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Crop Performance, Nitrogen Uptake and Soil Parameters as Influenced by Short-Term Nutrient Management Strategies under Cowpea-based System in Nalanda District of Bihar, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

This study sought to evaluate crop performance, nitrogen (N) uptake and soil parameters as influenced by short-term nutrient management strategies in a cowpea-based system. To fulfill the objective, 9 treatments of various nutrient management strategies (control (no fertilization), 100% N + 100% phosphorus and potassium (PK), natural farming1 (Beejamrit (field preparation) +Ghanjeevamrit (field preparation) +Jeevamrit (15 days interval)), natural farming2 (Beejamrit (field preparation + 30 days interval) + Ghanjeevamrit (field preparation+ 30 days interval) +Jeevamrit (15 days interval)), organic farming1 (Farmyard manure + Biofertilizer), organic farming2 (Vermicompost+ Biofertilizer), integrated nutrient mangement1 (50% N inorganic + 50% N organic as Vermicompost and 100% P and K through inorganic), integrated nutrient management2 (50% N inorganic + 50% N organic as Farmyard manure and 100% P and K through inorganic) and 125% N +100% PK) were arranged in a randomized block design and replicated three times in Nalanda College of Horticulture, Noorsarai (Nalanda). The cowpea crop was sown in September and harvested at maturity in November for two years in the cropping system of cowpea-potato-onion. Crop yield, N uptake and soil parameters were studied. Results showed that the cowpea yield and N uptake were highest in 125% N +100%PK, followed by 100% N+100%PK, integrated nutrient management2, integrated nutrient management1, organic farming2, organic farming1 and the lowest in natural farming practices. The increase in seed yield for the above treatments was 43, 33, 27, 23, 19, and 17%, respectively, over the control. The soil physical and physicochemical properties were limited affected by different nutrient management strategies compared to the control. Overall, this study concluded that fully (100% N) or high dose(125% N) applications improved crop performance and N uptake, whereas organic-based sources had low yield and N uptake but limited effect on soil physical and physicochemical characteristics. Therefore, it is recommended to continue organic-based nutrient management for a long-term, which may, over time, bring crop performance to par with inorganic-based nutrient management and soil sustainability.

Keywords: Natural farming; organic farming; seed yield; cowpea yield.

1. Introduction

Soil is the reservoir of organic and inorganic nutrients. These nutrients are supplied through organic and inorganic sources. Inorganic sources supply readily available nutrients. However, organic sources are unavailable and slowly mineralize to release available nutrients to plants. Due to environmental issues and declining crop performance with inorganic fertilization, the use of organic amendments has been prioritized (Kumar et al, 2023). Organic and natural farming are the practices which use organic sources of nutrients. Therefore, their impact on crop performance and soil health is always debatable.

Recently, intensive cultivation, use of high-yield varieties, and declining soil fertility has caused the requirement for a high dose of fertilization. A high dose of fertilizer may increase or decrease crop yield. Therefore, optimizing inorganic fertilizer dose is essential to enhance crop productivity.

Nutrient management strategies, organic sources alone or combined with chemical fertilizers, are sustainable and alternative approaches that can maintain soil and crop productivity (Padbhushan et al., 2022; Kumar et al., 2023). These strategies indicate significant efficiencies in existing fertilization practices that fulfill the crop's nitrogen needs and a range of favourable ecological impacts (Sahoo et al., 2022). These include integrated nutrient management; organic farming practice and natural farming practice (Kumari et al., 2026). Therefore, an investigation into the impact of different nutrient management strategies is essential to optimize crop performance, mainly in legume-based cropping systems.

Cowpea (*Vigna unguiculata* L.), known for its nitrogen-fixing ability and soil health benefits, is a promising solution (Carvalho et al. 2017). As a leguminous crop, cowpea can enhance nitrogen availability in soil by fixing atmospheric nitrogen, reducing dependence on chemical fertilizers, and improving soil quality. Studies have also shown that planting cowpea as a cover crop can be a sustainable practice that increases nutrients, benefiting the next crop by reducing the use of chemical fertilizers. This study compared cowpea performance, nitrogen uptake, and soil properties under chemical fertilizers alone, integrated nutrient management, organic farming, and natural farming. The study sought to assess the influence of various nutrient management strategies on cowpea performance, nitrogen uptake, and soil parameters under a cowpea-based system.

2. Materials and Methods

2.1 Description of the Study Area

The present study was conducted for two years (2024-26) under the ongoing natural farming programme at Nalanda College of Horticulture, Noorsarai (Nalanda). Nalanda is located in the Agro climatic Zone IIIA of the South Bihar Alluvial plain. The climate is subtropical, characterized by hot summers, humid rainy season and cool winters. The average rainfall in the region is <1000 mm, received during June to September through the southwest monsoon. The temperature varies in the region from 5-45 degree Celsius. The soils of Nalanda are sandy loam to clay loam, moderately fertile.

2.2 Experimental Design

The ongoing natural farming programme was established in Kharif 2024 under the cowpea-potato-onion cropping system. The experiment was laid out in a Randomized Block Design (RBD) with 9 treatments and 3 replications. The plot size was 6 m x 2 m, and the plant spacing was 50 cm x 25 cm. The experiment consisted 9 treatments of various nutrient management strategies (control (no fertilization), 100% N + 100% PK, natural farming1 (Beejamrit (field preparation) +Ghanjeevamrit (field preparation) +Jeevamrit (15 days interval)), natural farming2 (Beejamrit (field preparation + 30 days interval) + Ghanjeevamrit (field preparation+ 30 days interval) +Jeevamrit (15 days interval)), organic farming1 (Farmyard manure + Biofertilizer), organic farming2 (Vermicompost+ Biofertilizer), integrated nutrient mangement1 (50% N inorganic + 50% N organic as Vermicompost and 100% P and K through inorganic), integrated nutrient management2 (50% N inorganic + 50% N organic as Farmyard manure and 100% P and K through inorganic) and 125% N +100% PK). Each treatment was arranged in a randomized block design and replicated three times. The recommended dose of fertilizer (RDF) for cowpea was 20:60:60 (N: P_2O_5: K_2O) Kg ha^{-1}.

2.3 Data Collection Procedures

The cowpea was sown in September and harvested at maturity in November. The crop pod was collected four times, and seed yield was determined. The plant sample was collected at maturity and processed, air- and oven-dried, ground, further digested, and then distilled to estimate nitrogen content. One gram of plant sample in a Kjeldahl flask was added with 20 grams of digestion accelerator and mL of nitric acid. The plant material was digested at high temperature and was transferred to a Kjeldahl distillation flask. Distilled the content, and ammonia was collected in boric acid and titrated with 0.1 N sulphuric acid. The blank (without plant sample) and final readings were noted, and nitrogen concentration was calculated. The nitrogen uptake was determined from the product of nitrogen concentration and dry matter.

The final soil samples from each treatment at depths 0-15 cm (surface layer) and 15-30 cm (subsurface layer) were collected. The samplings were of two types: i. Sample collected using an auger for analysis of soil physical and chemical properties ii. Sample collected using a core sampler for bulk density. The first type of samples was air-dried in the laboratory and further processed for physical and chemical analysis. The second type of samples was freshly weighed and placed in the oven to dry and determine the bulk density. All the soil parameters were analyzed using standard protocols:

Ten grams of soil was weighed into a 50 ml beaker, and 25 ml distilled water was added, making a soil-water solution at a ratio of 1:2.5. The solution was stirred occasionally using a glass rod for 30 minutes. The instrument was calibrated using standard buffer solutions (pH 4.0, 7.0, and 9.2). The pH reading was done using a pH meter. 10 grams of soil was weighed into a 50 ml beaker, and 25 ml distilled water was added to make a soil-water solution at a ratio of 1:2.5. The soil-water solution was stirred occasionally using a glass rod for 30 minutes and kept overnight. The instrument was calibrated using a standard solution of 0.01 N potassium chloride with a conductivity of 1.41 dS m^{-1} at 25°C. The electrical conductivity was measured using a conductivity meter Soil texture was measured using the hydrometer method. The maximum water holding capacity was determined using Keen Raczkowski box method. The bulk density sample was collected using the core sampler method. The particle density was determined by using the pycnometer method.

2.4 Data Analysis

The soil and plant data collected from the ongoing natural farming programme were analyzed using a randomized block design. The least significant difference (LSD) was computed at the 5 per cent probability level as proposed by Steel and Torrie (1980). The software used for this data analysis was OPSTAT. The data presented for comparison of treatments by means and standard error.

3. Results and Discussions

3.1 Crop Performance

Crop performance depends on the availability and supply of essential nutrients in a balanced manner throughout the crop growth stage. Figure 1 shows that seed yield is influenced by different nutrient management strategies. Cowpea seed yield was significantly higher in the treatments applied with 100% N+100%PK (inorganic), organic farming 1 (farmyard manure) and 2 (vermicompost), integrated nutrient management 1 (50% N through inorganic+ 50% N through vermicompost) and 2 (50% N through inorganic+ 50% N through farmyard manure) and 125% N+100%PK (inorganic) compared to the control. The increase in seed yield for the above treatments was 43, 33, 27, 23, 19, and 17%, respectively, over the control. There was no significant increase in seed yield when natural farming 1 and 2 were performed, which increased by 6% and 8% over the control. The highest seed yield was observed in the treatment 125% N+100%PK (inorganic), and the lowest seed yield in the treatment natural farming excluding control. The study suggested that inorganic fertilizers provide the readily available nutrients that support favourable crop growth and higher yield. Similar results are reported by Paramesh et al. (2023) and Singh et al. (2026) in the maize crop. Chowdhuri et al. (2025) reported that natural farming lowered rice yield compared to integrated nutrient management in an acidic Alfisol. Short-term nutrient management through organic sources is unable to meet crop demand exactly, resulting in low productivity. A study showed that long-term applications of organic sources can improve long-term fertility and organic matter and may, over time, bring crop performance to par with inorganic-based nutrient management. Darjee et al. (2024) and Sharma and Chadak (2022) found that the application of bioorganic nutrient sources improved crop yield and nutrient uptake. Continuing the practice of integrated nutrient management may be the most sustainable approach for ensuring stable crop performance. Timsina (2018) demonstrated that organic sources alone were not enough to increase crop yields to meet global food demand. He also added that an integrated inorganic and organic source (at a ratio of 3:1) is preferred for stable crop performance. Hence, an appropriate rate of application of nutrients may meet crop requirements and result in better crop performance.

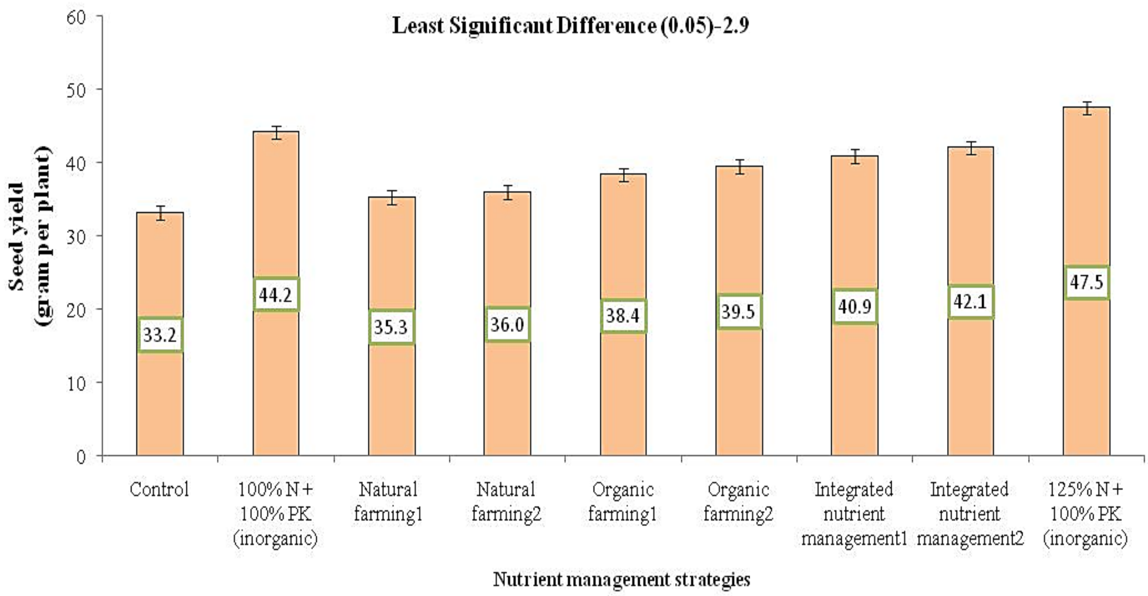

Fig. 1. Seed yield of cowpea as influenced by various nutrient management strategies

3.2 Plant Nitrogen Uptake

Nitrogen is one of the major macronutrients essential for plant growth and development. Study reports that soil available nitrogen increases the response of crop yield by improving nutrient uptake. Data in Figure 2 show that nitrogen uptake was significantly influenced by various nutrient management strategies. Plant nitrogen uptake was significantly higher in the treatments applied with 100% N+100%PK (inorganic), organic farming 1 (farmyard manure) and 2 (vermicompost), integrated nutrient management 1 (50% N through inorganic+ 50% N through vermicompost) and 2 (50% N through inorganic+ 50% N through farmyard manure) and 125% N+100%PK (inorganic) compared to the control. The increase in plant nitrogen uptake for the above treatments was 45, 34, 29, 25, 20, and 16%, respectively, over the control. There was no significant increase in plant nitrogen uptake when natural farming 1 and 2 were performed, which increased by 7% and 9% over the control. The highest nitrogen uptake was observed in the treatment 125% N+100%PK (inorganic), and the lowest nitrogen uptake was in the treatment natural farming excluding control. Similar results are reported by Singh et al. (2026) in the maize crop. According to them, an inorganic nitrogen source had the highest nitrogen uptake due to readily available nitrogen in the soil, resulting in improved crop growth and nutrient absorption. A study showed that the organic source had lower nitrogen uptake due to the slow mineralization of the organic source. However, long-term application may contribute to improved soil sustainability and result in improved nitrogen uptake. Integrated nutrient management ensures rapid nutrient availability through inorganic sources with the long-term soil health benefits of organic sources, resulting in sustainable crop performance.

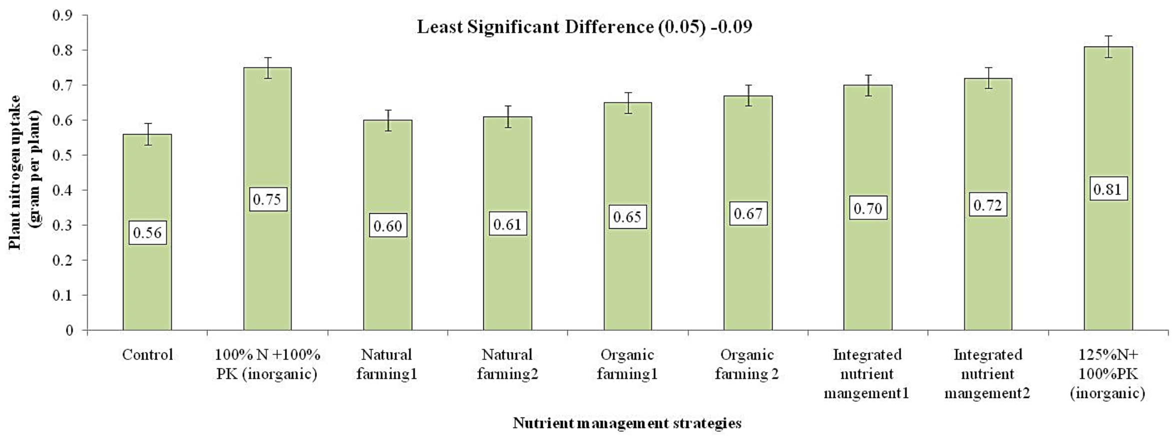

Fig. 2. Plant nitrogen uptake as influenced by various nutrient management strategies

3.3 Soil Physical Properties

Soil physical properties support plant growth by influencing water movement, air exchange, root penetration and soil structure. Data shown in Table 1 show the influence of different nutrient management strategies on water-holding capacity, bulk density, particle density and soil texture. Soil physical parameters did not vary, and no effect was obtained due to nutrient management options in both soil layers. Applications of inorganic sources, organic sources or their integration in the short-term had a limited impact on soil physical characteristics and, as a result, did not cause significant variation. If organic source application and integrated nutrient management continue, they may improve soil physical properties over time and contribute to soil sustainability. Texturally, the surface layer was sandy loam, and the subsurface layer was sandy clay loam.

3.4 Soil Physicochemical Properties

Soil physicochemical properties, such as pH and electrical conductivity, influence soil fertility, nutrient availability, water retention, and overall productivity. Data shown in Table 2 show the influence of various nutrient management strategies on soil pH and electrical conductivity. Soil pH and electrical conductivity were not significantly affected by different nutrient management options in both soil layers (Padbhushan et al., 2020). The duration of the study was short, which did not bring changes due to insufficient organic matter accumulation and the soil's capacity to buffer despite various nutrient management strategies.Similarly, Singh et al. (2026) and Darjee et al. (2024) reported that soil pH was not affected by inorganic fertilization and natural farming practices, respectively in post-harvest soil.

Table 1. Soil texture, water holding capacity, bulk density, and particle density as influenced by different nutrient management options

Soil depth (cm) / Treatment	Water holding capacity (%)		Bulk density (Mg m^{-3})		Particle density (Mg m^{-3})		Soil texture (%)	
	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Control	52.6	49.9	1.52	1.69	2.62	2.67	Sand -54	Sand-57
100% N + 100% PK (inorganic)	52.5	50.3	1.50	1.59	2.62	2.68		
Natural farming1	56.4	50.1	1.48	1.57	2.66	2.67	Silt-28	Silt-20
Natural farming2	56.6	50.2	1.45	1.58	2.65	2.62		
Organic farming1	59.6	51.0	1.41	1.58	2.67	2.65	Clay-19	Clay-21
Organic farming2	59.2	51.2	1.41	1.58	2.66	2.64		
Integrated nutrient management1	55.7	50.7	1.44	1.59	2.63	2.66		
Integrated nutrient management2	55.3	50.4	1.48	1.62	2.65	2.66		
125% N + 100% PK (inorganic)	52.6	50.1	1.48	1.66	2.63	2.67		
SEm(±)	0.72	0.84	0.04	0.04	0.09	0.12		
LSD (0.05)	NS	NS	NS	NS	NS	NS		

Non-significant

Table 2. Soil pH and electrical conductivity as influenced by different nutrient management options

Soil depth (cm) / Treatment	Soil pH		Electrical conductivity (dS m^{-1})	
	0-15	15-30	0-15	15-30
Control	7.1	6.7	0.17	0.17
100% N + 100% PK (inorganic)	6.9	6.8	0.19	0.20
Natural farming1	6.8	6.8	0.17	0.21
Natural farming2	7.0	7.1	0.24	0.20
Organic farming1	7.0	6.8	0.18	0.18
Organic farming2	6.8	6.9	0.24	0.25
Integrated nutrient management1	6.8	6.8	0.23	0.22
Integrated nutrient management2	6.7	7.1	0.20	0.18
125% N + 100% PK (inorganic)	6.9	7.0	0.13	0.22
SEm(±)	0.2	0.2	0.04	0.04
LSD (0.05)	NS	NS	NS	NS

Non-significant

3.5 Relationship between Crop and Soil Parameters

Correlation between seed yield and soil parameters, as shown in Table 3, shows that Water holding capacity was positive and significantly correlated with particle density, whereas negative and significantly correlated with bulk density. Bulk density was negative and significantly correlated with particle density.

Table 3. Correlation matrix between seed yield and soil parameters

	Seed yield	Water holding capacity	Bulk density	Particle density	Soil pH	Electrical conductivity
Water holding capacity	-0.322^{NS}					
Bulk density	-0.004^{NS}	-0.899**				
Particle density	-0.283^{NS}	0.902**	-0.709*			
Soil pH	-0.421^{NS}	-0.178^{NS}	0.188^{NS}	-0.244^{NS}		
Electrical conductivity	-0.266^{NS}	0.517^{NS}	-0.529^{NS}	0.245^{NS}	-0.227^{NS}	

**=significant at 5 %, ** = significant at 1 % and NS = non-significant*

4. Conclusion

The study showed that short-term nutrient management strategies were insufficient to change crop performance and nutrient uptake in natural farming. However, 125% nitrogen through inorganic sources produced the highest seed yield and nitrogen uptake, followed by 100% nitrogen through inorganic sources, integrated nutrient management and organic farming treatments compared to the control, suggesting optimized nitrogen may improve crop performance. Soil physical and physicochemical properties improved only to a limited extent during the study period. Crop response to nutrient management was observed earlier than soil properties variations. Overall, long-term nutrient management strategies are required to understand the sustained impacts on crop performance and soil sustainability under cowpea-based systems.

5. Limitation

The study was conducted for only two years at a single location and evaluated soil properties after short-term exposure to the nutrient management treatments. This duration may have been insufficient for organic and natural inputs to mineralise fully or produce measurable changes in soil physical and physicochemical characteristics. The findings are therefore specific to the tested cowpea-based system, soil conditions, treatment combinations, and seasonal environment. Longer multi-location studies across additional cropping cycles are required to assess the stability of crop responses and the cumulative effects of the management strategies on soil sustainability.

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Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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