

Integrated Nutrient Management for Lentil Cultivation: Improving Soil Fertility, Nutrient Content, and Economic Returns

Bimesh Dahal^{1*}, Animesh Ghosh Bag¹, Sabina Raut²

¹Department of Soil Science and Agriculture Chemistry, Lovely Professional University, Jalandhar - Delhi, Grand Trunk Road, Phagwara, Punjab, India.

²Department of Floriculture and Landscaping, Lovely Professional University, Jalandhar - Delhi, Grand Trunk Road, Phagwara, Punjab, India.

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Corresponding Author: **Bimesh Dahal** | E-Mail: (Bimeshdahal@gmail.com)

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ABSTRACT

Context: Overuse of chemical fertilizers reduces soil fertility, which highlights the need to switch to integrated farming practices for sustainable growth.

Purpose: A field experiment was conducted to analyse the effects of various integrated nutrient management strategies on soil fertility generally, nutrient level fluctuations in the soil, plant uptake, and nutrient content and economic consequences in lentil farming.

Method: Eight different treatments representing various nutrient sources were used in the experiment, which used a Randomized Block Design. Each treatment had three replications.

Result: The results indicated that there was no significant difference among 8 different treatments for soil pH and EC. The available nitrogen, available phosphorus and available potassium in soil and content in straw and seed were found highest in T_8 while protein content in seed was also found highest in T_8 (24.85%) followed by T_7 (24.50%). But the economics of cultivation indicated T_4 to be the best with the highest B:C ratio (1.96).

Conclusion: The proper and balanced usage of organic and inorganic sources of nutrient increased soil accessible nutrient pool and there was abundant of the remainder of nutrient in the soil. The impact of combined RDF, rhizobium, vermicompost and FYM may be the reason in higher nutrient content in soil, plants and quality of lentil.

Implication: The practice of integrated nutrient management strategies are for improving lentil cultivation's soil fertility, nutrient uptake, protein content, and overall economic viability.

Keywords: Integrated Nutrient Management, Rhizobium, Vermicompost, Lentil, NPK, Nutrient Uptake, organic carbon

1. INTRODUCTION

As a plant that pollinates itself most of the time, lentil shows little tendency to spontaneously cross-pollinate. Its ability to fix atmospheric nitrogen makes it one of the legume family members that enhance soil fertility. Due to their higher proportion of amino acids, lentils are an essential part of our daily diets, helping to balance out the inadequate amount of amino acids found in cereals (Nene, 2006). 26% protein, 1.3% fat, 57% carbs, 2.1% minerals, and 3.2% fibers make up a lentil's composition (Ali, Zuberi, and Sarker, 2012; Singh et al., 2013). Lentils are an essential part of the cropping system in agricultural agriculture and are often used in crop rotation techniques (Wang et al., 2012).

Consistently declining soil nutrients pose a serious challenge to sustainable agriculture, with disastrous consequences, especially for poorer farmers. Growing prices for chemical fertilizers are a problem since farmers can't afford to use the required dosage, which lowers yields. It becomes essential to apply biological and mineral fertilizers sparingly in order to preserve soil fertility (Tan et al., 2005). It is important to understand that a crop cannot be completely supplied by a single source of fertilizer and that substituting one nutrient for

another is not a workable option. Instead, a synergistic application of a variety of fertilizers is more beneficial. To uphold output and quality benchmarks, it is imperative to reduce reliance on chemical fertilizers while concurrently amplifying the utilization of organic fertilizers. (Hazra, 2016).

The term "Integrated Nutrient Management" (INM) describes the practice of applying chemical fertilizers and organic fertilizers in tandem to maintain soil fertility and provide plants with the necessary nutrients for maximum crop yields. Ecological, social, and economic viability is demonstrated by the holistic approach of INM, which shows its potential to increase crop yields through the synergistic application of organic, chemical, and biofertilizers (Kanala et al., 2021). Typical methods used in INM include Farm Yard Manure (FYM), chemical and biofertilizers, and a range of crop and soil improvement strategies such as compost, crop wastes, and green manures (Selim, 2018). This methodical approach highlights the careful use of organic and biofertilizers in combination with inorganic sources, highlighting the complex nature of integrated nutrition management (INM) (Antil, 2012). While, incorporating both biological and mineral nutrients increases crop productivity and financial gains while also preserving soil fertility (Kannan et al., 2013).

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One essential aspect of integrated natural farming (INM) is its capacity to blend effectively effective components, guaranteeing the best possible management of fertilizers, uniform and suitable application of amounts and types, and direct plant uptake for increased yields without disturbing the soil's natural nutrient balance or contaminating the surrounding environment.

When compared to potential yields, the average seed yield from lentil cultivation is relatively lower. Legumes are very productive when grown under conditions of poor nutrient management, particularly acidic soil. In addition to using biofertilizers like Rhizobium, chemical fertilizers applied through soil and foliar approaches can also be used to address nutrient deficits by increasing the availability of native soil nutrients through pH neutralization. Thus, a trial was carried out in 2021–2022 at Lovely Professional University's official field in Phagwara, Punjab, India, with the main objective of determining how effective integrated nutrient management is in terms of soil parameters, nutrient uptake, quality, and the financial aspects of lentil cultivation.

2. Materials and Methods

2.1. Experimental Site

The trial, which focused on soil science and agricultural chemistry, was carried out in the research area of the Lovely Professional University School of Agriculture during the rabi season of 2021–2022. The soil's textural analysis identified it as sandy clay loam. The soil's initial chemical examination revealed that the soil had an organic carbon content of 0.30%, 200 kg ha⁻¹ of available nitrogen, 26.77 kg ha⁻¹ of available phosphorus, and 109.76 kg ha⁻¹ of available potassium.

2.2. Description of the treatments

The experiment design used for the experiment was randomized block design (RBD) which consists of 8 treatments and 3 replications.

Table 1. Treatments used in an experiment

| Symbols | Treatments |
|--------------------------|---|
| T ₁ (Control) | 100 % RDF (20:40:20 kg ha ⁻¹) |
| T ₂ | 75% RDF(15:30:15) + Vermicompost (2.5 t ha ⁻¹) |
| T ₃ | 75% RDF(15:30:15) + FYM (5 t ha ⁻¹) |
| T ₄ | 75% RDF(15:30:15) + Rhizobium (7.5 kg ha ⁻¹) |
| T ₅ | 75% RDF(15:30:15) + Rhizobium (7.5 kg ha ⁻¹) + Vermicompost (2.5 t ha ⁻¹) |
| T ₆ | 75% RDF(15:30:15) + Rhizobium (7.5 kg ha ⁻¹) + FYM (5 t ha ⁻¹) |
| T ₇ | 75% RDF(15:30:15) + Rhizobium (7.5 kg ha ⁻¹) + Vermicompost (1.25 t ha ⁻¹) + FYM (2.5 t ha ⁻¹) |
| T ₈ | 50% RDF (10:20:10 kg ha ⁻¹) + Rhizobium (7.5 kg ha ⁻¹) + Vermicompost (2.5 t ha ⁻¹) + FYM (5 t ha ⁻¹) |

The size of plot for experimentation was 5m x 2m with a spacing of 10cm x 20cm. Urea was used to supply nitrogen, single super phosphate for potassium, and MOP for potassium. The application of FYM and vermicompost was done before sowing in a uniform way. The application of Rhizobium in soil was done by mixing it with molasses at the rate of 7.5 kg ha⁻¹. The variety Pant-639 was sowed on 29th November 2021. Lentil was grown in an irrigated environment and harvested on 4th April, 2022. Different soil and plant samples were collected at different stages of growth. The plant and seed samples were grounded and digested (3:1 ratio) in the di-acid mixture (HNO₃:HClO₃). The nitrogen test was done in Kjeldahl assembly (Jackson, 1973). The digested mixture was used for the test of phosphorus (Yellow colour method- Jackson, 1973) and potassium (Flame photometer method (Jackson, 1973)). The soil was tested for pH (Electronic glass electrode method (Jackson, 1967)), electrical conductivity (Electrical conductivity method (Jackson, 1968)), organic carbon (Rapid titration method, (Walkey and Black, 1934) available nitrogen (Alkaline Potassium Permanganate method, Subbaiah and Asija, 1956) available phosphorus (Olsen's method, Olsen et al. 1954) and available potassium (Flame photometer method, Merwin and Peech, 1950). The crude protein content in the plant was calculated by multiplying nitrogen by the factor 6.25. (A.O.A.C., 1960). The economics of the cultivation was calculated on each plot by calculating their cost of cultivation, net gain, net return and B:C ratio. The data analysis program SPSS (Statistical Package for Social Sciences) was used for data analysis.

RESULTS

The observations obtained from the experiment related to soil characteristics, plant nutrient characteristics and nutrient uptake throughout investigation were statistically studied and verified for significance. In a result, data or output from all the treatments and parameters are discussed elaborately with suitable tables, figures and graphs for better understanding.

Soil parameters

Soil pH

Figure 1 depicts the results for eight different treatments (T₁ to T₈) that show the pH values at three different times during the crop growth phase. Analyzing the pH values of the various treatments in comparison allows evaluation of the effects of different fertilizer management approaches on soil pH. It is found that there are very slight differences in pH across the treatments, usually varying by 0.1 units during the crop's growth. It seems improbable that these slight variations in pH will have a major impact on crop growth and total production. Notably, the pH readings show only small variations in pH for most of the treatments, ranging from 8.27 to 8.63. This uniformity suggests that the treatments used have a very consistent impact on the pH of the soil.

For most treatments, the pH levels don't change much during the course of the crop growth cycle. The efficacy of the treatments in preserving a stable soil pH during the crop growth phase is demonstrated by the low pH fluctuation between 60 and 90 DAS or at harvest. Notably, from 60 DAS to harvest, the pH values of various treatments (T₄, T₅, T₆, and T₈) show a modest increase.

All three phases of crop growth are shown to have constant pH levels in Treatment T₇, demonstrating the stability and balance that the particular mix of nutrients or management strategies achieves in preserving the pH of the soil. The fact that treatments T₂ and T₃ also retain constant pH levels throughout time suggests a consistent, long-lasting influence on soil pH management. Treatment T₁, on the other hand, exhibits a modest drop in pH values from 60 DAS until harvest, suggesting that the nutrients or active substances in T₁ may gradually acidify the soil. These findings confirm that the applied treatments successfully control the pH of the soil within a range that is ideal for lentil growth, highlighting the importance of proper pH management of the soil to optimize nutrient availability to the plants.

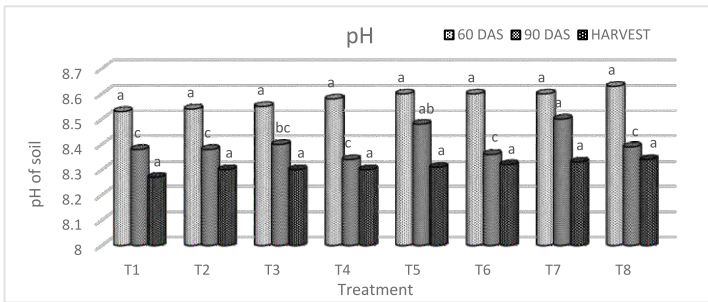


Figure 1. Effect of Integrated Nutrient Management on pH of soil at different stages

Electrical conductivity (mhos cm⁻¹)

Significant differences in the soil's electrical conductivity (EC) values between the different treatments are shown by the analysis. These treatments probably correspond to various methods of fertilizing the soil or managing nutrients. Treatment T₁ (0.339 mhos cm⁻¹) and Treatment T₂ (0.34) had the closest margins of error in terms of EC values at 60 DAS, with Treatment T₅ having the lowest value (0.32 mhos cm⁻¹). The EC values of treatments T₃, T₄, T₆, T₇, and T₈ were comparable, ranging from 0.325 to 0.336 mhos cm⁻¹. Treatment T₅ had the greatest EC value (0.358 mhos cm⁻¹) at 90 DAS, while Treatment T₇ had the lowest (0.316 mhos cm⁻¹). With a few small exceptions, the majority of other treatments had EC values that fell in between these extremes.

Treatment T₅ maintained the highest EC value (0.343 mhos cm⁻¹) at the time of harvest, while Treatment T₁ had the lowest value (0.317 mhos cm⁻¹). Compared to Treatments T₇, T₂, and T₄, which showed noticeably greater EC values, Treatments T₃, T₅, and T₈ showed lower EC values. Notably, during all three-time points, Treatments T₅ and T₇ continuously showed the highest and lowest EC values, respectively. Most treatments showed little variation in EC values over time, suggesting that the treatments had a fairly steady effect on soil electrical conductivity. Furthermore, over the course of the analysis, Treatment T₁ continuously showed lower EC values, whereas Treatments T₅ and T₂ constantly showed greater EC values.

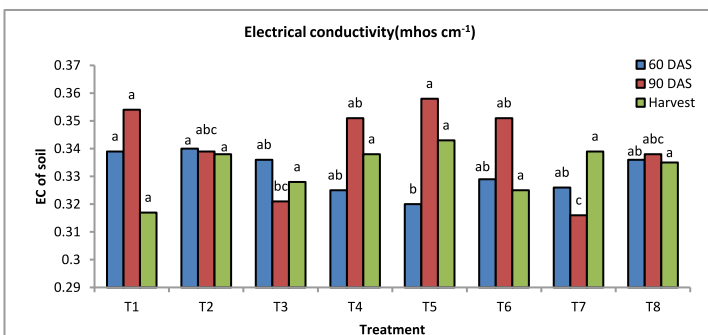


Figure 2. Effect of Integrated Nutrient Management on electrical conductivity of soil at different stages

Oxidizable Organic Carbon (OC)

The graph in Figure 3 data shows the variations in soil organic carbon (OC) content that resulted from the application of various fertilizers in comparison to the control treatment (T₁) at three different time points: 60 days after sowing (DAS), 90 DAS, and at harvest. At all three time intervals, there is an overall rise in soil OC content for all treatments (T₂ to T₈) compared to the control treatment (T₁). This shows that the application of fertilizers from various sources had a good impact on the soil's levels of organic carbon. Given that Treatment T₈ has the greatest OC concentration (0.57%), this fertilizer mix is responsible for the largest increase in soil organic carbon. The baseline without any extra fertilizers, T₁, has the lowest OC content (0.29%). While treatments T₄, T₅, T₆, and T₇ have intermediate values ranging from 0.39% to 0.51%, treatments T₂ and T₃ have substantially lower OC content (0.35% and 0.36%, respectively). Except the control treatment (T₁), most treatments see a decrease in OC content in soil as compared to 60 DAS. 90 DAS continues the pattern of increasing OC content in T₈ (0.46%) and lower OC content in T₁ (0.30%). While the readings for T₂ and T₃ remain almost the same at 0.37%, the OC content for T₄, T₅, T₆, and T₇ ranges from 0.39% to 0.52%. Similar to the trend shown at 60 DAS, there is a modest rise in soil OC content at harvest compared to 90 DAS. T₁ has the lowest OC concentration (0.32%), while treatment T₈ still has the highest (0.56%). T₂ and T₃ keep their OC content at 0.37%. The OC concentration in treatments T₄, T₅, T₆, and T₇ ranges from 0.39% to 0.50%.

The information shows that the application of various fertilizers raises the amount of soil organic carbon at each of the three growth stages. While T₁ represents the control with the lowest OC content, treatment T₈ consistently has the greatest OC content. The variations in OC content over time show how different fertilizers affect the dynamics of soil organic carbon.

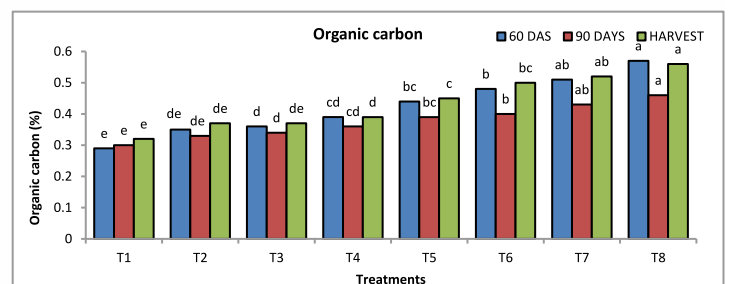


Figure 3. Effect of Integrated Nutrient Management on organic carbon of soil at different stages

Available Nitrogen, Phosphorus and Potassium

Table 2 provides information on soil nutrient availability (N, P, and K) for various treatments at three distinct growth stages: 60 days after sowing (DAS), 90 DAS, and at harvest. The levels of nutrients that are readily available shifted over time, from 60 DAS to 90 DAS, and then again after harvest. The majority of treatments often cause the nutrients to become less accessible between 60 and 90 DAS, then either slightly increase or stabilize at harvest.

The available N levels at 60 DAS were between 277.22 and 347.07 kg ha⁻¹. The maximum amount of accessible N belongs to treatment T₆, followed by treatments T₇ (330.70 kg ha⁻¹), T₅, and T₆ (312.15 kg ha⁻¹ and 323.81 kg ha⁻¹, respectively). All treatments revealed a modest reduction in available N at 90 DAS compared to 60 DAS, but the general trend held.

The maximum amount of accessible N is still in T₈ (333.69 kg ha⁻¹), followed by T₇ (317.70 kg ha⁻¹). The available N levels dropped even further from the 90 DAS stage through harvest, and treatment T₈ continued to have the highest available N while treatment T₁ had the lowest. T₅ and T₆ are the next highest in terms of available N at harvest (256.54 kg ha⁻¹ and 297.71 kg ha⁻¹, respectively), but T₈ retains the highest level (298.63 kg ha⁻¹). At each of the three-time intervals, the control therapy, T₁, consistently has the lowest N. At all growth stages, the available nitrogen levels in the soil varied significantly between treatments. At all three stages, treatment T₈ consistently had the highest nitrogen availability, whereas T₁ consistently had the lowest.

The amount of phosphorus that was readily available in the soil varied according to growth phases and treatment. There was no discernible difference between the treatments at 60 DAS, and T₈ displayed the highest available P while T₁ displayed the lowest. The maximum available P (42.75 kg ha⁻¹) is present in treatment T₈ at 60 DAS, followed by treatment T₇ (39.56 kg ha⁻¹). When compared to 60 DAS, available P decreased at 90 DAS, while treatment T₈ maintained to have the highest level. T₈ still has the greatest available P at 90 DAS and harvest (36.17 kg ha⁻¹ and 32.75 kg ha⁻¹, respectively). T₈ continued to have the highest levels of accessible P at harvest, while T₁ recorded the lowest

levels. At each of the three time intervals, the control treatment, T₁, consistently has the lowest P that is available.

Treatment T₁ had the most K readily available at 60 DAS (183.68 kg ha⁻¹), followed by T₂ (149.33 kg ha⁻¹). The available K content did not differ significantly across some treatments. T₈ had the maximum available K at 90 DAS and harvest (172.45 kg ha⁻¹ and 147.99 kg ha⁻¹, respectively). In contrast to previous treatments, T₇ and T₈ demonstrated increased available K at 90 DAS compared to 60 DAS. Available K levels dropped from the 90 DAS stage to harvest. However, statistical analysis failed to find any appreciable variations between the regimens. At each of the three-time points, the control therapy, T₁, has relatively more accessible K than the other treatments. Due to various treatments and growth stages, the soil's available potassium concentration varied.

While T₁ stands in for the control with substantially reduced nutritional availability, treatments T₇ and T₈ consistently demonstrate higher nutrient levels when compared to other treatments. The changes in nutrient levels over time show how different treatments have an impact on nutrient dynamics in the soil. The accuracy and crucial difference values shed light on the validity and importance of the variations in nutrient levels that have been detected.

Table 2. Effect of Integrated Nutrient Management on available Nitrogen, phosphorus and Potassium of soil at different stages

| Treatment | Available N in soil (kg ha ⁻¹) | | | Available P in soil (kg ha ⁻¹) | | | Available K in soil (kg ha ⁻¹) | | |
|----------------|--|----------|---------|--|----------|----------|--|------------|---------|
| | 60 DAS | 90 DAS | Harvest | 60 DAS | 90 DAS | Harvest | 60 DAS | 90 DAS | Harvest |
| T ₁ | 277.22f | 252.87e | 194.73d | 34.63a | 26.11c | 18.15c | 183.68a | 130.33d | 116.44a |
| T ₂ | 279.91ef | 268.79d | 206.0cd | 37.46a | 28.37bc | 19.74c | 149.33bc | 138.30cd | 122.75a |
| T ₃ | 295.06de | 276.72d | 216.70c | 38.43a | 29.06bc | 20.80bc | 160.53ab | 145.44bcd | 128.27a |
| T ₄ | 309.43cd | 283.13cd | 223.97c | 37.38a | 30.24bc | 21.07bc | 155.31ab | 143.06bcd | 131.43a |
| T ₅ | 312.15c | 291.78c | 241.38b | 35.80a | 30.69bc | 25.58abc | 162.03ab | 151.80abcd | 136.95a |
| T ₅ | 323.81bc | 297.71c | 256.54b | 35.77a | 31.25abc | 27.44ab | 164.27ab | 158.94abc | 138.52a |
| T ₇ | 330.70b | 317.70b | 284.71a | 39.56a | 33.36ab | 30.36a | 123.20c | 162.12ab | 143.26a |
| T ₈ | 347.07a | 333.69a | 298.63a | 42.75a | 36.17a | 32.75a | 121.71c | 172.45a | 147.99a |
| CD @ 5% | 15.04 | 13.97 | 11.97 | 8.21 | 4.89 | 10.08 | 30.08 | 6.68 | 7.42 |
| SE(m) | 4.98 | 4.62 | 3.96 | 2.72 | 1.62 | 3.33 | 10.20 | 2.21 | 2.46 |

Table 3. Effect of Integrated Nutrient Management on NPK content (straw and seed) and uptake in lentil at harvest

| Treatment | Nitrogen content in seed and straw (%) and uptake (kg ha ⁻¹) | | | | | Phosphorus content in seed and straw (%) and uptake (kg ha ⁻¹) | | | | | Potassium content in seed and straw (%) and uptake (kg ha ⁻¹) | | | | |
|----------------|--|----------------|------------|---------------|----------------|--|----------------|------------|---------------|----------------|---|----------------|------------|---------------|----------------|
| | Straw N (%) | Straw N uptake | Seed N (%) | Seed N uptake | Total N Uptake | Straw P (%) | Straw P uptake | Seed P (%) | Seed P uptake | Total P Uptake | Straw K (%) | Straw K uptake | Seed K (%) | Seed K uptake | Total K Uptake |
| T ₁ | 1.67d | 22.63g | 3.68d | 42.52f | 65.14f | 0.16e | 2.17f | 0.49c | 5.68d | 7.85e | 1.42d | 19.16e | 1.54d | 17.77f | 36.93f |
| T ₂ | 1.71d | 25.13f | 3.70d | 47.00e | 72.13e | 0.20d | 2.99e | 0.51c | 6.42c | 9.41de | 1.77c | 25.99d | 2.21c | 27.85e | 53.84e |
| T ₃ | 1.75cd | 25.75f | 3.73cd | 47.96e | 73.71e | 0.24c | 3.66d | 0.52c | 6.69c | 10.35cd | 1.76c | 25.84d | 2.18c | 28.25e | 54.09e |
| T ₄ | 1.81c | 27.63e | 3.75bcd | 51.52d | 79.15d | 0.25bc | 3.69d | 0.52c | 7.10bc | 10.79cd | 1.80c | 27.51d | 2.23c | 30.56d | 58.07de |
| T ₅ | 1.89b | 29.53d | 3.81bc | 53.60d | 83.13d | 0.27b | 4.16c | 0.54c | 7.58b | 11.73bc | 1.93bc | 30.12c | 2.25bc | 31.58d | 61.70cd |
| T ₆ | 1.93b | 31.76c | 3.83b | 56.89c | 88.65c | 0.28a | 4.54b | 0.56bc | 8.25b | 12.79b | 1.80c | 29.71c | 2.26bc | 33.58c | 63.29c |
| T ₇ | 2.04a | 36.73b | 3.92a | 63.84b | 100.57b | 0.28a | 5.03a | 0.64ab | 10.48a | 15.52a | 2.11ab | 38.04b | 2.33b | 37.92b | 75.96b |
| T ₈ | 2.08a | 38.93a | 3.98a | 67.51a | 106.44a | 0.28a | 5.19a | 0.67a | 11.39a | 16.68a | 2.21a | 41.09a | 2.43a | 41.17a | 82.26a |
| CD @ 5% | 0.071 | 1.25 | 0.089 | 2.23 | 2.54 | 0.022 | 0.18 | 0.091 | 0.94 | 1.52 | 0.191 | 2.03 | 0.095 | 1.98 | 3.87 |
| SE(m) | 0.023 | 0.43 | 0.029 | 0.73 | 0.84 | 0.007 | 0.063 | 0.030 | 0.33 | 0.50 | 0.063 | 0.67 | 0.031 | 0.65 | 1.20 |

Nitrogen content (seed and straw) and uptake in lentil-

When compared to the control treatment (T₁), the data shown in Table 3 show a considerable impact on the nitrogen content of both lentil straw and seed. Both the nitrogen content of lentil straw and lentil seed differed considerably between treatments. The treatment T₈ had the highest nitrogen content at harvest, with 2.08 percent in the straw and 3.9 percent in the seeds, closely followed by T₇ with 2.0 percent in the straw and 3.9 percent in the seeds. The lowest nitrogen content was found in straw (1.67%) and seed (3.68%) in the control treatment T₁. The nitrogen concentration in both straw and seed was moderate for treatments T₂, T₃, T₄, T₅, and T₆. At the time of harvest, treatment T₈ had the maximum nitrogen uptake by straw and seed, at 38.93 kg ha⁻¹ and 67.51 kg ha⁻¹, respectively. The lowest nitrogen uptake by straw (22.63 kg ha⁻¹) and seed (45.52 kg ha⁻¹) was seen in the control treatment T₁ at harvest. In comparison to the control treatment, straw and seed substantially more readily absorbed nitrogen from all other treatments.

In comparison to T₁, all other treatments had significantly higher total nitrogen uptake when both straw and seed were taken into account. The maximum total nitrogen uptake was shown by treatment T₈, at 106.44 kg ha⁻¹, followed by treatment T₇, at 100.57 kg ha⁻¹. The lowest total nitrogen intake was seen in treatments T₂ and T₃, albeit their values were not substantially different from one another. T₄, T₅, and T₆ treatments revealed an intermediate total nitrogen uptake.

The results demonstrate that treatments T₁ and T₂ had the lowest nitrogen content, while treatments T₈ and T₇ consistently had increased nitrogen content in both straw and seeds at the time of harvest. Similar to straw, seeds also showed a trend in their nitrogen content, with T₈ showing the highest nitrogen content and T₁ closely behind. On the other hand, seeds from T₁ and T₂ had the least nitrogen. The predicted nitrogen intake by seed and straw followed a similar pattern, with T₁ exhibiting the lowest nitrogen uptake for both, and T₈ having the greatest uptake values. Additionally, compared to the control treatment (T₁), all other treatments had significantly increased total nitrogen uptake, which takes both straw and seed into account.

The total nitrogen intake was highest in treatment T₈, while it was lowest in treatment T₁. These conclusions show that various treatments have a major impact on nitrogen dynamics in lentil straws and seeds. While T₁, the control treatment, reported the lowest nitrogen values, treatment T₈ proved to be the most successful in encouraging higher nitrogen content and uptake.

Phosphorus content (seed and straw) and uptake in lentil

The results (Table 3) showed that when different sources of nutrients were applied, the phosphorus content in lentil seed and straw increased significantly over control in all other treatments.

The data analysis shows that the control treatment (T₁) and other treatments had significantly different phosphorus contents. The highest phosphorus level in straw was specifically found in treatments T₅, T₇, and T₈, with all three treatments reaching 0.28%. The least amount of phosphorus was found in straw (0.16%) in T₁. The intermediate values for treatments T₂, T₃, T₄, and T₅ were 0.20%, 0.24%, 0.25%, and 0.27%, respectively. Notably, both treatments T₃ and T₄ had phosphorus contents of 0.25%. Treatments T₃ and T₄ both revealed 0.52% phosphorus concentration in seeds, while treatments T₂ and T₅ showed 0.51% and 0.54%, respectively. Treatments T₅ and T₇ seeds had phosphorus contents that were measured at 0.56% and 0.64%, respectively. The overall uptake of phosphorus for treatment T₂ was 9.41 kg ha⁻¹, but the total uptakes for treatments T₅, T₆, and T₇ were 11.73 kg ha⁻¹, 12.79 kg ha⁻¹, and 15.52 kg ha⁻¹, respectively.

Overall, the findings suggest that, in comparison to the control treatment (T₁), treatments T₅, T₇, and T₈ consistently had higher phosphorus content and uptake. This shows that both the phosphorus levels in straw and seeds were increased more effectively by these treatments. The results can boost crop productivity and nutrient usage in lentil farming and have significant ramifications for nutrient management systems.

Potassium content (seed and straw) and uptake in lentil

A comprehensive evaluation of the data (Table 3) demonstrated that different treatments had a substantial impact on potassium content in straw and seed compared to T₁ (control).

The results of the analysis show that the potassium content of the control treatment (T_1) and all other treatments differed significantly from one another. Straw from treatment T_8 had a potassium concentration of 2.21%, while straw from treatment T_1 had a potassium content of 1.42%. With values of 1.77%, 1.76%, and 1.80%, respectively, treatments T_2 , T_3 , and T_4 's potassium content did not differ significantly from one another. Similar results were seen for treatments T_5 , T_6 , and T_7 , which showed 1.93%, 1.80%, and 2.11%, respectively, of potassium in straw.

At the time of harvest, the potassium concentration of seeds followed a similar pattern to that of straw. T_1 had seeds with the least potassium concentration, 1.54%, and T_8 had the most, 2.43%. Potassium concentration in seeds did not significantly differ across treatments T_2 , T_3 , and T_4 , with values of 2.21%, 2.18%, and 2.23%, respectively. Similar potassium levels in seeds were found in treatments T_5 and T_6 , both measuring 2.25%. In seeds from treatment T_7 , there was 2.33% potassium.

In comparison to the control treatment (T_1), all treatments had significantly increased potassium total absorption, which takes into account both straw and seed. T_1 had the lowest total potassium uptake (36.93 kg ha^{-1}), while treatment T_8 had the greatest (82.26 kg ha^{-1}). Treatments T_2 and T_3 had potassium uptakes of 54.84 kg ha^{-1} and 54.09 kg ha^{-1} , respectively, with no discernible difference between them. The potassium uptakes for treatments T_4 and T_5 were also comparable, at 58.07 kg ha^{-1} and 61.70 kg ha^{-1} , respectively. Potassium was taken up by 63.29 kg ha^{-1} and 75.96 kg ha^{-1} , respectively, in treatments T_5 and T_7 . The data also demonstrated how seeds and straw absorbed potassium. With 8.0 kg ha^{-1} for straw and 55.98 kg ha^{-1} for seed, T_8 had the maximum uptake. With straw uptake at 2.35 kg ha^{-1} and seed uptake at 14.49 kg ha^{-1} , T_1 had the lowest uptake.

Overall, the findings show that, in comparison to the control treatment (T_1), treatments T_8 , T_7 , and T_5 had considerably greater potassium content and uptake. These findings emphasize how crucial it is to choose the best treatments to raise potassium levels in both straw and seeds, which will ultimately increase crop yields and nutrient management in the production of lentils.

Protein content in seed

Results (Figure 4) revealed that there was a significant difference in protein percent of lentil seed among the treatments as a source and the form of the nutrients differ. Treatment T_1 (23.02 %) recorded the lowest of protein content in lentil seed followed by T_2 (23.12 %). Treatment T_3 (23.33 %) and T_4 (23.46 %) have similar percentages of protein in the seed. Treatment T_5 and T_6 have protein content of 23.83 % and 23.94 %. Treatment T_7 (24.50 %) and T_8 (24.85 %) have no significant difference in the protein content although T_8 recorded the highest percentage of protein in seed.

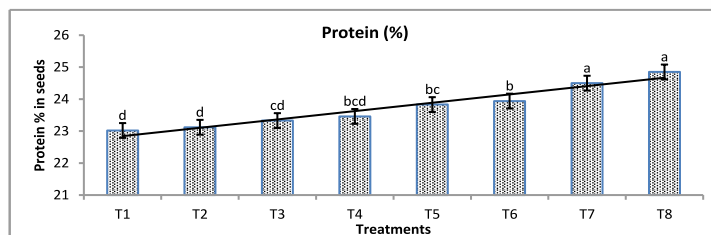


Figure 4. Effect of Integrated Nutrient Management on protein content in seed of Lentil

Economics

The overall cost of production and the total price paid for each treatment are revealed by analysing Table 4. The cost of cultivation for Treatment T_8 , which applied 50% NPK ($10:20:10 \text{ kg ha}^{-1}$) plus Rhizobium (7.5 kg ha^{-1}) plus 100% FYM @ 5 t ha^{-1} + 100% vermicompost (2.5 t ha^{-1}), was the highest at Rs. 66,930 per hectare. Treatment T_7 came in second at Rs. 62,145 per hectare, while treatment T_1 had the lowest cost at Rs. 46,360 per hectare. The cultivation costs for Treatments T_2 , T_3 , and T_6 were similar at Rs. 52,770, Rs. 53,520, and Rs. 50,050 per hectare, respectively. Similar production costs were also experienced by treatments T_4 and T_5 , which were Rs. 57,770 and Rs. 56,520 per acre, respectively.

For each treatment, the benefit-cost (B:C) ratio, a critical economic metric, was determined. The highest B:C ratio was seen in treatment T_4 at 1.96, while treatment T_8 had the lowest B:C ratio at 1.69. The B:C ratios for treatments T_1 and T_5 were 1.83 and 1.85, respectively. The B:C ratios for treatments T_2 , T_3 , and T_6 were also comparable, coming in at 1.71, 1.70, and 1.72, respectively. The B:C ratio for treatment T_7 , was 1.77.

The various nutrient management techniques used can be blamed for the variance in the B:C ratio between the various treatments. The lowest B:C ratio was achieved by applying 50% NPK ($10:20:10 \text{ kg ha}^{-1}$) + Rhizobium (7.5 kg ha^{-1}) + 100% FYM @ 5 t ha^{-1} + 100% vermicompost (2.5 t ha^{-1}). This was likely a result of the higher yield per hectare attained by using a lot of fertilizers and bulky manures like vermicompost and FYM. As a result of lower cultivation costs but possibly lower yields, treatments like 100% RDF, 75% RDF + Rhizobium, and 75% RDF + Rhizobium + FYM that used less fertilizer or bulky manure displayed greater B:C ratios. The application of such materials was the cause of the higher cultivation costs in treatments using bulky manure, while treatments using little to no bulky manure were responsible for the lower production costs.

Overall, the B:C ratio research points to treatments that can maximize both production and financial gains for lentil cultivation, including balanced nutrient management strategies, suitable fertilization, and proper use of bulky manure. These results offer insightful information that will help farmers and governments decide on nutrient management tactics to increase lentil yield and profitability.

Table 4. Effect of Integrated Nutrient Management on Economics of lentil

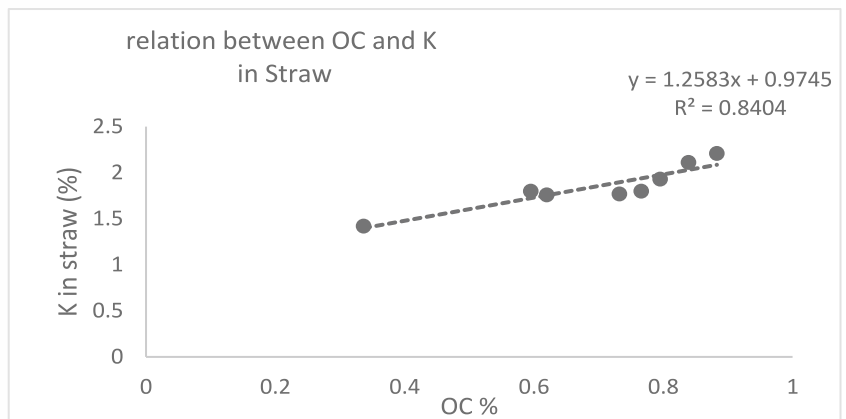
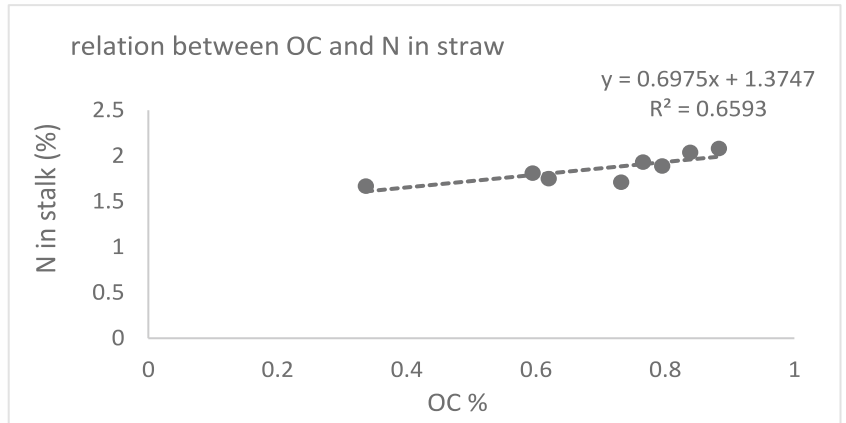
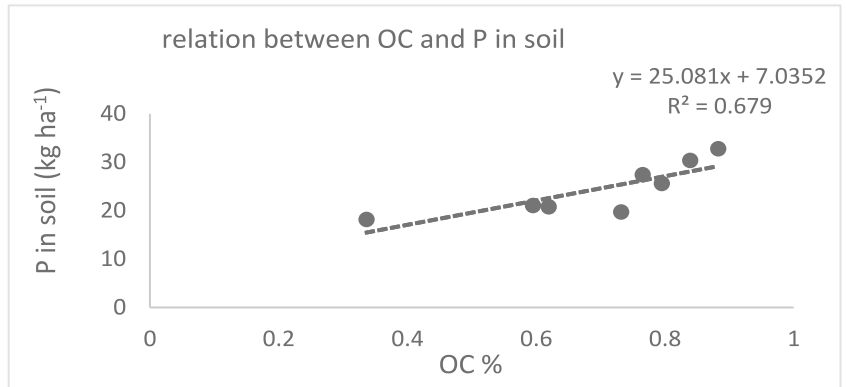
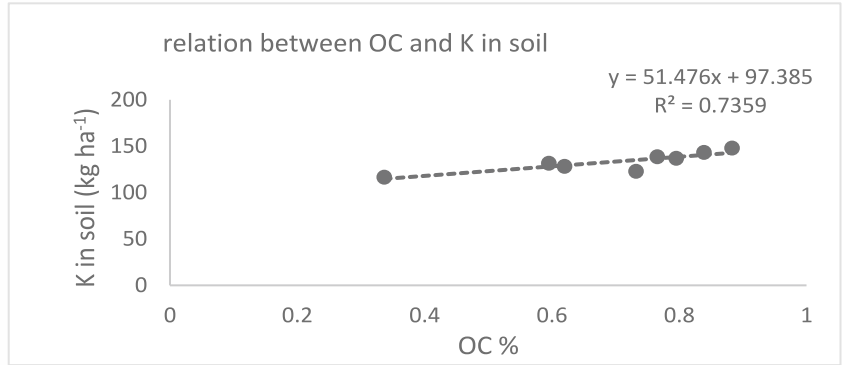
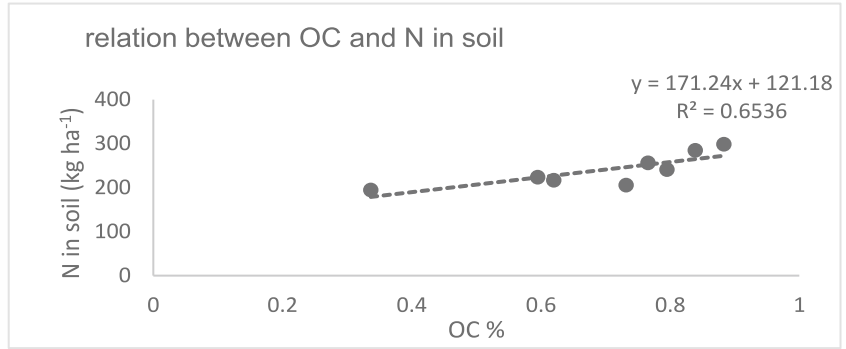
| Economics of lentil cultivation | | | | | | | | |
|---------------------------------|---------------------------|-----------------------|-----------------|------------------------------|------------|---------------------------|-----------------|-----------|
| Treatment | Cost of cultivation (Rs.) | Fertilizer price (Rs) | Total cost (Rs) | Yield (kg ha ⁻¹) | Price (Rs) | Total price received (Rs) | Total cost (Rs) | B:C ratio |
| T ₁ | 45000 | 1360 | 46360 | 1416.05 | 60 | 84963 | 46360 | 1.83 |
| T ₂ | 45000 | 7770 | 52770 | 1506 | 60 | 90360 | 54770 | 1.71 |
| T ₃ | 45000 | 8520 | 53520 | 1520.55 | 60 | 91233 | 53520 | 1.70 |
| T ₄ | 45000 | 5050 | 50050 | 1632.76 | 60 | 97965.6 | 49020 | 1.96 |
| T ₅ | 45000 | 12770 | 57770 | 1653.33 | 60 | 99199.8 | 57770 | 1.72 |
| T ₆ | 45000 | 11520 | 56520 | 1742 | 60 | 104520 | 56520 | 1.85 |
| T ₇ | 45000 | 17145 | 62145 | 1835.73 | 60 | 110143.8 | 57145 | 1.77 |
| T ₈ | 45000 | 21930 | 66930 | 1885.89 | 60 | 113153.4 | 64930 | 1.69 |

Table 5. Correlations among different soil and plant parameters

| | pH | EC | OC | N in soil | P in soil | K in soil | N in Straw | N in seed | Uptake of N | P in Straw | P in seed | Uptake of P | K in Straw | K in seed | Uptake of K |
|-------------|--------|-------|--------|-----------|-----------|-----------|------------|-----------|-------------|------------|-----------|-------------|------------|-----------|-------------|
| pH | 1 | | | | | | | | | | | | | | |
| EC | 0.076 | 1 | | | | | | | | | | | | | |
| OC | -0.297 | 0.674 | 1 | | | | | | | | | | | | |
| N in soil | -0.157 | 0.356 | .808* | 1 | | | | | | | | | | | |
| P in soil | -0.141 | 0.338 | .824* | .993** | 1 | | | | | | | | | | |
| K in soil | -0.216 | 0.467 | .858** | .969** | .964** | 1 | | | | | | | | | |
| N in Straw | -0.146 | 0.396 | .812* | .995** | .990** | .979** | 1 | | | | | | | | |
| N in seed | -0.077 | 0.356 | .791* | .996** | .990** | .959** | .990** | 1 | | | | | | | |
| Uptake of N | -0.166 | 0.402 | .821* | .996** | .983** | .967** | .991** | .992** | 1 | | | | | | |
| P in Straw | -0.385 | 0.507 | .834* | .839** | .835** | .940** | .867** | .808* | .834* | 1 | | | | | |
| P in seed | -0.064 | 0.327 | .758* | .974** | .956** | .902** | .951** | .980** | .976** | .718* | 1 | | | | |
| Uptake of P | -0.171 | 0.399 | .826* | .995** | .980** | .969** | .986** | .991** | .997** | .842** | .980** | 1 | | | |
| K in Straw | -0.099 | 0.670 | .917** | .907** | .890** | .928** | .905** | .908** | .925** | .836** | .900** | .935** | 1 | | |
| K in seed | -0.443 | .715* | .924** | .710* | 0.693 | .814* | .716* | 0.682 | .738* | .863** | 0.649 | .752* | .879** | 1 | |
| Uptake of K | -0.216 | 0.554 | .904** | .959** | .941** | .965** | .954** | .952** | .973** | .870** | .939** | .977** | .981** | .865** | 1 |

*. Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).



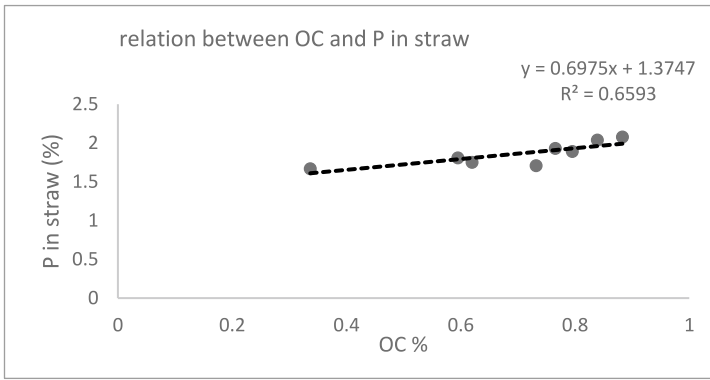


Figure 5. Graphical representation of relationship between organic carbon and N, P, K content in soil and stalk with regression equation

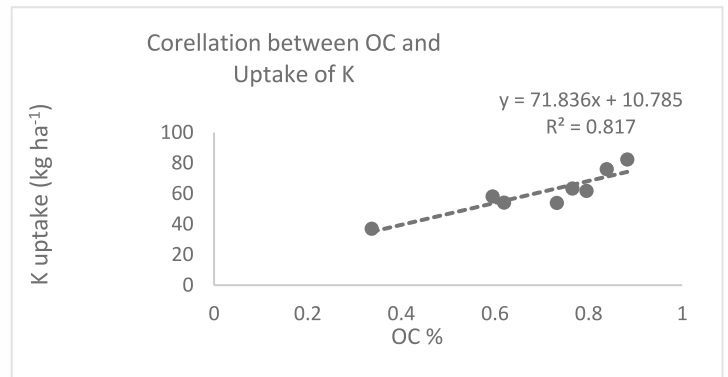
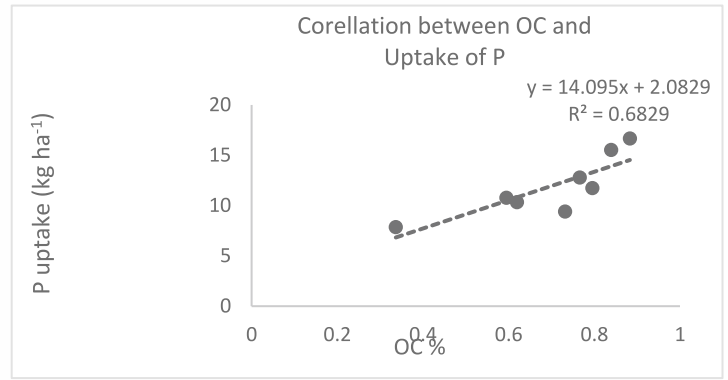
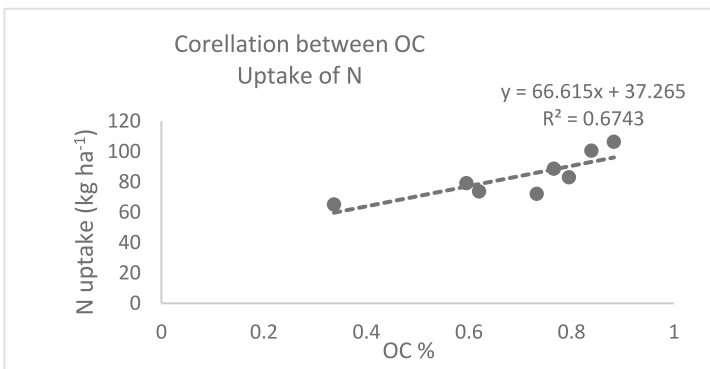
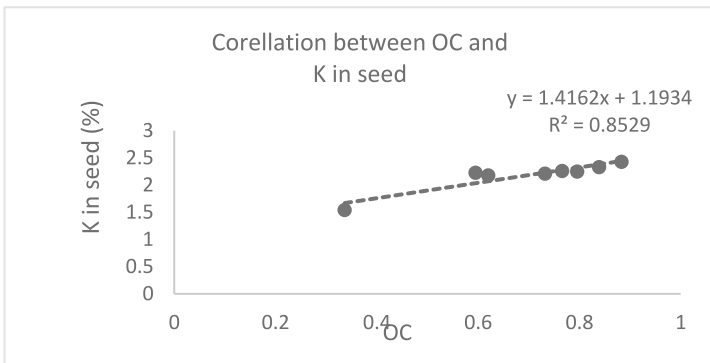
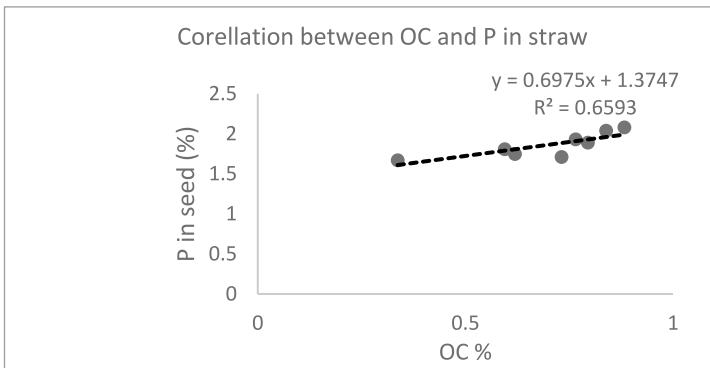
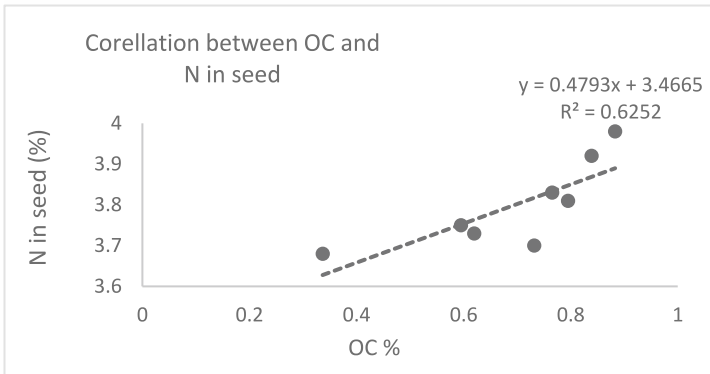


Figure 6. Graphical representation of the relationship between organic carbon and N, P, K content in seed and their uptake with the regression equation

Discussion

Soil pH and EC

According to the findings, there were no appreciable variations in the pH and EC levels between the four treatment groups. The use of organic manures and biofertilizers, whether alone or in conjunction with inorganic fertilizers, resulted in a little drop in soil pH across all treatments. This pH drop can be attributable to the acidifying impact brought on by urea and organic acids generated during the breakdown process of organic amendments. (Srikanth et al., 2000)

Available Organic carbon, Nitrogen, phosphorus and Potassium

The highest levels of organic carbon (0.56%), available nitrogen (298.63 kg ha⁻¹), available phosphorus (32.75 kg ha⁻¹) and available potassium (147.99 kg ha⁻¹) were achieved in the soil when 50% NPK (10:20:10 kg ha⁻¹), Rhizobium (7.5 kg ha⁻¹), 100% farmyard manure (FYM) at a rate of 5 tons per hectare, and 100% vermicompost at a rate of 2.5 tons per hectare were applied.

The addition of rhizobium, farmyard manure (FYM), and vermicompost has resulted in a significant increase in the soil's available nutrient reserve. Their beneficial effects on aiding in the mineralization of native nutrients have been linked to this phenomena. Notably, a notable increase in available nitrogen, available phosphorus, available potassium, and soil organic carbon has been noted following crop harvest. It is crucial to understand that although some nutrients are not directly used by plants, the excess nutrients help to improve the nutritional content of the soil as a whole (Netwal, 2003). Long-term sustainable agricultural productivity is fostered and soil fertility is elevated as a result of this methodical strategy.

According to Ghyanshyam et al. (2010), applying vermicompost/FYM, biofertilizer, and other nutrients at the same time produced the ideal conditions for microbial and

chemical activity, which improved nutrient availability and mineralization in the soil. Panda et al. (2012) and Chesti and Ali et al. (2012) came to similar outcomes in their studies on green gram. The combination of vermicompost, FYM, rhizobium, and recommended fertilizer dose (RDF) produced a treatment regimen that enhanced the nutritional content of the plants, especially nitrogen, phosphorus, and potassium, while also increasing the availability of soil nutrients. Moreover, the application of fertilizers such as vermicompost and farmyard manure has significantly enhanced nutrient accessibility, which in turn has promoted a favorable impact on the decomposition process of the soil's indigenous nutrient reservoir (Thenua et al., 2010).

In order to maintain soil health, a balanced soil fertility profile, and enhanced nutrient accessibility that results in increased soil fertility, the application of biofertilizers and organic manures is critical. These natural inputs show notable and long-lasting benefits with no negative side effects. Notably, through the process of biological nitrogen fixation, biofertilizers are essential to the fixation of atmospheric nitrogen. Furthermore, they support overall plant health by aiding in the solubilization of plant nutrients and the synthesis of chemicals that promote growth (Thenua et al., 2010).

Farmers can lessen their reliance on synthetic fertilizers, whose use may have negative environmental effects, by implementing biofertilizers and organic manures into agricultural methods. By gradually improving the soil's nutritional composition, these eco-friendly substitutes aid in the creation of improved and sustainable agricultural systems. In addition to promoting the soil's long-term productivity, using biofertilizers and organic manures guarantees that the soil's fertility will be maintained for upcoming generations.

Growth in nodule masses in both fresh and dry weights has been linked to the use of fertilizers and bio-inoculants, which may help to improve soil fertility. The observed enhancement can be ascribed to the actions of particular microorganisms implicated in the transformation of nutrients, specifically in the solubilisation of native phosphorus in the soil via the release of organic acids. Moreover, these microbes have a positive effect on potassium availability by lowering fixation losses and reducing leaching losses brought on by organic acids (Singh et al., 2012).

The application of organic manure, rhizobium, and a moderate amount of the recommended fertilizer dose (RDF) together has a good effect on soil nutrient availability, including organic carbon, nitrogen, phosphorus, and potassium. Together, these substances encourage root formation, growth, and nodulation, hastening the nitrogen fixation process. Additionally, the release of native phosphorus from the soil solution in lentil crops promotes early root growth and nodule development in the plant roots, further enhancing the symbiotic nitrogen fixation process. The symbiotic connection that exists between the microorganisms in the soil and the plant is essential for improving crop health and nutrient uptake, which in turn increases agricultural output and sustainability (Khandelwal et al., 2012; Kumari et al., 2012).

It has been demonstrated that rhizobium culture, suggested fertilizer dosages, and organic sources improve lentil plant nodulation, leghemoglobin concentration in root nodules, soil nitrogen availability, and dry matter production (Arya et al., 2007). Notably, it has been discovered that rhizobium increases the availability of both soil nitrogen and phosphorus due to its ability to solubilize phosphorus and fix nitrogen symbiotically. These results are consistent with earlier studies done by Singh and Pareek (2003).

Nutrient Content in seeds and straw and uptake by plant

The combination of fertilizers and the previously described manures produced the ideal soil conditions for chemical and microbiological processes. By supporting nutrient mineralization and increasing the amount of nutrients that are readily available to plants, this promoted enhanced nutrient absorption (Singh and Chauhan, 2004). Significant improvements in nodulation, increased leghemoglobin content in root nodules, increased nitrogen uptake, available soil nitrogen content, and increased dry matter production in lentil crops were observed when recommended doses of fertilizers, vermicompost, farmyard manure (FYM), and rhizobium culture were applied (Sharma and Sharma, 2004).

In agreement with the research conducted by Kumawat et al. (2010) and Khandelwal et al. (2012), the increased content and absorption of nitrogen, phosphorus, and potassium in lentil seeds and straw, as well as the higher content of seed protein, can be attributed to the plants' improved nitrogen fixation process and increased nutrient utilization (Khanna et al., 2006). The increased uptake of phosphate, potassium, and nitrogen can be ascribed to the effect that nutritional content and biomass output have on absorption of nutrients. Both of these variables were positively impacted by the application of vermicompost and FYM, which increased nutrient accumulation. Moreover, the higher phosphorus and nitrogen content and absorption in seeds and straw were probably because of the higher nitrogen and phosphorus level that stimulated plant uptake (Singh and Pareek, 2003). The increased availability of nitrogen can be linked to the higher protein content in seeds, as suggested by the work of Mathur (2000) and Rajkhowa et al. (2003).

Overall, the combined utilization of organic manures, biofertilizers such as rhizobium, and the appropriate doses of fertilizers collaboratively contribute to enhancing soil fertility, promoting plant nutrient uptake, and ultimately augmenting crop yield.

Protein content

The results of this study show that the protein concentration was greatly increased by applying a combination of 50% NPK (10:20:10 kg ha⁻¹), Rhizobium (7.5 kg ha⁻¹), 100% farmyard manure (FYM) at a rate of 2.5 tons per hectare, and 100% vermicompost at a rate of 2.5 tons per hectare. The higher protein concentration is thought to be caused by the seeds' higher nitrogen content, which is probably related to the plants' better ability to access nitrogen. Increased nutrient translocation to the crop's reproductive segments has been made possible by the improvement in metabolic processes, leading to higher nutrient content in the crop's straw and seeds (Yadav, 2001).

Notably, the higher nitrogen intake linked to the vermicompost/FYM treatment has affected the protein content, which is consistent with the results of Meena (2005) and Gupta et al. (2009). Protein metabolism is largely dependent on nitrogen, and the higher nitrogen concentration in the seeds that results from increased nitrogen availability to the plants and accelerated metabolic activities is closely linked to the observed increase in protein content in treatments that include inorganic, biofertilizer, and organic manures. Increased nutrient translocation to the crop's reproductive components accounts for the higher nutrient levels found in the straw and seeds.

Economics

With a score of 1.96, the treatment designated as T4, which applied 75% of the prescribed dose of fertilizer (RDF) in

conjunction with vermicompost, showed the most advantageous benefit-to-cost (B:C) ratio. Treatment T8, on the other hand, which had the highest production cost, produced the lowest B:C ratio. Treatment T8's higher production costs can be ascribed to the use of large amounts of organic manures, specifically farmyard manure (FYM) and vermicompost. The costs incurred in the application and acquisition of these organic inputs may have contributed to this cost increase.

The decline in the B:C ratio within treatment T8 can be attributed to the marginal increase in grain yield compared to the associated production costs. This minimal increase in the grain yield, when juxtaposed with the elevated cost of production, contributed to the reduction in the overall benefit-to-cost ratio.

Conclusion

The application of 50% NPK (10:20:10 kg ha⁻¹) along with Rhizobium (7.5 kg ha⁻¹) and 100% farmyard manure (FYM) at a rate of 5 tons per hectare and 100% vermicompost at a rate of 2.5 tons per hectare should be prioritized over other treatments, according to the study's findings. Research on the availability of organic carbon, nitrogen, phosphorus, and potassium as well as soil pH and electrical conductivity (EC) levels demonstrates the significant benefits of integrating organic manures, biofertilizers, and inorganic fertilizers for soil fertility and nutrient accessibility.

The nutritional content of the soil, nodulation, leghemoglobin content, and general crop health have all improved with the application of the prescribed dosages of fertilizers, vermicompost, farmyard manure, and rhizobium culture. When these organic inputs are applied in conjunction with biofertilizers, the soil experiences increased nitrogen fixation, enhanced nutrient mineralization, and solubilization of native phosphorus. As a consequence of the plants' increased ability to absorb nutrients, the protein content of their seeds has significantly increased.

It is important to stress that using biofertilizers, organic manures, and the appropriate amounts of fertilizers helps to promote sustainable and ecologically friendly farming methods. By lowering reliance on synthetic fertilizers, these techniques protect soil health, increase soil fertility, and raise agricultural productivity over the long run. Though the increase in grain yield compared to the production costs was relatively modest, treatments involving excessive amounts of bulky organic manures, like FYM, resulted in lower benefit-to-cost ratios (B:C ratios) and higher production costs. Therefore, it is important to take the financial implications into account.

Overall, the results of this study underscore the significance of implementing a well-balanced combination of organic and inorganic inputs to support soil health, nutrient availability, and crop yield. These environmentally friendly farming practices not only benefit farmers economically but also contribute to the preservation of soil fertility and the environment for future generations.

Data Availability

The data that support this study are available in the article.

Disclosure statement

The authors declare no conflicts of interest.

Declaration of Funding

This research did not receive any specific funding.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by BimeshDahal, AnimeshGhosh Bag and Sabina Raut. The first draft of the manuscript was written by BimeshDahal and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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