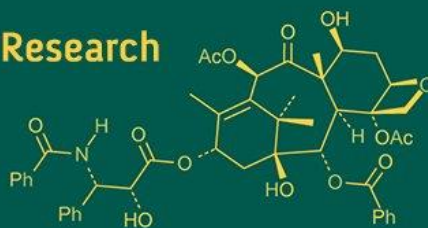


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Economic analysis and soil parameters of chia (*Salvia hispanica* L.) as influenced by nutrient management under Shisham based agroforestry system in Chhattisgarh plains

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Abstract

The experiment was carried out conducted during the rabi seasons of 2023-24 and 2024-25 at the Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh. The experiment was laid out in a Randomized Block Design (RBD) with 8 treatments and 3 replications. The treatments included various combinations of NPK fertilizers and organic manures (FYM) to (T₁) NPK 30:20:25 kg ha⁻¹, (T₂) NPK 60:40:50 kg ha⁻¹, (T₃) NPK 90:60:75 kg ha⁻¹, (T₄) NPK 120:80:100 kg ha⁻¹, (T₅) NPK 30:20:25 kg ha⁻¹ + 5 t fym ha⁻¹, (T₆) NPK 60:40:50 kg ha⁻¹ + 5 t fym ha⁻¹, (T₇) NPK 90:60:75 kg ha⁻¹ + 5 t fym ha⁻¹ and (T₈) 10 t fym ha⁻¹ evaluate the effects of integrated and sole nutrient applications on chia performance under partial tree shade. The results revealed that nutrient management significantly influenced the growth, yield, and economic returns of chia. Among all treatments, NPK 90:60:75 kg ha⁻¹ (T₃) recorded seed yield (645.20 kg ha⁻¹), and economic return (₹2,38,221 ha⁻¹ net return with a B:C ratio of 3.80). Initial soil organic carbon was 0.42%, increasing to 0.46-0.53% across treatments, with the highest improvement under NPK 90:60:75 kg ha⁻¹ + 5 t FYM ha⁻¹ (T₇). Available nitrogen improved from 176.21 kg ha⁻¹ to a maximum of 196.42 kg ha⁻¹ under the same treatment. Phosphorus and potassium also increased, especially under integrated management (T₅ to T₇). Soil pH remained nearly stable (6.35-6.65), while EC ranged between 0.25-0.35 dS/m. Integrated application (T₇: NPK 90:60:75 kg ha⁻¹ + 5 t FYM ha⁻¹) also produced competitive results while improving soil organic carbon and supporting Shisham tree growth.

Keywords: Chia crop (*Salvia hispanica*), agroforestry system, economic analysis, soil fertility

Introduction

The word "chia" is derived from the term *chian*, which means oily. *Salvia hispanica*, one of the two plants commonly referred to as "chia," is native to Mexico and Guatemala, belonging to the Lamiaceae family (Ixtaina *et al.*, 2008) [4]. The plant is seasonal that can grow up to 1.5 meters tall, with its main edible part being the seed. Chia is a short-day flowering plant that thrives in light to medium clay or sandy loam soils. The high concentration of omega-3 fatty acids is linked to a reduced risk of coronary artery disease, type 2 diabetes, hypertension, rheumatoid arthritis, autoimmune disorders, and cancer. Similarly, noted that chia seeds, rich in omega-3 fatty acids, were traditionally used for medicinal purposes, such as treating boils and relieving knee and foot pain. The cultivation of *Chia* (*Salvia hispanica* L.) under an *Dalbergia sissoo* (Indian Rosewood) agroforestry system presents a promising opportunity for sustainable farming. *Dalbergia sissoo* is a nitrogen-fixing tree species that improves soil fertility, provides partial shade, and enhances moisture retention, creating a favourable microclimate for chia growth.

Agroforestry is any sustainable land-use system that uses management techniques that are appropriate for the local population social and cultural traits as well as the economic and ecological conditions of the area to maintain or increase total yields by combining food crops (annuals), tree crops (perennials), and/or livestock on the same unit of land, either alternately or simultaneously. Agroforestry is defined as "a dynamic, ecologically based, natural resources management system that diversifies and sustains production for increased social, economic, and environmental benefits for land users at all levels through the integration of trees on farms and in the agricultural landscape."

Material and Methods

The experiment was carried out conducted during the rabi seasons of 2023-24 and 2024-25 at the Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya (IGKV), Raipur, Chhattisgarh. The experiment was laid out in a Randomized Block Design (RBD) with 8 treatments and 3 replications. The treatments included various combinations of NPK fertilizers and organic manures (FYM) to (T₁) NPK 30:20:25 kg ha⁻¹, (T₂) NPK 60:40:50 kg ha⁻¹, (T₃) NPK 90:60:75 kg ha⁻¹, (T₄) NPK 120:80:100 kg ha⁻¹, (T₅) NPK 30:20:25 kg ha⁻¹ + 5 t fym ha⁻¹, (T₆) NPK 60:40:50 kg ha⁻¹ + 5 t fym ha⁻¹, (T₇) NPK 90:60:75 kg ha⁻¹ + 5 t fym ha⁻¹ and (T₈) 10 t fym ha⁻¹ evaluate the effects of integrated and sole nutrient applications on chia performance under partial tree shade. The economics of the experiment was calculated based on the prevailing market prices during the period of experimentation. This included assessing the cost of cultivation, gross returns, net returns, and benefit-cost ratio for each treatment to determine the overall profitability of the agroforestry system.

1. Cost of cultivation (Rs ha⁻¹)

The cost of cultivation was calculated by considering various input costs such as seeds, manure, fertilizers, and labour charges for all field operations. The cost was worked out treatment-wise and expressed in rupees per hectare (₹ ha⁻¹). Detailed breakdowns of these costs are provided in Appendix I for reference.

2. Gross returns (Rs ha⁻¹)

The gross monetary returns were calculated by multiplying the grain yield with the prevailing market price of chia seeds and expressed in rupees per hectare (₹ ha⁻¹).

3. Net returns (Rs ha⁻¹)

The net returns per hectare were calculated by deducting the total cost of cultivation from the gross returns and expressed in rupees per hectare (₹ ha⁻¹).

Net returns (Rs. ha⁻¹) = Gross returns (Rs. ha⁻¹) - Total cost of cultivation (Rs. ha⁻¹)

4. Benefit cost ratio

The Benefit-Cost (B:C) ratio was calculated using the following formula:

This ratio helps in evaluating the profitability of the experiment by comparing the benefits (returns) obtained per unit cost invested. A B:C ratio greater than 1 indicates a profitable outcome.

$$\text{Benefit cost ratio} = \frac{\text{Gross return (ha}^{-1}\text{)}}{\text{Total cost of cultivation (ha}^{-1}\text{)}}$$

Soil Parameter

A composite soil sample was collected from the experimental plot both before sowing and after harvest from each plot at a depth of 0-30 cm. The collected soil samples were shade-dried, powdered using a pestle and mortar, and passed through a 2 mm sieve. These processed samples were then used for the estimation of soil pH, available nitrogen, phosphorus, and potassium.

1. Soil pH

The pH of the soil-water suspension (1:2.5 ratio) was determined using the potentiometric method. A pH meter fitted with a combined glass electrode was used for the measurement, following the procedure described by Jackson (1973) [5].

2. Available nitrogen (kg ha⁻¹)

The available nitrogen content of the soil was estimated using the alkaline potassium permanganate method. In this process, mineralizable nitrogen compounds are oxidized with hot alkaline KMnO₄ solution in the presence of NaOH. The ammonia (NH₄) released during oxidation was distilled and trapped in a boric acid solution containing a mixed indicator. The trapped ammonia was then quantified by titration against a standard sulphuric acid solution, following the procedure described by Subbaiah and Asija (1956) [12].

3. Available phosphorus (kg ha⁻¹)

The available phosphorus content in the soil samples was determined using Olsen's method. The soil samples were extracted with Olsen's extractant containing 0.5M NaHCO₃ (pH 8.5) for 30 minutes and then filtered. In the filtrate, a phosphomolybdate blue colour was developed by adding ammonium molybdate, antimony-potassium-tartrate, and ascorbic acid in an H₂SO₄ system. The intensity of the blue colour developed was measured at a wavelength of 660 nm using a spectrophotometer, following the procedure described by Jackson (1973) [5].

4. Available potassium (kg ha⁻¹)

Available potassium in the soil samples was determined using neutral normal ammonium acetate (NH₄OAc) at a 1:5 soil-to-extractant ratio. The soil was extracted with NH₄OAc, and the concentration of potassium in the extract was measured using flame photometry, following the procedure described by Jackson (1973) [5].

Statistical analysis

The data for all measured parameters of chia were meticulously collected, systematically tabulated, and computed before being statistically analyzed using a Word-Excel spreadsheet following a randomized block design.



Plate 1: Weighing of seed yield

Result and discussion

Crop Economics Analysis

The economics of chia cultivation as influenced by nutrient management showed significant variation across treatments. The cost of cultivation ranged from Rs. 76,530/ha (T_1) to Rs. 77,605.00/ha (T_8), with the lowest cost observed under minimal input conditions and the highest in organic-based treatments. The gross return was highest under T_3 (Rs. 3,22,600 ha^{-1}), which also had the highest seed yield of 645.2 $kg\ ha^{-1}$, demonstrating the strong effect of balanced nutrient application on productivity. In contrast, T_8 , despite incurring the highest cultivation cost, produced the lowest gross return (Rs. 2,22,150 ha^{-1}) and seed yield (444.3 $kg\ ha^{-1}$), indicating suboptimal nutrient use efficiency under this treatment.

The net return followed a similar trend, with T_3 yielding the highest net profit of Rs. 2,38,221 ha^{-1} , followed by T_7 (Rs. 2,06,221 ha^{-1}) and T_4 (Rs. 2,05,717 ha^{-1}). This highlights the importance of integrated nutrient management in maximizing returns. The most favourable benefit: cost (B:C) ratio was observed in T_3 (3.8), reflecting the best economic performance, while T_6 showed the lowest B:C ratio of (3.4), indicating poor economic viability. Treatments T_4 and T_7 also showed moderate profitability B:C ratio of (3.3), suggesting that even moderate levels of input can yield satisfactory returns. Overall, the findings emphasize that optimum nutrient management, particularly in T_3 , significantly enhances both productivity and profitability in chia cultivation.

Table 1: Chia Economics as influenced by nutrient management practices

Treatments	Cost of Cultivation (Rs. ha^{-1})	Seed yield ($kg\ ha^{-1}$)	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Benefit: Cost ratio
T_1	76,530	462.3	2,31,150	1,54,620	3.0
T_2	80,686	487.0	2,43,500	1,62,814	3.0
T_3	84,379	645.2	3,22,600	2,38,221	3.8
T_4	88,308	588.05	2,94,025	2,05,717	3.3
T_5	79,030	519.8	2,59,900	1,80,870	3.2
T_6	83,186	575.2	2,87,600	2,04,414	3.4
T_7	86,879	586.2	2,93,100	2,06,221	3.3
T_8	77,605	444.3	2,22,150	1,44,545	2.8

Soil Parameters

Soil chemical properties recorded before and after harvest of chia crop as influenced by different nutrient management treatments.

Soil pH

The soil pH after harvest of chia crop was not significantly affected by different nutrient management treatments. Initial soil pH across treatments was uniform at 6.5, while post-harvest soil pH ranged from 6.3 to 6.5.

Table 2: Soil parameters as influenced by nutrient management practices

Treatments	Soil Parameters				
	Soil pH (initial)	Soil pH (after harvest)	Available N ($kg\ ha^{-1}$) (after harvest)	Available P_2O_5 ($kg\ ha^{-1}$) (after harvest)	Available K_2O ($kg\ ha^{-1}$) (after harvest)
T_1 NPK 30:20:25 $kg\ ha^{-1}$	6.5	6.4	265	22.7	296
T_2 NPK 60:40:50 $kg\ ha^{-1}$	6.5	6.4	263	23.0	297
T_3 NPK 90:60:75 $kg\ ha^{-1}$	6.5	6.3	264	23.3	298.5
T_4 NPK 120:80:100 $kg\ ha^{-1}$	6.5	6.4	266	24.0	301.5
T_5 NPK 30:20:25 $kg\ ha^{-1}$ + 5 t fym ha^{-1}	6.5	6.5	275	22.5	298.75
T_6 NPK 60:40:50 $kg\ ha^{-1}$ + 5 t fym ha^{-1}	6.5	6.5	278	22.9	298.79
T_7 NPK 90:60:75 $kg\ ha^{-1}$ + 5 t fym ha^{-1}	6.5	6.4	279	23.2	299.2
T_8 10 t fym ha^{-1}	6.5	6.5	265	21.5	295.0
SEm $\pm$	0.001	0.025	2.383	0.255	0.720
CD @ (P=0.05)	0.002	0.059	5.635	0.602	1.702

Initial soil available nutrients: Nitrogen - 270 kg/ha , Phosphorus - 22 kg/ha , Potassium - 300 kg/ha . Minor depletion observed after cropping depending on nutrient management treatments.

Slight reductions were observed in treatments with higher chemical fertilizer application. The highest post-harvest pH (6.5) was recorded in T_5 (NPK 30:20:25 $kg\ ha^{-1}$ + 5 t FYM ha^{-1}), T_6 , and T_8 (10 t FYM ha^{-1}), indicating that FYM application helped maintain or buffer soil pH. The lowest pH (6.3) was found in T_3 (NPK 90:60:75 $kg\ ha^{-1}$), suggesting minor acidification due to higher chemical inputs. However, overall changes were minimal, and differences remained statistically non-significant.

Available Nitrogen ($kg\ ha^{-1}$)

Post-harvest soil nitrogen content showed limited variation among treatments and was not significantly influenced by

nutrient management practices. The available nitrogen ranged from 263 $kg\ ha^{-1}$ (T_2) to 279 $kg\ ha^{-1}$ (T_7). The highest nitrogen was observed in T_7 NPK 90:60:75 $kg\ ha^{-1}$ + 5 t fym ha^{-1}), highlighting the contribution of organic manure in maintaining soil fertility. On the other hand, lower available nitrogen was recorded in treatments with higher chemical fertilizer inputs such as T_2 (263 $kg\ ha^{-1}$) and T_3 (264 $kg\ ha^{-1}$). This suggests a possible increase in nitrogen uptake by chia plants or leaching losses under higher NPK application. Organic supplementation helped maintain nitrogen status more effectively.

Available Phosphorus (P_2O_5) ($kg\ ha^{-1}$)

The available phosphorus in soil after harvest showed slight variations, ranging from 21.5 to 24.0 $kg\ ha^{-1}$, though not statistically significant. T_4 recorded the highest phosphorus availability (24.0 $kg\ ha^{-1}$), followed by T_7 (23.2 $kg\ ha^{-1}$),

while the lowest was observed in T₈ (21.5 kg ha⁻¹). The results indicate that organic manure application contributed to better phosphorus retention in soil compared to sole chemical fertilizer use, where depletion was more evident.

Available Potassium (K₂O) (kg ha⁻¹)

Available potassium levels after harvest varied from 295 kg ha⁻¹ to 301.5 kg ha⁻¹. Although the variation was not statistically significant, treatments with FYM showed relatively higher potassium availability. T₄ again topped with 301.5 kg ha⁻¹, while T₇ (299.2 kg ha⁻¹) and T₅ (298.79 kg ha⁻¹) also maintained good potassium levels. The lowest value in T₃ (275 kg ha⁻¹) may be attributed to higher crop uptake and lesser replenishment. Overall, the results highlight that integrated nutrient management involving FYM helps maintain potassium reserves in the soil.

Conclusion

Economic evaluation supported the agronomic findings. T₃ resulted in the highest gross return (₹3,22,600 ha⁻¹), net return (₹2,38,221 ha⁻¹), and B:C ratio (3.80). T₄ and T₇ also performed well economically, affirming that balanced fertilization is not only agronomically effective but also economically viable. Integrated nutrient management (especially T₇) emerged as a sustainable alternative that balances productivity with long-term soil health.

Soil nutrient status improved under most treatments, particularly where FYM was integrated. Initial soil organic carbon was 0.42%, increasing to 0.46-0.53% across treatments, with the highest improvement under NPK 90:60:75 kg ha⁻¹ + 5 t FYM ha⁻¹ (T₇). Available nitrogen improved from 176.21 kg ha⁻¹ to a maximum of 196.42 kg ha⁻¹ under the same treatment. Phosphorus and potassium also increased, especially under integrated management (T₅ to T₇). Soil pH remained nearly stable (6.35-6.65), while EC ranged between 0.25-0.35 dS/m. These results confirm that integrated nutrient management not only enhances crop growth but also contributes to long-term soil fertility improvement.

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