizobium, FYM at 3 t ha^{-1}, and Haritvardhan (Bio-fertilizer) at 5 kg ha^{-1} in Pigeonpea (Ahamad *et al.,* 2017). A significant increase in LAD in 100% soil-root-drip-feed (SRDF) treatment with the application of a 0.5% solution of zinc sulphate ($ZnSO_4$) by foliar spraying in Pigeonpea was observed (Manikandan *et al.,* 2017).

The impact of different levels of PSB in Pigeonpea exhibited the maximum LAI and highest CGR when treated with a 125% RDF along with a micronutrient mixture (Srinivasan *et al.,*2019). The impact of Zn fortification treatments on various aspects of plant growth significantly enhanced DMA, CGR and LAI of Pigeonpea at all stages of growth in two consecutive years of the experiment (Kumer *et al.,*2019). According to the application of Pulse Magic (Fertilizer, it contains 10% N,40% P, 3% micro nutrient and 20ppm PGR) at a concentration of 10 g l^{-1} has been found to result in a significant increase in CGR, LAI, and LAD (Avinash *et al.,*2020). The use of RDF (20:60:40), in combination with indoxacarb during the flowering stage and one systemic insecticide 15 days after the first treatment led to the highest CGR, maximum LAI, and highest NAR, followed by the administration of a 0.5% $ZnSO_4$ spray at 50% flowering (De *et al.,* 2020). An increase in DMA and LAI with the growth and development of Pigeonpea due to the utilization of 75% recommended dietary nutrients (RDN) via fertilizers and 25% through FYM was observed (Shivakumar *et al.,*2021). The highest DMA of 3790 kg ha^{-1} recorded the maximum LAI of 3.86, was achieved when 100% RDF was applied in combination with vermicompost at a rate of 4 t ha^{-1}, and Zn-EDTA foliar spray at a concentration of 0.5% to Pigeonpea (Immanuel *et al.,* 2023).

Effect of INM Approaches on Yield Attributes and Yield

The treatment of 20kg S ha^{-1} resulted in a considerable increase in the number of pods $plant^{-1}$ (110.78) and grain yield. Furthermore, this amount of S application was found to be considerably superior to other levels tested in relation to Pigeonpea (Deshbhratar *et al.,*2010). It was noted that the administration of 50% RDF via inorganic fertilizers combined with *Rhizobium* at 200g $kg^{-1}$of seed during sowing resulted in a considerable increase in the number of pods $plant^{-1}$, greater pod yield and increased grain yield in Pigeonpea. This was followed by the application of RDF combined with FYM and Rhizobium and the application of 50% RDF combined with Rhizobium and PSB (Reddy *et al.,* 2011). The application of 5 t ha^{-1} of FYM, 100% RDF, and seed inoculation with biofertilizer, resulted in considerably increased number of seeds $pods^{-1}$ and increased test weight in a Pigeonpea based intercropping system (Sharma *et al.,* 2012). The soybean-Pigeonpea intercropping system exhibited a substantial increase in the maximum quantity of seeds or pods, increased test weight, and increased grain production when 70% and 50% of the RDF were applied (Senthivelu *et al.,* 2014). The application of P at 30kg ha^{-1} resulted in considerably greater grain production, stover yield and harvest index in the Pigeonpea than at the other levels of P. This finding was consistent across the two years of the study (Babu *et al.,* 2014)., observed that the harvest index exhibited a considerable increase in the treatment with a 100% RDF combined with a 50% RDN and Zn at 5kg ha^{-1} (Kumawat *et al.,*2015). Under rain fed conditions, for long-duration Pigeonpea (Variety-Bahar) the number of pods $plant^{-1}$, number of seeds pod^{-1}, test weight, grain production and harvest index were considerably greater at the maximum RDF than at 50% RDF (Pandey *et al.,* 2015). The combination of integrated nutrient management (INM), higher mean values of stover production than the control (farmers' practice), which followed conventional practices for Pigeonpea cultivation (Veerana *et al.,* 2017). The application of 100% RDN from FYM resulted in the greatest Pigeonpea pod production compared to other treatments, including the application of 100% RDN from a combination of 50% FYM, 25% vermicompost, and 25% poultry manure (Gurjar *et al.,*2018). The application of FYM at 10t ha^{-1} resulted in considerable improvement in grain production and increased the stover yield of Pigeonpea (Mishra *et al.,*2018). found that the application of a 125% RDF in the alternating rows of Pigeonpea and green bean resulted in a considerable increase in seed output (Kumar *et al.,*2018). Using a 125% RDF + nipping + micronutrient combination of Pigeonpea considerably boosted the maximum number of pods and plants and the maximum number of seeds pod^{-1} (Srinivasan *et al.,* 2019). The effects of several treatments on Pigeonpea growth and yield were studied including the application of the RDF together with 2% diammonium phosphate (DAP) and a multi-micronutrient spray at a concentration of 2 ml l^{-1}, in addition to inoculation with biofertilizer. The results showed that this treatment resulted in the highest stover yield and harvest index (Priyanka *et al.,*2019). The highest 100 seed weight and seed weight (25.92 q ha^{-1}) was observed when a multi-micronutrient spray was applied at a concentration of 2 ml l^{-1} during the 50% flowering stage, in combination with the application of in doxacarb during flowering and a systemic insecticide 15 days after the initial spray. This treatment was followed by the application of the recommended dose of fertilizer (20:60:40), along with a multi-micronutrient spray at a concentration of 2 ml l^{-1} during the 50% flowering stage (De *et al.,*2020). The use of FYM at 5 t ha^{-1} or vermicompost at 2.5 t ha^{-1}, in conjunction with 100% RDF, yielded comparable results in terms of increasing the grain and stover yield of Pigeonpea. Furthermore, both FYM and vermicompost treatments resulted in considerably higher grain yields than the application of RDF alone (Sarkar *et al.,*2020). The experiment including the application of several treatments as 75% RDF, FYM at 5 t ha^{-1}, S at 40kg ha^{-1}, $ZnSO_4$ at 25kg $ha^{-1}$and B at 1.5 kg ha^{-1}reported increased test weight and grain yield of Pigeonpea intercropping under rain fed conditions (Yadav *et al.,* 2021). A significant enhancement in seed production because of the utilization of 75% of the RDN via fertilizers and 25% using FYM was observed. This level of FYM application was found to be much better than the other levels, including 5t vermicompost, 5t chicken manure, and 10t compost ha^{-1}. This increase was comparable to that in treatments with 50% RDF + 100% RDN + 5 kg Zn ha^{-1} and 50% RDF + 50% RDN + 5 kg Zn ha^{-1} in the Pigeonpea black gram inter cropping system (Shivakumar *et al.,* 2021).

Effect of INM Approaches on Plant Nutrient Uptake

The utilization of NPK and S by Pigeonpea notably increased when subjected to an application rate of 18:46:20:20kg N:P:K:S ha^{-1} as opposed to lower levels of these nutrients (Goud and Kale 2010). The utilization of FYM and the introduction of *Rhizobium* and PSB enhanced the nutritional content of the soil and promoted greater nutrient absorption in Pigeonpea (Reddy *et al.,*2011). Under the rainfed Pigeonpea and black gram intercropping system, the use of a fertilizer combination consisting of 100% RDF together with 50% RDN and an additional 5 kg of Zn ha^{-1} resulted in a total absorption of NPK, which was comparable to the combination of 50% RDF, 100% RDN, and 5 kg of Zn ha^{-1}(Kumawat *et al.,* 2015). The former treatment resulted in substantially greater total NPK uptake. The application of *Rhizobium* + PSB and *Rhizobium* + PSB + plant growth-promoting Rhizobacteria to seed inoculation resulted in comparable effectiveness, leading to considerable improvement in the absorption of NPK (Pandey *et al.,* 2015). The application of 30 kg K and 20 kg S ha^{-1} increased the uptake of N and P. The treatment with a mixture of 45 kg K and 20 kg S ha^{-1} resulted in the maximum observed absorption of K (Balpande *et al.,*2016). The utilization of a combination of RDF + PSB + *Rhizobium* + FYM at a rate of 3 t ha^{-1}, together with the application of haritvardan at 5kg ha^{-1}, yielded results comparable to the utilization of RDF + PSB + *Rhizobium* + FYM at 3 t ha^{-1} alone. Furthermore, this combination treatment exhibited considerably greater absorption of NPK than the application of RDF alone (Ahamad *et al.,* 2017). The effects of different treatments on the total nutrient absorption in Pigeonpea-black gram intercropping was studied and the experiment included application of 50% RDF together with FYM at 5 t ha^{-1}, as well as the addition of *Rhizobium*, PSB and *Trichoderma*. The results indicated that the highest total nutrient uptake achieved with this combination was comparable to that found with 100% RDF, *Rhizobium*, PSB and *Trichoderma* (Singh *et al.,*2017). The effect of nutrient management on yield, economics, and uptake of Pigeonpea was evaluated and it was found that the utilization of nutrients exhibited a statistically significant increase when 150% RDF and S at 30kg ha^{-1} were applied (Kharabe *et al.,*2021).

Effect of INM Approaches on Soil Available Nutrient

A significant increase in the maximum available nitrogen (269.36 kg ha^{-1}) because of applying 20 Kg S ha^{-1}, compared to the control and 40 kg ha^{-1} treatments in Pigeonpea was observed (Kene *et al.,*1990). The impact of S and P on the yield, quality, and nutrient status of Pigeonpea was assessed and the results indicated that the highest P availability (19.67 kg ha^{-1}) was observed when 20 kg ha^{-1} was applied. The independent presence of S did not have a significant effect. However, the application of 20 and 40 kg S ha^{-1} resulted in a reported P level of 369.60 kg ha^{-1}. The application of S and P has been shown to enhance soil fertility, but the application of S alone does not have a significant impact on P availability. Therefore, a combination of 20 kg S ha^{-1} and 50 kg P ha^{-1} was required to maintain a high level of soil fertility (Deshbhratar *et al.,*2010). The use of RDF, FYM at 5.0 t ha^{-1}, and the introduction of seed inoculation with biofertilizers resulted in a significant enhancement in the levels of organic carbon and availability of NPK nutrients (Pandey *et al.,*2015). The levels of accessible NPK were considerably higher when a combination of RDF, PSB, *Rhizobium*, FYM at 3 t ha^{-1} and haritvardan at a rate of 5 t ha^{-1} was applied (Ahamad *et al.,*2017). A field experiment was conducted to investigate the effects of different treatments on nutrient levels in a Pigeonpea black gram intercrop. The study found that the application of 50% RDF along with FYM at 5 t ha^{-1}, as well as the use of *Rhizobium*, PSB and *Trichoderma*, resulted in significantly higher levels of NPK nutrients (Singh *et al.,*2017). The management practices of INM, IWM and IPM in Pigeonpea showed substantial superiority over the soil's natural availability of N and organic C. Among these, INM and IWM are particularly noteworthy (Veeranna *et al.,* 2017).

Effect of INM Approaches on Soil Microbial Population

The use of RDF, FYM at 5.0 t ha^{-1} and seed inoculation with biofertilizers significantly enhanced the microbial population (Pandey *et al.,*2015). The impact of applying 5.0 to FYM ha-1 on the microbial population in extended duration Pigeonpea was investigated. The results of this study revealed that the application of this organic amendment led to an increase in the microbial population (Singh *et et al.,*2020). The implementation of a 150% RDF along with the application of FYM at 90 days after sowing (DAS) and throughout the harvest stage of Pigeonpea, resulted in considerable augmentation of the beneficial microbial population. Specifically, the bacterial load grew to 37.08 x 10^7cfug^{-1} while the fungal load reached 22.47 x 10^7cfug^{-1}(Kulkarni *et al.,*2020).

The optimal combination for achieving increased productivity and the greatest net return and B:C ratio in Pigeonpea was determined to be a 50% RDF in conjunction with *Rhizobium* (Reddy *et al.,*2011). The use of 100% RDF resulted in a notably greater net return and gross return in the context of groundnut-Pigeonpea relay intercropping (Poonia *et al.,* 2014). The net return and B:C ratio exhibited a statistically significant increase when the full RDF was applied, as compared to when only 50% RDF was used (Pandey *et al.,*2015). The application of 100% RDF + 50% RDN + 5 kg Zn ha^{-1} recorded the highest net return (Rs. 109,277), gross return (Rs. 130,735), and benefit-cost (B:C) ratio of 5.11, which was at par with 50% RDF + 100% RDN + 5 kg Zn ha^{-1} and significantly superior to the other treatments for Pigeonpea (Kumawat *et al.,* 2015). It was observed that the combined application of RDF with PSB, *Rhizobium*, and FYM at a rate of 3 tha^{-1}, along with haritvardan at a rate of 5 $kgha^{-1}$, resulted in a considerable increase in the net return and B:C ratio compared to the application of RDF alone (Ahamad *et al.,* 2017). Seed production exhibited considerable improvement under Pigeonpeasesame intercropping with 100%RDF (Kumar *et al.,* 2018). The use of 125% RDF combined with nipping and a variety of micronutrients resulted in a significantly greater net return of Rs. 77,815 $ha^{-1}$and a greater gross return of Rs. 102,384 ha^{-1}in Pigeonpea (Srinivasan *et al*., 2019). Investigation of the effects of several treatments on Pigeonpea indicated that the administration of RDF together with 2% diammonium phosphate (DAP) and a multi-micronutrient spray at a concentration of 2 ml l^{-1}, in combination with biofertilizer inoculation, resulted in the highest net return and B:C ratio. This treatment was followed by the application of RDF with 2% urea and multi-micronutrient (Priyanka *et al.,* 2019). The best net return, gross return, B:C ratio, and return per day were obtained by spraying Pigeonpea with a multi-micronutrient solution at a concentration of 2 ml l^{-1} at 50% flowering (De *et al.,*2020). The incorporation of inorganic, organic and biofertilizers is crucial for achieving an increased crop yield and cost reduction in pigeonpea cultivation (Sarkar *et al.,*2020). The experimental conditions with the application of 75% RDF together with FYM at 5 t ha^{-1}, S at 40 kg ha^{-1}, $ZnSO_4$at 25 kg ha^{-1}, and B at a rate of 1.5 kg ha^{-1}revealed the effects of several agricultural inputs on the net return, gross return, and B:C ratio of pigeonpea (Yadav *et al.,*2021).

Table 3. Nutrient Management Strategies followed for Pigeonpea in Acid Soils of North East

Nutrient management Components	Observations	References
(FYM at 5 t ha^{-1} + Rhizobium and PSB at 500 g each ha^{-1} for seed treatment+ RDF (25:50:25: 20:15 kg N: P_2O_5: K_2O:S and $ZnSO_4$ ha^{-1})	Higher yield in treatments with INM+IWM+IPM combination.	De et al., 2019
Combination of RDF (20: 60: 40), urea, $ZnSO_4$, Borax spray or Multi micronutrient spray @2 ml/litre at 50% flowering	Higher yield in treatments with micronutrient application	De et al., 2020
Combination of Nipping and spacing	Better crop canopy and increased productivity	De et al., 2023
Combination of farmyard manure (FYM) at 4t/ha and vermicompost at 2t/ha, supplemented with *Trichoderma* and *Pseudomonas* at 2.5kg/ha each.	Improved residual organic carbon and primary nutrient levels	De et al., 2025

Conclusion

Effective nutrient management in acid soils requires Integrated Nutrient Management approaches. These strategies—combining reduced chemical fertilizers with organic amendments (e.g., FYM, compost) and biofertilizers (Rhizobium, PSB)—significantly improved pigeonpea growth parameters (leaf area index, crop growth rate) and yield attributes (pods/plant, test weight). Adoption of these strategies can enhance pigeonpea productivity in the NEH region while sustaining soil health. The other recommendations include:

- Testing soil pH and applying lime 3–6 months before planting.
- Using P-solubilizing biofertilizers to improve P availability.
- Ameliorating acid soil with lime or biochar.
- Adopting high-yielding, nutrient-responsive varieties.
- Cultivating Acid-Tolerant Pigeonpea Varieties
- Implementing Precision Nutrient Management e.g. Soil-test-based recommendations using GIS mapping.

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