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## Effect of integrated nutrient management practices on growth, yield, and economics of groundnut (*Arachis hypogaea* L.)

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### Abstract

Groundnut (*Arachis hypogaea* L.) is one of the most important oilseed-legume crops cultivated throughout the tropical and subtropical regions of the world owing to its high oil and protein content, excellent nutritional quality, and multiple industrial uses. Despite its economic importance, the productivity of groundnut in India remains considerably lower than its attainable potential because of poor soil fertility, imbalanced fertilizer use, low organic matter content, and declining soil biological activity. Integrated Nutrient Management (INM), which integrates inorganic fertilizers with organic manures and beneficial microbial inoculants, has emerged as an effective strategy for improving nutrient use efficiency, sustaining soil health, and enhancing crop productivity. Keeping these aspects in view, a field experiment was conducted during the Kharif season of 2025-26 at the Research Farm of the Faculty of Agricultural Sciences and Allied Industries, Rama University, Kanpur, Uttar Pradesh, to evaluate the influence of different integrated nutrient management practices on the growth, yield, soil health, and economics of groundnut. The experiment was laid out in a Randomized Block Design comprising eleven treatments with three replications. The treatments consisted of different phosphorus levels either alone or in combination with Rhizobium inoculation, vermicompost, mycorrhizal inoculant (Myco F. UNO), and liquid bio-stimulant. Significant differences among treatments were observed for all growth, yield, soil, and economic parameters. Treatment T<sub>10</sub> [45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost @ 2.5 t ha<sup>-1</sup> + Myco F. UNO (soil application) + Liquid bio-stimulant (seed treatment)] recorded the maximum plant height (48.7 cm), number of branches (11.3 plant<sup>-1</sup>), leaf area index (5.12), nodules per plant (81.5), fresh nodule weight (298.4 mg plant<sup>-1</sup>), dry nodule weight (85.6 mg plant<sup>-1</sup>), pod yield (33.2 q ha<sup>-1</sup>), haulm yield (49.4 q ha<sup>-1</sup>), biological yield (82.6 q ha<sup>-1</sup>), and harvest index (40.2%). The same treatment also improved post-harvest soil fertility by increasing organic carbon (0.65%), available nitrogen, phosphorus and potassium, microbial biomass carbon, and dehydrogenase activity. Economically, T<sub>10</sub> produced the highest gross return (₹166,000 ha<sup>-1</sup>), net return (₹116,500 ha<sup>-1</sup>), and benefit:cost ratio (3.35). The findings clearly demonstrated that the integration of moderate phosphorus with vermicompost and beneficial microbial inoculants substantially enhanced nutrient availability, biological nitrogen fixation, root development, crop productivity, soil quality, and farm profitability. Therefore, the integrated nutrient management module comprising 45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> along with Rhizobium, vermicompost, Myco F. UNO, and liquid bio-stimulant may be recommended for sustainable and profitable groundnut cultivation under the Central Plain Zone of Uttar Pradesh.

**Keywords:** Groundnut, integrated nutrient management, phosphorus, rhizobium, vermicompost, mycorrhiza, bio-stimulant, soil fertility, pod yield, economics

### Introduction

Groundnut (*Arachis hypogaea* L.) is an important annual oilseed-legume crop of the family Fabaceae, widely cultivated in tropical and subtropical regions due to its high nutritional, economic, and industrial value. It serves as both a food and cash crop, contributing significantly to nutritional security, edible oil production, livestock feed, and rural livelihoods. Known as the "King of Oilseeds," groundnut kernels contain about 45-50% oil and 25-30% protein, along with carbohydrates, dietary fibre, vitamins (A, E, and B-complex), minerals, and antioxidant compounds (Upadhyaya *et al.*, 2020; Bishi *et al.*, 2020; Kumar *et al.*, 2022) [4, 16, 33]. The crop is consumed in various forms such as roasted nuts, peanut butter, confectionery, and edible oil.

Its haulm is valuable fodder, while shells are used in industrial products, enhancing its economic importance (Nigam *et al.*, 2019; Singh *et al.*, 2023) <sup>[22, 30]</sup>.

Globally, groundnut is cultivated on about 30 million hectares with production exceeding 55 million tonnes, with Asia and Africa contributing nearly 90% of the output (FAOSTAT, 2024). China and India are leading producers. In India, it occupies around 5-6 million hectares with production of 10-12 million tonnes. Major producing states include Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, Karnataka, Maharashtra, and Uttar Pradesh. However, the average productivity ( $1.6\text{--}2.0\text{ t ha}^{-1}$ ) remains below its potential, indicating scope for improvement (ICAR-DGR, 2024; FAOSTAT, 2024) <sup>[12]</sup>. Low productivity in India is mainly due to factors such as erratic rainfall, moisture stress, poor soil fertility, nutrient deficiencies (especially phosphorus, sulphur, calcium, boron, and zinc), low organic carbon, and imbalanced fertilizer use (Meena *et al.*, 2021; Kumar and Yadav, 2022) <sup>[15, 20]</sup>. Continuous cultivation without proper nutrient replenishment has degraded soil health, affecting root growth, nutrient uptake, and pod development (Jat *et al.*, 2021; Sharma *et al.*, 2023) <sup>[13, 28]</sup>. Hence, balanced nutrient management is essential for sustaining productivity. Phosphorus is a key nutrient for groundnut growth, playing a vital role in energy transfer, cell division, photosynthesis, and root development (Marschner, 2012) <sup>[19]</sup>. Adequate phosphorus enhances nodulation, flowering, peg formation, and pod development, ultimately improving yield and oil content (Baligar *et al.*, 2018; Meena *et al.*, 2023) <sup>[2, 21]</sup>. However, its availability is often limited due to fixation in soils, reducing fertilizer efficiency (Vance *et al.*, 2003; Kumar *et al.*, 2022) <sup>[16, 34]</sup>.

Excessive use of chemical fertilizers has improved yields but also caused soil degradation, reduced microbial activity, and nutrient imbalance (Ladha *et al.*, 2020; Jat *et al.*, 2021) <sup>[13, 17]</sup>. This has increased the need for integrated nutrient management (INM), which combines inorganic fertilizers with organic and biological inputs to improve nutrient use efficiency and maintain soil health (Mahajan *et al.*, 2021) <sup>[18]</sup>. Organic sources like vermicompost improve soil structure, water retention, and microbial activity while supplying nutrients gradually (Atiyeh *et al.*, 2002; Singh *et al.*, 2022) <sup>[1, 29]</sup>. Biofertilizers such as *Rhizobium* enhance biological nitrogen fixation, reducing dependence on synthetic fertilizers and improving crop growth (Peoples *et al.*, 2009; Giller, 2019) <sup>[10]</sup>. Similarly, arbuscular mycorrhizal fungi improve phosphorus uptake, water absorption, and stress tolerance (Smith and Read, 2008) <sup>[31]</sup>. Combined use of these inputs often results in better growth and yield due to synergistic effects (Smith *et al.*, 2015; Verma *et al.*, 2023) <sup>[32, 35]</sup>.

Vermicompost further enhances soil fertility by improving porosity, nutrient availability, and microbial biomass (Edwards *et al.*, 2011; Sinha *et al.*, 2019) <sup>[8]</sup>. In addition, liquid bio-stimulants containing amino acids, humic substances, and plant growth regulators improve physiological processes, nutrient uptake, and stress tolerance, leading to higher productivity (du Jardin, 2015; Calvo *et al.*, 2014) <sup>[5, 7]</sup>. Studies have shown that integrated application of phosphorus, vermicompost, *Rhizobium*, and mycorrhiza improves growth, yield, nutrient uptake, and soil health in groundnut (Jat *et al.*, 2021; Kumar *et al.*, 2022; Meena *et al.*, 2023; Sharma *et al.*, 2023) <sup>[13, 15, 16, 21, 28]</sup>. However, responses vary with soil and climatic conditions, highlighting the need for location-specific recommendations. The alluvial soils of the Central Plain Zone of Uttar Pradesh are characterized by low organic carbon and moderate phosphorus levels, with declining biological activity. Limited information is available on integrated nutrient management practices under these conditions. Therefore,

identifying an efficient and economical nutrient management strategy is essential for improving productivity and soil health. Therefore, the present investigation was undertaken to evaluate the effect of different integrated nutrient management practices on the growth, yield, soil fertility, soil biological properties, and economics of groundnut (*Arachis hypogaea* L.) under the Central Plain Zone of Uttar Pradesh. The findings are expected to provide practical recommendations for enhancing productivity, maintaining soil health, and improving profitability under alluvial soil conditions.

## 2. Materials and Methods

The experiment on integrated nutrient management in groundnut (*Arachis hypogaea* L.) was conducted during Kharif 2025-26 at the Research Farm of FASAI, Rama University, Kanpur, Uttar Pradesh. The site lies at  $26^{\circ}29'$  N latitude and  $80^{\circ}18'$  E longitude with an altitude of 126 m above mean sea level. The climate is subtropical with hot summers, cool winters and monsoon rainfall (June-September). About 80-85% of rainfall occurs during the monsoon. Temperature ranged from  $31.4\text{--}37.8^{\circ}\text{C}$  (maximum) and  $22.1\text{--}26.4^{\circ}\text{C}$  (minimum), with relatively high humidity during crop growth.

Soil samples (0-15 cm) were collected before sowing and analyzed. The soil was sandy loam, slightly alkaline (pH 7.8-8.0), with low electrical conductivity ( $<0.30\text{ dS m}^{-1}$ ) and organic carbon (0.45-0.55%). It was low in nitrogen and medium in phosphorus and potassium. The experiment was laid out in a Randomized Block Design (RBD) with 11 treatments and 3 replications. Treatments included different phosphorus levels alone or combined with vermicompost, *Rhizobium*, Myco F. UNO and bio-stimulant. The experiment was laid out in a Randomized Block Design (RBD) comprising eleven treatments with three replications. The treatments consisted of different combinations of inorganic phosphorus, organic manure and biofertilizers. Treatment  $T_1$  served as the absolute control without any fertilizer or manure application, while  $T_2$  received the recommended dose of fertilizers (RDF) @  $20:40:20\text{ kg N}_2\text{O}_{52}\text{O ha}^{-1}$ . Treatment  $T_3$  consisted of  $30\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  + *Rhizobium*, whereas  $T_4$  comprised  $30\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  + vermicompost. Treatments  $T_5$  and  $T_6$  received  $45\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  in combination with *Rhizobium* and vermicompost, respectively. Similarly,  $T_7$  and  $T_8$  consisted of  $60\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  combined with *Rhizobium* and vermicompost, respectively. Treatment  $T_9$  included the integrated application of  $45\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  + *Rhizobium* + vermicompost, while  $T_{10}$  comprised  $45\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  + *Rhizobium* + vermicompost + Myco F. UNO + liquid bio-stimulant. The final treatment,  $T_{11}$ , consisted of  $60\text{ kg P}_2\text{O}_5\text{ ha}^{-1}$  + *Rhizobium* + vermicompost + Myco F. UNO + liquid bio-stimulant. These treatment combinations were designed to evaluate the individual and combined effects of inorganic phosphorus, organic nutrient sources and beneficial microbial inoculants on the growth, productivity, soil health and economics of groundnut under the alluvial soil conditions of the Central Plain Zone of Uttar Pradesh.

### 2.4 Crop

A suitable groundnut variety was sown after proper land preparation. Seeds were treated with *Rhizobium* and bio-stimulant as per treatments. Myco F. UNO was applied in soil. Sowing was done at  $40 \times 20\text{ cm}$  spacing using  $100\text{--}120\text{ kg seed ha}^{-1}$ . Nitrogen and potassium were applied uniformly, while phosphorus was applied as per treatments. Vermicompost was incorporated before sowing. Standard agronomic practices were followed. Growth parameters (plant height, branches, leaf area index) were recorded at different stages. Nodulation was studied at 60 DAS. Yield attributes (pods per plant, kernels per pod,  $100\text{--}$

kernel weight) and yields (pod and haulm) were recorded at harvest. Soil properties and microbial activity were analyzed after harvest. Economic analysis included cost, returns and benefit-cost ratio.

Data were analyzed using ANOVA for RBD. Treatment differences were tested at 5% significance using F-test and Critical Difference (CD). Standard error (SEm) was also calculated. The field experiment was conducted during the Kharif season 2025-26 at the Research Farm, Rama University, Kanpur. The soil was sandy loam with pH 7.8-8.0, organic carbon 0.45-0.55%, and medium fertility status. Design: Randomized Block Design with 11 treatments and 3 replications. Variety: High-yielding bunch-type groundnut variety suitable for the region. Spacing: 40 cm × 20 cm Seed rate: 100-120 kg ha<sup>-1</sup>

### 3. Results and Discussion

#### 3.1 Effect of Integrated Nutrient Management Practices on Growth Parameters of Groundnut

Growth is one of the most reliable indicators of crop response to nutrient management and directly influences the productivity of groundnut. Integrated application of inorganic fertilizers, organic manures and beneficial microorganisms significantly improved plant growth, leaf development and nodulation over the control. The analysis of variance revealed that all the growth parameters were significantly influenced by different integrated nutrient management treatments, indicating the positive role of balanced nutrient supply and biological inputs in promoting vegetative growth and root development (Singh *et al.*, 2019; Kumar and Yadav, 2020) [15, 29].

**Table 1:** Effect of integrated nutrient management practices on growth parameters of groundnut

| Treatment       | Plant height (cm) | Branches plant <sup>-1</sup> | Leaf area index | Nodules plant <sup>-1</sup> | Fresh weight of nodules (mg plant <sup>-1</sup> ) | Dry weight of nodules (mg plant <sup>-1</sup> ) |
|-----------------|-------------------|------------------------------|-----------------|-----------------------------|---------------------------------------------------|-------------------------------------------------|
| T <sub>1</sub>  | 28.4              | 4.1                          | 2.18            | 17.6                        | 68.4                                              | 18.2                                            |
| T <sub>2</sub>  | 35.6              | 6.7                          | 3.45            | 41.8                        | 142.6                                             | 42.5                                            |
| T <sub>3</sub>  | 37.2              | 7.2                          | 3.68            | 48.5                        | 168.4                                             | 48.9                                            |
| T <sub>4</sub>  | 36.8              | 7.0                          | 3.59            | 45.2                        | 155.7                                             | 45.6                                            |
| T <sub>5</sub>  | 39.5              | 8.1                          | 3.92            | 55.4                        | 192.3                                             | 56.8                                            |
| T <sub>6</sub>  | 39.1              | 7.9                          | 3.85            | 52.6                        | 183.5                                             | 53.7                                            |
| T <sub>7</sub>  | 40.8              | 8.6                          | 4.12            | 59.3                        | 215.8                                             | 61.4                                            |
| T <sub>8</sub>  | 40.4              | 8.4                          | 4.05            | 57.1                        | 208.6                                             | 59.2                                            |
| T <sub>9</sub>  | 43.2              | 9.4                          | 4.48            | 67.8                        | 248.7                                             | 72.5                                            |
| T <sub>10</sub> | 48.7              | 11.3                         | 5.12            | 81.5                        | 298.4                                             | 85.6                                            |
| T <sub>11</sub> | 47.9              | 10.9                         | 4.98            | 78.4                        | 285.2                                             | 82.3                                            |
| SEm ±           | 0.89              | 0.27                         | 0.12            | 1.62                        | 6.85                                              | 2.14                                            |
| CD (P=0.05)     | 2.65              | 0.82                         | 0.36            | 4.85                        | 20.48                                             | 6.40                                            |

The data presented in Table 2 clearly indicate that integrated nutrient management practices exerted a significant influence on all the growth parameters of groundnut. Among the treatments, T<sub>10</sub> (45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant) consistently recorded the highest values for plant height (48.7 cm), number of branches (11.3 plant<sup>-1</sup>), leaf area index (5.12), nodules per plant (81.5), fresh nodule weight (298.4 mg plant<sup>-1</sup>) and dry nodule weight (85.6 mg plant<sup>-1</sup>). The superiority of this treatment demonstrated the synergistic interaction among inorganic phosphorus, organic nutrient sources and beneficial microorganisms, which collectively improved nutrient availability, root proliferation and physiological efficiency (Patel *et al.*, 2021) [23].

Plant height increased significantly from 28.4 cm under the control (T<sub>1</sub>) to 48.7 cm under T<sub>10</sub>, representing an increase of nearly 71.5% over the untreated control. Similarly, treatments T<sub>2</sub> and T<sub>3</sub> recorded plant heights of 35.6 cm and 37.2 cm, respectively, indicating progressive improvement with nutrient addition. The number of branches increased from 4.1 in T<sub>1</sub> to 11.3 branches plant<sup>-1</sup> in T<sub>10</sub>, while intermediate treatments such as T<sub>5</sub> (8.1 branches) and T<sub>9</sub> (9.4 branches) also showed considerable improvement. The leaf area index improved from 2.18 in control to 5.12 in T<sub>10</sub>, with treatments T<sub>7</sub> (4.12), T<sub>8</sub> (4.05) and T<sub>9</sub> (4.48) also exhibiting higher values compared to lower input treatments. The improvement in vegetative growth can be attributed to the continuous and balanced nutrient supply provided through vermicompost together with enhanced phosphorus availability and biological nitrogen fixation by Rhizobium. In addition, Myco F. UNO and the liquid bio-stimulant likely stimulated root growth, chlorophyll synthesis, enzymatic activity and photosynthetic efficiency, resulting in greater dry matter

accumulation and vigorous crop growth. Similar improvements in growth parameters of groundnut under integrated nutrient management have been reported by Joshi and Patel (2021) [14, 23] and Sharma *et al.* (2020) [20], who observed that the integration of inorganic fertilizers with vermicompost and Rhizobium significantly enhanced vegetative growth and productivity.

Nodulation was markedly influenced by integrated nutrient management. Treatment T<sub>10</sub> produced the maximum 81.5 nodules plant<sup>-1</sup>, fresh nodule weight (298.4 mg plant<sup>-1</sup>) and dry nodule weight (85.6 mg plant<sup>-1</sup>), which were significantly superior to all other treatments. In comparison, the control (T<sub>1</sub>) recorded only 17.6 nodules plant<sup>-1</sup> with fresh and dry weights of 68.4 mg and 18.2 mg, respectively. Treatments such as T<sub>5</sub> (55.4 nodules), T<sub>7</sub> (59.3 nodules) and T<sub>9</sub> (67.8 nodules) also showed substantial increases in nodulation. The increase in nodulation was primarily due to effective Rhizobium inoculation, adequate phosphorus availability and improved rhizosphere conditions created by vermicompost. Phosphorus is indispensable for ATP synthesis and energy transfer during biological nitrogen fixation, while vermicompost provides a favourable habitat for beneficial microorganisms by improving soil aeration, moisture retention and microbial activity. Arbuscular mycorrhiza further enhanced phosphorus uptake through an extensive hyphal network, thereby strengthening the Rhizobium-legume symbiosis. Similar observations have been reported by Meena *et al.* (2018) [20] and Gupta *et al.* (2019) in groundnut and other legumes where combined application of phosphorus, biofertilizers and organic manures significantly increased nodulation and nitrogen fixation. The performance of treatment T<sub>11</sub> was statistically comparable with T<sub>10</sub> for several growth parameters but remained slightly inferior despite receiving a higher phosphorus dose (60 kg P<sub>2</sub>O<sub>5</sub>

ha<sup>-1</sup>). Treatment T<sub>11</sub> recorded plant height of 47.9 cm, 10.9 branches plant<sup>-1</sup>, leaf area index of 4.98, 78.4 nodules plant<sup>-1</sup>, fresh nodule weight of 285.2 mg and dry nodule weight of 82.3 mg. This finding suggests that increasing phosphorus beyond the optimum level did not produce additional growth benefits when adequate nutrients and biological inputs were already available. The results indicate that balanced nutrient management rather than excessive fertilizer application is more effective for achieving maximum crop growth. Similar conclusions have been reported by Verma *et al.* (2020) [35] and Singh and Kumar (2021) [29], where integrated nutrient management involving moderate fertilizer doses with organic amendments and microbial inoculants proved superior to higher doses of chemical fertilizers alone.

Among the intermediate treatments, T<sub>9</sub> also recorded appreciably higher plant height (43.2 cm), branches (9.4 plant<sup>-1</sup>), leaf area index (4.48) and nodulation (67.8 nodules plant<sup>-1</sup>) compared with treatments receiving phosphorus alone or in combination with only one organic input. Treatments receiving vermicompost or Rhizobium individually such as T<sub>4</sub> (36.8 cm height, 7.0 branches, 45.2 nodules), T<sub>6</sub> (39.1 cm height, 7.9 branches, 52.6 nodules) and

T<sub>8</sub> (40.4 cm height, 8.4 branches, 57.1 nodules) consistently performed better than their corresponding phosphorus-alone combinations, indicating that organic manure and biofertilizers substantially improved nutrient availability and nutrient use efficiency. These observations are consistent with reports by Reddy *et al.* (2019) [25] and Choudhary *et al.* (2020) [6] that integrated nutrient management enhances soil physical, chemical and biological properties, resulting in better crop growth, nutrient uptake and sustainable productivity.

### 3.2 Effect of Integrated Nutrient Management Practices on Yield Attributes and Yield of Groundnut

Yield attributes are the ultimate expression of vegetative growth and reproductive efficiency of a crop and are greatly influenced by balanced nutrient availability throughout the crop growth period. The integrated application of inorganic fertilizers, organic manures and biofertilizers significantly improved the yield attributes and yield of groundnut over the control. The analysis of variance indicated significant differences among treatments for pods plant<sup>-1</sup>, kernels pod<sup>-1</sup>, 100-kernel weight, pod yield, haulm yield, biological yield and harvest index (Table 2).

**Table 2:** Effect of integrated nutrient management practices on yield attributes and yield of groundnut

| Treatment       | Pods plant <sup>-1</sup> | Kernels pod <sup>-1</sup> | 100-kernel weight (g) | Pod yield (q ha <sup>-1</sup> ) | Haulm yield (q ha <sup>-1</sup> ) | Biological yield (q ha <sup>-1</sup> ) | Harvest index (%) |
|-----------------|--------------------------|---------------------------|-----------------------|---------------------------------|-----------------------------------|----------------------------------------|-------------------|
| T <sub>1</sub>  | 12.2                     | 1.68                      | 27.8                  | 8.4                             | 19.2                              | 27.6                                   | 30.4              |
| T <sub>2</sub>  | 23.4                     | 1.85                      | 34.6                  | 19.2                            | 33.8                              | 53.0                                   | 36.2              |
| T <sub>3</sub>  | 25.1                     | 1.88                      | 36.2                  | 21.5                            | 36.4                              | 57.9                                   | 37.1              |
| T <sub>4</sub>  | 24.8                     | 1.86                      | 35.9                  | 20.8                            | 35.6                              | 56.4                                   | 36.9              |
| T <sub>5</sub>  | 27.6                     | 1.92                      | 38.4                  | 24.3                            | 39.5                              | 63.8                                   | 38.1              |
| T <sub>6</sub>  | 27.2                     | 1.90                      | 38.1                  | 23.9                            | 39.1                              | 63.0                                   | 37.9              |
| T <sub>7</sub>  | 29.5                     | 1.94                      | 39.8                  | 25.8                            | 41.2                              | 67.0                                   | 38.5              |
| T <sub>8</sub>  | 29.1                     | 1.93                      | 39.5                  | 25.4                            | 40.8                              | 66.2                                   | 38.4              |
| T <sub>9</sub>  | 32.4                     | 1.96                      | 42.3                  | 27.6                            | 43.5                              | 71.1                                   | 38.8              |
| T <sub>10</sub> | 38.6                     | 2.05                      | 46.5                  | 33.2                            | 49.4                              | 82.6                                   | 40.2              |
| T <sub>11</sub> | 37.4                     | 2.02                      | 45.8                  | 31.9                            | 47.8                              | 79.7                                   | 40.0              |
| SEm ±           | 0.71                     | 0.04                      | 0.58                  | 0.62                            | 0.78                              | 1.35                                   | 0.47              |
| CD (P=0.05)     | 2.12                     | 0.12                      | 1.75                  | 1.85                            | 2.35                              | 4.05                                   | 1.42              |

The data presented in Table 3 clearly demonstrate that integrated nutrient management practices significantly enhanced all yield attributes and yield parameters of groundnut. Among all the treatments, T<sub>10</sub> (45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant) recorded the highest values for pods per plant (38.6), kernels per pod (2.05), 100-kernel weight (46.5 g), pod yield (33.2 q ha<sup>-1</sup>), haulm yield (49.4 q ha<sup>-1</sup>), biological yield (82.6 q ha<sup>-1</sup>) and harvest index (40.2%), indicating the superiority of integrated nutrient management over individual nutrient application.

Pod yield, being the principal economic yield, increased markedly from 8.4 q ha<sup>-1</sup> under the control (T<sub>1</sub>) to 33.2 q ha<sup>-1</sup> under T<sub>10</sub>, representing an increase of approximately 295% over the untreated control and about 73% over the recommended dose of fertilizers (T<sub>2</sub>). Likewise, haulm yield increased from 19.2 q ha<sup>-1</sup> in T<sub>1</sub> to 49.4 q ha<sup>-1</sup> in T<sub>10</sub>, while biological yield increased from 27.6 q ha<sup>-1</sup> to 82.6 q ha<sup>-1</sup>. The remarkable improvement in yield can be attributed to balanced nutrient availability throughout the crop growth period, enhanced root development, efficient biological nitrogen fixation, greater photosynthetic activity and improved translocation of assimilates from source to sink. Similar findings have been reported by Sharma *et al.* (2020) [26], Kumar *et al.* (2022) [16] and Meena *et al.* (2023) [21], who observed significant enhancement in pod yield and biomass production through integrated application of inorganic fertilizers, vermicompost and biofertilizers.

The number of pods per plant increased significantly from 12.2 in the control to 38.6 under T<sub>10</sub>, while kernels per pod increased from 1.68 to 2.05. Similarly, the 100-kernel weight increased from 27.8 g under T<sub>1</sub> to 46.5 g under T<sub>10</sub>. These improvements indicate better flowering, successful peg penetration, enhanced pod setting and improved kernel filling under balanced nutrient management. Adequate phosphorus supply promoted flowering and reproductive development, whereas vermicompost maintained continuous nutrient availability and improved soil moisture conditions. Rhizobium inoculation supplied biologically fixed nitrogen during reproductive growth, while Myco F. UNO enhanced phosphorus uptake and root activity. The liquid bio-stimulant further improved physiological efficiency by stimulating enzymatic activity and assimilate partitioning towards developing pods. Similar observations were reported by Patel *et al.* (2021) [23], Verma *et al.* (2020) and Singh and Kumar (2021) [29].

Treatment T<sub>11</sub>, which received a higher phosphorus dose (60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>) along with the same organic and biological inputs, produced pod yield of 31.9 q ha<sup>-1</sup>, haulm yield of 47.8 q ha<sup>-1</sup> and biological yield of 79.7 q ha<sup>-1</sup>, remaining statistically at par with T<sub>10</sub> for several parameters. However, the slightly lower values compared with T<sub>10</sub> suggest that increasing phosphorus beyond the optimum level did not proportionately increase yield. This indicates that 45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> in combination with vermicompost and microbial inoculants was sufficient to satisfy crop nutrient

demand under the prevailing soil conditions. Similar results have been documented by Jat *et al.* (2021) <sup>[13]</sup>, who concluded that balanced nutrient application is more beneficial than excessive fertilizer use for maximizing nutrient use efficiency and crop productivity.

Among the intermediate treatments, T<sub>9</sub> also performed exceptionally well, producing 32.4 pods plant<sup>-1</sup>, 42.3 g test weight, 27.6 q ha<sup>-1</sup> pod yield and 43.5 q ha<sup>-1</sup> haulm yield. Treatments receiving phosphorus together with either Rhizobium or vermicompost (T<sub>5</sub>-T<sub>8</sub>) consistently outperformed those receiving lower phosphorus doses (T<sub>3</sub> and T<sub>4</sub>), confirming the beneficial role of integrated nutrient management in improving reproductive growth and yield formation. Vermicompost not only supplied nutrients but also improved soil physical properties and microbial activity, while Rhizobium enhanced nitrogen fixation and nutrient uptake. The combined action of these inputs resulted in better peg formation, higher pod retention and improved kernel development, ultimately leading to increased economic yield. Comparable findings have been reported by Reddy *et al.* (2019) <sup>[25]</sup>, Choudhary *et al.* (2020) <sup>[6]</sup> and Kumar *et al.* (2022).

Harvest index also improved significantly with integrated nutrient management, increasing from 30.4% under the control to 40.2%

under T<sub>10</sub>. The higher harvest index indicates greater efficiency in partitioning photosynthates towards economic yield under balanced nutrient supply. Improved nutrient availability, higher photosynthetic efficiency and better source-sink relationship collectively enhanced the conversion of total biomass into pod yield. Similar improvements in harvest index under integrated nutrient management have been reported in groundnut by Sharma *et al.* (2022) <sup>[27]</sup> and Meena *et al.* (2023) <sup>[21]</sup>.

### 3.3 Effect of Integrated Nutrient Management Practices on Post-harvest Soil Fertility

Soil fertility is one of the most important indicators of the sustainability of nutrient management practices, as it determines the long-term productive capacity of agricultural soils. The incorporation of organic manures together with inorganic fertilizers and beneficial microorganisms not only supplies nutrients to the crop but also improves the physico-chemical properties of the soil after harvest. In the present investigation, integrated nutrient management practices significantly influenced post-harvest soil fertility parameters including soil organic carbon, available nitrogen, available phosphorus and available potassium. The results are presented in Table 3.

**Table 3:** Effect of integrated nutrient management practices on post-harvest soil fertility of groundnut

| Treatment       | Organic carbon (%) | Available N (kg ha <sup>-1</sup> ) | Available P <sub>2</sub> O <sub>5</sub> (kg ha <sup>-1</sup> ) | Available K <sub>2</sub> O (kg ha <sup>-1</sup> ) |
|-----------------|--------------------|------------------------------------|----------------------------------------------------------------|---------------------------------------------------|
| T <sub>1</sub>  | 0.42               | 148                                | 16.5                                                           | 228                                               |
| T <sub>2</sub>  | 0.48               | 168                                | 21.6                                                           | 246                                               |
| T <sub>3</sub>  | 0.50               | 174                                | 23.8                                                           | 252                                               |
| T <sub>4</sub>  | 0.53               | 178                                | 24.2                                                           | 258                                               |
| T <sub>5</sub>  | 0.54               | 183                                | 25.4                                                           | 265                                               |
| T <sub>6</sub>  | 0.56               | 186                                | 25.9                                                           | 269                                               |
| T <sub>7</sub>  | 0.57               | 191                                | 27.2                                                           | 276                                               |
| T <sub>8</sub>  | 0.59               | 194                                | 27.8                                                           | 281                                               |
| T <sub>9</sub>  | 0.61               | 198                                | 28.6                                                           | 288                                               |
| T <sub>10</sub> | 0.65               | 202                                | 29.8                                                           | 295                                               |
| T <sub>11</sub> | 0.64               | 200                                | 29.3                                                           | 292                                               |
| SEm ±           | 0.01               | 2.14                               | 0.52                                                           | 3.24                                              |
| CD (P=0.05)     | 0.03               | 6.38                               | 1.55                                                           | 9.65                                              |

The data presented in Table 4 revealed that integrated nutrient management significantly improved post-harvest soil fertility compared with the control. Treatment T<sub>10</sub> (45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant) recorded the highest soil organic carbon (0.65%), available nitrogen (202 kg ha<sup>-1</sup>), available phosphorus (29.8 kg ha<sup>-1</sup>) and available potassium (295 kg ha<sup>-1</sup>). These values were significantly superior to the control and most of the other treatments, indicating that integrated nutrient management not only enhanced crop productivity but also enriched the soil nutrient reserve.

Organic carbon increased substantially from 0.42% under the control (T<sub>1</sub>) to 0.65% under T<sub>10</sub>, representing an improvement of nearly 55%. The increase in soil organic carbon may be attributed to the incorporation of vermicompost, which supplied stabilized organic matter and humic substances to the soil. Vermicompost also stimulated microbial decomposition and humification processes, leading to greater carbon sequestration and improved soil aggregation. Similar increases in soil organic carbon following integrated nutrient management have been reported by Ladha *et al.* (2020) <sup>[17]</sup>, Jat *et al.* (2021) <sup>[13]</sup> and Kumar *et al.* (2022), who observed that continuous addition of organic amendments substantially improved soil quality and nutrient cycling.

Available nitrogen also increased markedly under integrated

nutrient management. The maximum available nitrogen (202 kg ha<sup>-1</sup>) was recorded under T<sub>10</sub>, followed closely by T<sub>11</sub> (200 kg ha<sup>-1</sup>) and T<sub>9</sub> (198 kg ha<sup>-1</sup>), whereas the control recorded only 148 kg ha<sup>-1</sup>. The higher nitrogen availability may be attributed to effective biological nitrogen fixation by Rhizobium, increased mineralization of organic nitrogen from vermicompost and enhanced microbial activity in the rhizosphere. The gradual release of nitrogen from vermicompost synchronized well with crop demand, thereby reducing nutrient losses and improving residual soil fertility. Similar findings were reported by Peoples *et al.* (2009), Giller (2019) <sup>[10]</sup> and Sharma *et al.* (2022) <sup>[27]</sup>, who demonstrated that integration of biofertilizers with organic nutrient sources significantly increased soil nitrogen availability after legume cultivation.

Available phosphorus showed a progressive increase with increasing levels of integrated nutrient management. Treatment T<sub>10</sub> recorded the highest available phosphorus (29.8 kg ha<sup>-1</sup>), which was significantly higher than the control (16.5 kg ha<sup>-1</sup>). Improved phosphorus availability can be attributed to the direct application of phosphorus fertilizers together with enhanced solubilization by Rhizobium and mycorrhizal fungi. The extensive hyphal network of arbuscular mycorrhiza increased phosphorus absorption from soil microsites beyond the depletion zone, while organic acids released during decomposition of vermicompost reduced phosphorus fixation in the alkaline soil.

Similar observations have been reported by Smith and Read (2008) [31], Meena *et al.* (2023) [21] and Verma *et al.* (2023) [35], who observed improved phosphorus availability under integrated application of chemical fertilizers, organic manures and mycorrhizal inoculation.

Available potassium also increased significantly from 228 kg ha<sup>-1</sup> under the control to 295 kg ha<sup>-1</sup> under T<sub>10</sub>. The increase in available potassium may be attributed to the release of exchangeable potassium from vermicompost and enhanced weathering of potassium-bearing minerals due to increased microbial activity. Improved soil physical conditions under organic amendments also reduced nutrient losses and promoted greater retention of exchangeable potassium in the soil. Comparable findings have been reported by Choudhary *et al.* (2020) [6], Singh *et al.* (2022) [30] and Kumar *et al.* (2022), who reported significant improvements in available potassium following integrated nutrient management in oilseed and legume crops.

Although treatment T<sub>11</sub> received a higher phosphorus dose (60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup>), it remained statistically at par with T<sub>10</sub> for most soil fertility parameters, indicating that application of phosphorus beyond the optimum level produced only marginal improvement

in residual soil fertility. On the other hand, treatments receiving vermicompost either alone or in combination with Rhizobium (T<sub>6</sub>, T<sub>8</sub> and T<sub>9</sub>) consistently recorded higher soil fertility than treatments receiving only inorganic phosphorus. These findings clearly emphasize the beneficial role of organic nutrient sources in improving nutrient retention, microbial activity and overall soil quality.

### 3.5 Effect of Integrated Nutrient Management Practices on Economics of Groundnut

Economic evaluation is one of the most important criteria for assessing the practical feasibility and profitability of any nutrient management practice. Although certain integrated nutrient management practices increase the initial cost of cultivation due to the inclusion of organic manures and microbial inoculants, the additional expenditure is often compensated by higher crop productivity and greater economic returns. The economics of groundnut cultivation under different integrated nutrient management treatments was evaluated in terms of cost of cultivation, gross returns, net returns and benefit-cost (B:C) ratio. The results are presented in Table 4.

**Table 4:** Effect of integrated nutrient management practices on economics of groundnut cultivation

| Treatment       | Cost of cultivation (₹ ha <sup>-1</sup> ) | Gross returns (₹ ha <sup>-1</sup> ) | Net returns (₹ ha <sup>-1</sup> ) | B:C ratio |
|-----------------|-------------------------------------------|-------------------------------------|-----------------------------------|-----------|
| T <sub>1</sub>  | 28,400                                    | 42,000                              | 13,600                            | 1.48      |
| T <sub>2</sub>  | 41,800                                    | 96,000                              | 54,200                            | 2.30      |
| T <sub>3</sub>  | 43,200                                    | 1,07,500                            | 64,300                            | 2.49      |
| T <sub>4</sub>  | 44,500                                    | 1,04,000                            | 59,500                            | 2.34      |
| T <sub>5</sub>  | 44,800                                    | 1,21,500                            | 76,700                            | 2.71      |
| T <sub>6</sub>  | 45,900                                    | 1,19,500                            | 73,600                            | 2.60      |
| T <sub>7</sub>  | 46,300                                    | 1,29,000                            | 82,700                            | 2.79      |
| T <sub>8</sub>  | 47,600                                    | 1,27,000                            | 79,400                            | 2.67      |
| T <sub>9</sub>  | 48,200                                    | 1,38,000                            | 89,800                            | 2.86      |
| T <sub>10</sub> | 49,500                                    | 1,66,000                            | 1,16,500                          | 3.35      |
| T <sub>11</sub> | 51,200                                    | 1,59,500                            | 1,08,300                          | 3.12      |
| SEm ±           | 612                                       | 2,845                               | 2,654                             | 0.08      |
| CD (P=0.05)     | NS                                        | 8,486                               | 7,915                             | 0.24      |

The economic analysis (Table 6) revealed that integrated nutrient management practices significantly influenced the profitability of groundnut cultivation. The cost of cultivation increased progressively with the addition of organic manures, biofertilizers and bio-stimulants because of the higher cost of these inputs. The minimum cost of cultivation (₹28,400 ha<sup>-1</sup>) was recorded under the control (T<sub>1</sub>), whereas the maximum cost (₹51,200 ha<sup>-1</sup>) was incurred under T<sub>11</sub>, followed closely by T<sub>10</sub> (₹49,500 ha<sup>-1</sup>). Despite the relatively higher cultivation cost, the integrated nutrient management treatments generated substantially greater economic returns due to their superior productivity.

Among all the treatments, T<sub>10</sub> (45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant) proved to be the most profitable treatment by recording the highest gross return (₹1,66,000 ha<sup>-1</sup>), net return (₹1,16,500 ha<sup>-1</sup>) and benefit-cost ratio (3.35). The remarkable increase in profitability under T<sub>10</sub> was primarily attributed to its significantly higher pod yield and haulm yield, which substantially enhanced the marketable produce. Although the inclusion of vermicompost, microbial inoculants and bio-stimulants slightly increased the production cost, the additional investment was more than compensated by the increase in gross income, resulting in the maximum net profit.

Treatment T<sub>11</sub>, comprising 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant, recorded the second highest gross return (₹1,59,500 ha<sup>-1</sup>), net return

(₹1,08,300 ha<sup>-1</sup>) and benefit-cost ratio (3.12). However, despite receiving a higher phosphorus dose, its profitability remained slightly lower than T<sub>10</sub> because of the increased input cost coupled with only a marginal increase in yield. This finding suggests that application of phosphorus beyond the optimum level is economically less efficient and does not proportionately increase returns.

Among the remaining integrated nutrient management treatments, T<sub>9</sub> also recorded appreciably higher gross return (₹1,38,000 ha<sup>-1</sup>), net return (₹89,800 ha<sup>-1</sup>) and B:C ratio (2.86), indicating that the combined application of phosphorus, Rhizobium and vermicompost substantially improved profitability over the sole application of inorganic fertilizers. Similarly, treatments T<sub>7</sub> and T<sub>8</sub> recorded B:C ratios of 2.79 and 2.67, respectively, while treatments receiving only phosphorus with Rhizobium or vermicompost produced comparatively lower but economically viable returns. The control treatment (T<sub>1</sub>) recorded the lowest gross return (₹42,000 ha<sup>-1</sup>), net return (₹13,600 ha<sup>-1</sup>) and B:C ratio (1.48), primarily because of poor crop growth and significantly lower pod yield.

The higher profitability under integrated nutrient management may be attributed to the balanced supply of nutrients throughout the crop growth period, improved nutrient use efficiency, enhanced biological nitrogen fixation, better root development and increased photosynthetic activity, which collectively resulted

in superior yield and higher economic returns. Vermicompost improved soil physical properties and nutrient availability, Rhizobium enhanced biological nitrogen fixation, while Myco F. UNO increased phosphorus uptake and nutrient acquisition. The liquid bio-stimulant further stimulated physiological processes responsible for improved biomass production and yield. These synergistic effects ultimately translated into greater economic benefits.

The present findings are in close agreement with those reported by Sharma *et al.* (2022) <sup>[27]</sup>, Kumar *et al.* (2022), Meena *et al.* (2023) <sup>[21]</sup> and Singh *et al.* (2023) <sup>[30]</sup>, who observed that integrated application of inorganic fertilizers, organic manures and biofertilizers significantly increased gross returns, net returns and benefit-cost ratio in groundnut by improving nutrient use efficiency and crop productivity. Similar economic advantages of integrated nutrient management have also been documented in several legume crops, where balanced fertilization with organic amendments enhanced farm profitability while maintaining soil health over the long term.

#### 4. Conclusion

The study revealed that integrated nutrient management significantly enhanced growth, yield, soil fertility, biological properties, and profitability of groundnut under alluvial soils of the Central Plain Zone of Uttar Pradesh. Among all treatments, T<sub>10</sub> (45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant) performed best. Treatment T<sub>10</sub> improved vegetative growth, nodulation, and yield attributes, resulting in the highest pod yield (33.2 q ha<sup>-1</sup>) and a nearly 295% increase over control. It also enhanced soil organic carbon, available nutrients, and microbial activity, indicating improved soil health. Economically, T<sub>10</sub> recorded the highest net return (₹116,500 ha<sup>-1</sup>) and benefit-cost ratio (3.35), making it the most profitable option despite higher input costs.

#### Recommendation

Based on the findings of the present investigation, the integrated application of 45 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> + Rhizobium + Vermicompost + Myco F. UNO + Liquid bio-stimulant (T<sub>10</sub>) is recommended for groundnut cultivation under the alluvial soils of the Central Plain Zone of Uttar Pradesh. This nutrient management practice effectively enhances crop growth, yield, soil fertility, microbial activity, and economic returns while contributing to sustainable soil health and efficient nutrient utilization. Adoption of this integrated nutrient management module can therefore improve the productivity and profitability of groundnut cultivation under similar agro-ecological conditions.

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