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Economic analysis and chemical analysis of Mentha (*Mentha arvensis* L.) cultivation as influenced by integrated nutrient management under Karanj (*Pongamia pinnata*) based agroforestry system

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Abstract
The experiment was carried out at Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.) during the rabi seasons of 2023-24 and 2024-25. The suitable experimental design was laid out on Randomize Block Design (RBD), where in 8 Treatments and 3 Replications were carried out on the field, Treatments included combinations of recommended doses of nutrients (RDN), farmyard manure (FYM), and vermicompost to compare the impact of integrated and sole nutrient applications. The treatments were divided into fertilization application of T_1 (100% RDN (150: 60: 60 N: P_2O_5: K_2O kg ha^{-1}), T_2 75% RDN, T_3 50% RDN, T_4 75% RDN + 5 t fym ha^{-1}, T_5 50% RDN + 10 t fym ha^{-1}, T_6 75% RDN + 1 t Vermicompost ha^{-1}, T_7 50% RDN + 2 t Vermicompost ha^{-1} and T_8 Control. Mentha's vegetative growth and yield attributes, with T_6 (75% RDN + 1 t vermicompost ha^{-1}), T_5 (50% RDN + 10 t FYM ha^{-1}), and T_7 (50% RDN + 2 t vermicompost ha^{-1}) performing the best in terms of fresh herbage yield (up to 419.4 q ha^{-1}) and oil yield (up to 286.5 kg ha^{-1}). Treatment T_6 (75% RDN + 1 t vermicompost ha^{-1}) recorded the highest net return (1,73,604 Rs ha^{-1}) and benefit: cost ratio (2:0), followed closely by T_1, T_7 and T_5. Although T_1 (100% RDN) had a high gross return, its cost of cultivation was also higher, reducing overall profitability.

Keywords: Mentha (*Mentha arvensis*), economic analysis, Karanj (*Pongamia pinnata*), agroforestry system

Introduction
Mentha arvensis L., commonly known as Japanese mint or corn mint, belongs to the Lamiaceae family and is a perennial herb. It has a dark green, quadrangular stem reaching a height of 60-90 cm, with opposite leaves at each node. This species is widely cultivated globally due to its high menthol content (Liu and Lawrence, 2007) [3]. The cultivation of *Mentha arvensis* started in Japan around 1870, earning it the name Japanese mint, before spreading to Brazil, China, Taiwan, and other countries. In 1952, the CSIR-Drug Research Laboratory (DRL), Jammu, introduced in India from Japan under the United Nations Educational, Scientific, and Cultural Organization (UNESCO) initiative. In India, mint cultivation spans approximately 0.30 million hectares, yielding an annual production of 30,000 metric tons of essential oil with an average productivity of 120 kg ha^{-1} during 2014-15. Commercial cultivation primarily occurs as a spring season crop (January-February to April-May) in the Tarai and central regions of Uttar Pradesh, as well as in Uttarakhand, Punjab, Bihar, and Haryana (Upadhyay *et al.*, 2012) [6].

Hydro-distillation of menthol mint produces essential oil containing 70-80% menthol, which is widely used in pharmaceutical, food, and cosmetic industries. Additionally, mint oil serves as an eco-friendly insecticide. India, alongside China and the USA, is a major global producer of menthol mint oil, with significant exports to the USA and European countries. Over the past few decades, extensive research and development efforts, including nutrient management, weed control, organic farming, and integrated nutrient management, have been undertaken to enhance the yield and quality of menthol mint (Upadhyay *et al.*, 2014) [6]. Significant variation has been observed in the yield and essential oil quality of menthol mint varieties, such as Himalaya and Kosi, cultivated in different regions.

The essential oil extracted from the aerial parts of the plant through steam distillation contains natural menthol, menthone, menthyl acetate, and pulegone, among other compounds. India leads the world in the production and export of mint oil and its derivatives, contributing 80% of global production, followed by China (9%), Brazil (7%), and the USA (4%). By 2014, global production of essential oil from *Mentha arvensis L*. had reached 18,000 tonnes, making it the second-largest essential oil crop worldwide.

Mint oil prices surged in 2017 due to a 40% decline in production compared to the previous year. As one of the most sought-after essential oils, mint oil has widespread applications in flavouring and the pharmaceutical industry, attributed to its analgesic, cooling, and antimicrobial properties.

Materials and Methods

The field experiment was meticulously planned and executed at the Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, spanning the years 2023 to 2025. The experiment was carried out at Raipur, which is located in the South-Eastern part of Chhattisgarh. With 21°.23"39.77"N latitude and 81°.69"44.30"E longitude and having an altitude of 295 m above mean sea level. The treatments were divided into fertilization application of T_1 (100% RDN (150: 60: 60 N: P_2O_5: K_2O kg ha-^{1}), T_2 75% RDN, T_3 50% RDN, T_4 75% RDN + 5 t fym ha-^{1}, T_5 50% RDN + 10 t fym ha-^{1}, T_6 75% RDN + 1 t Vermicompost ha-^{1}, T_7 50% RDN + 2 t Vermicompost ha-^{1} and T_8 Control.

Crop Economics: The economic analysis of the experiment was conducted based on the prevailing market prices during the period of study. The assessment included the calculation of total cost of cultivation, gross returns, net returns, and benefit-cost ratio (BCR) for each treatment.

Cost of cultivation (Rs. ha^{-1})

The cost of cultivation was estimated by accounting for various input expenses, including seeds, manure, fertilizers, irrigation, and labour charges for all field operations. The calculations were performed treatment-wise and expressed in rupees per hectare (₹ ha^{-1}). A detailed breakdown of these costs is provided in Appendix I for reference.

Gross return (Rs. ha^{-1})

The gross monetary returns were determined by multiplying the total grain yield of Mentha with the prevailing market price per unit and expressed in rupees per hectare (₹ ha^{-1}). This calculation provided an estimate of the total revenue generated from the crop under different treatment conditions.

Net return (Rs. ha^{-1})

The net returns per hectare were obtained by subtracting the total cost of cultivation from the gross monetary returns, providing an estimate of the actual profit earned per hectare. The values were expressed in rupees per hectare (₹ ha^{-1}), allowing for a comparative economic evaluation of different treatment combinations.

Net returns (Rs. ha-^{1}) = Gross returns (Rs. ha-^{1})-Total cost of cultivation (Rs. ha-^{1})

B:C ratio

This ratio helps in assessing the economic viability of different treatment combinations by comparing the benefits (returns) obtained per unit cost invested. A B:C ratio greater than 1 indicates a profitable outcome, whereas a ratio below 1 suggests that the cost of cultivation exceeds the returns, making the treatment economically unfeasible.

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

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

Statistical analysis: The data of all parameters of Chia collected precisely was tabulated, computed and statistical analysis done by using word-excel spreadsheet a randomize block design. The growth parameters data of height and DBH were summarized with standard deviation and presented.

Results and Discussion

Chemical Analysis

Nitrogen uptake and Nitrogen content before harvest

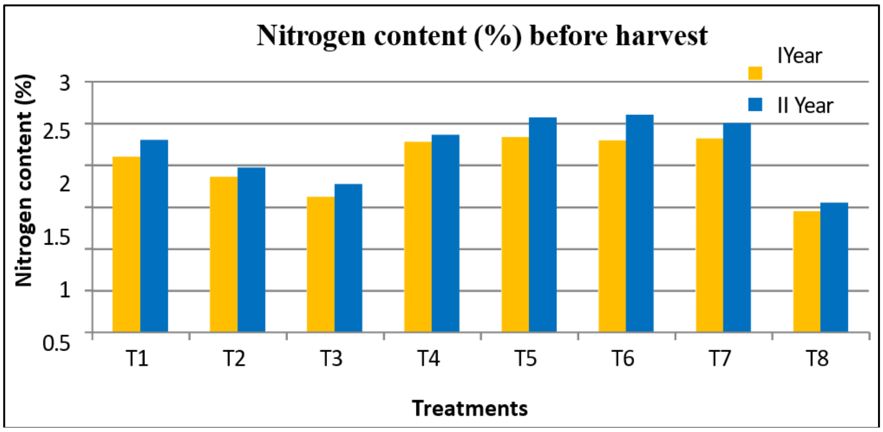
The nitrogen uptake (kg ha^{-1}) and nitrogen content (%) in mentha before harvest, as influenced by various nutrient management treatments under the Karanj-based agroforestry system, are presented in Table 1. The data reveals significant differences in nitrogen accumulation within the plant tissues across the different treatments.

The data presented in Table 1 provides a detailed two-year comparison of nitrogen uptake (kg ha^{-1}) and nitrogen content (%) in mentha before harvest across various nutrient management treatments. Notably, most treatments exhibited an increase in nitrogen uptake in Year II (ranging from a slight increase in 75% RDN to a substantial rise in 50% RDN + 2 t Vermicompost ha^{-1} from 52.20 to 62.55 kg ha^{-1}) compared to Year I (where uptake ranged from a low of 2.32 Kg ha^{-1} in the control to a high of 84.64 Kg ha^{-1} in 50% inorganic + 10 t FYM ha^{-1}). The 100% RDN treatment showed consistently high uptake, increasing from 76.35 kg ha^{-1} in Year I to 78.10 Kg ha^{-1} in Year II. However, the integrated nutrient management strategies generally surpassed this, with 75% RDN + 5 t FYM ha^{-1} increasing from 81.89 to 83.04 kg ha^{-1}, 75% RDN + 1 t Vermicompost ha^{-1} showing a marginal increase from 82.53 to 82.79 kg ha^{-1}, and the standout treatment of 50% inorganic + 10 t FYM ha^{-1} maintaining the highest uptake across both years (84.64 Kg ha^{-1} in Year I and 85.21 kg ha^{-1} in Year II). Conversely, treatments with reduced inorganic nitrogen alone (75% RDN at 66.28 Kg ha^{-1} in Year I and 67.98 kg ha^{-1} in Year II; 50% RDN at 59.22 Kg ha^{-1} in Year I and 61.01 kg ha^{-1} in Year II) showed lower uptake. The 50% RDN+ 2t Vermicompostha^{-1} treatment demonstrated a considerable improvement in Year II, reaching 62.55 Kg ha^{-1} from 52.20 kg ha^{-1} in Year I. The control group consistently recorded the lowest uptake, increasing slightly from 2.32 kg ha^{-1} in Year I to 3.02 kg ha^{-1} in Year II.

Table 1: The nitrogen uptake (kg ha^{-1}) and nitrogen content (%) in mentha before harvest

Treatment	Nitrogen uptake and Nitrogen content before harvest			
	I Year		II Year	
	Nitrogen Content (%)	Nitrogen Uptake (kg ha^{-1})	Nitrogen Content (%)	Nitrogen Uptake (kg ha^{-1})
T_1:100% RDN (150:60:60N:P_2O_5:K_2O Kg ha^{-1})	2.10	76.35	2.3	78.20
T_2:75% RDN	1.86	66.28	1.97	67.98
T_3:50% RDN	1.62	59.22	1.77	61.01
T_4:75% RDN + 5 t FYM ha^{-1}	2.28	81.89	2.36	83.03
T_5:50% inorganic + 10 t FYM ha^{-1}	2.34	84.64	2.57	85.21
T_6:75% RDN + 1 t Vermicompost ha^{-1}	2.30	82.53	2.60	82.79
T_7:50% RDN + 2vt Vermicompost ha^{-1}	2.32	83.35	2.50	84.20
T_8: control	1.45	52.20	1.55	52.88
SEm ±	0.04	2.32	0.07	3.02
CD @ (P = 0.05)	0.12	6.94	0.21	9.06

Similar trends were observed for nitrogen content (%). The 100% RDN treatment maintained a high content, increasing from 2.10% in Year I to 2.30% in Year II. Integrated treatments also showed high content, with 75% RDN + 5 t FYM ha^{-1} increasing from 2.28% to 2.36%, and 75% RDN + 1 t Vermicompost ha^{-1} showing a slight increase from 2.32% to 2.50%. The 50% inorganic + 10 t FYM ha^{-1} treatment exhibited the highest nitrogen content in both years (2.34% in Year I and 2.57% in Year II). Reduced RDN treatments showed lower content (75% RDN at 1.86% in Year I and 1.97% in Year II; 50% RDN at 1.62% in Year I and 1.77% in Year II), while 50% RDN + 2 t Vermicompost ha^{-1} increased from 1.45% to 1.55%. The control group had the lowest content, increasing from 0.04% to 0.07%. These values clearly demonstrate the superior nitrogen uptake and content achieved through integrated nutrient management, particularly with the 50% inorganic + 10 t FYM ha^{-1} treatment, compared to sole reliance on inorganic fertilizers or no nitrogen application (control). The Critical Difference (CD) at P = 0.05 would be crucial to statistically validate the significance of these observed numerical differences between the treatments in both years.



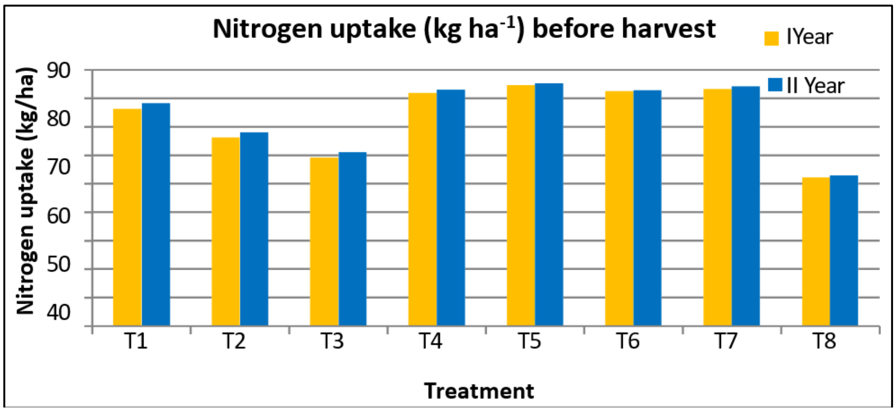


Fig 1: The nitrogen uptake (kg ha^{-1}) and nitrogen content (%) in Mentha before harvest

Further examination of the specific values reveals the magnitude of the benefits derived from integrated nutrient management. For instance, in Year I, the 50% inorganic + 10 t FYM ha^{-1} treatment exhibited a nitrogen uptake of 84.64 Kg ha^{-1}, significantly higher than the 76.35 Kg ha^{-1} observed in the 100% RDN treatment. This trend persisted in Year II, with the integrated treatment reaching 85.21 kg ha^{-1} compared to 78.10 kg ha^{-1} for 100% RDN. Similarly, the nitrogen content in the 50% inorganic + 10 t FYM ha^{-1} treatment was 2.34% in Year I and 2.57% in Year II, consistently surpassing the 2.10% and 2.30% recorded for the 100% RDN treatment in the respective years. These numerical differences underscore the enhanced efficiency of nutrient utilization and accumulation when combining organic and inorganic sources, potentially due to improved soil health, nutrient availability, and root development fostered by the organic matter. The vermicompost-amended treatments also demonstrated notable improvements, particularly the 50% RDN + 2 t Vermicompost ha^{-1} treatment, which showed an increase in nitrogen uptake from 52.20 kg ha^{-1} to 62.55 kg ha^{-1} and nitrogen content from 1.45% to 1.55% between Year I and Year II, suggesting a positive long-term impact of vermicompost application on nitrogen dynamics.

Conversely, the treatments relying solely on reduced levels of inorganic nitrogen demonstrated consistently lower nitrogen uptake and content. For example, the 75% RDN treatment achieved nitrogen uptakes of 66.28 Kg ha^{-1} and 67.98 Kg ha^{-1} in Year I and Year II, respectively, and nitrogen contents of 1.86% and 1.97%. These values are substantially lower than those observed in the 100% RDN and integrated treatments, highlighting the yield-limiting potential of insufficient inorganic nitrogen supply when not supplemented with organic sources. The control treatment's minimal nitrogen uptake (2.32 Kg ha^{-1} in Year I and 3.02 Kg ha^{-1} in Year II) and negligible nitrogen content (0.04% and 0.07%) serve as a stark reminder of the absolute necessity of nitrogen fertilization for mentha production. The statistical significance of the differences between these specific numerical values, as determined by comparison against the CD (P = 0.05) value, would provide a more robust assessment of the practical implications of these findings for optimizing nutrient management practices in mentha cultivation.

Economics analysis

The economic analysis of Mentha cultivation under different nitrogen management treatments revealed significant variations in terms of cost of cultivation, oil yield, gross return, net return, and benefit-cost (B:C) ratio (Table 2).

The highest oil yield of 286.5 kg ha^{-1} was recorded under T_6 treatment, which also resulted in the highest gross return (₹ 3,43,797 ha^{-1}) and net return (₹ 1,73,604 ha^{-1}), with a B:C ratio of 2.0**.** This suggests that T_6 was the most profitable among all the treatments. Similarly, T_1 (273.1 kg ha^{-1}) and T_4 (268.3 kg ha^{-1}) also recorded high oil yields with corresponding net returns of ₹ 1,64,549 and ₹ 1,59,263 ha^{-1}, respectively. Both these treatments achieved a favourable B:C ratio of 1.9-2.0, indicating their economic viability.

Table 2: Economics analysis of Mentha as influenced by Nitrogen management

Treatment	Cost of Cultivation (Rs. ha-1)	Oil yield Kg ha^{-1})	Gross return (Rs. ha-1)	Net return (Rs. ha-1)	B:C ratio
T_1	1,63,168	273.1	327717	164549	2.0
T_2	1,60,194	195.5	234598	74404	1.4
T_3	1,57,309	182.8	219358	62049	1.3
T_4	1,62,694	268.3	321957	159263	1.9
T_5	1,59,809	264.3	317157	157348	1.9
T_6	1,70,193	286.5	343797	173604	2.0
T_7	1,77,309	278.3	333957	156648	1.8
T_8	1,51,433	159.6	191518	40085	1.2

Conversely, T_8, which produced the lowest oil yield of 159.6 kg ha^{-1}, resulted in the lowest gross return (₹ 1,91,518 ha^{-1}) and net return (₹ 40,085 ha^{-1}), along with a poor B:C ratio of 1.2, indicating it to be the least economical option.T_2 and T_3, despite having slightly lower input costs, also yielded suboptimal returns due to their low oil yield (195.5 and 182.8 kg ha^{-1}, respectively), resulting in net returns of ₹ 74,404 and ₹ 62,049 ha^{-1}. Their B:C ratios of 1.3-1.4 further affirm the inefficiency of these nitrogen levels in maximizing profits. The results clearly indicate that balanced nitrogen management, particularly under T_6, is critical for optimizing both yield and economic returns in Mentha cultivation. Treatments T_1 and T_4 also emerged as close alternatives for economic feasibility.

Conclusion

The economic analysis reinforced the agronomic results. Treatments T_6 and T_7 achieved the highest net returns and benefit: cost ratios, suggesting that reduced chemical use combined with organics is both profitable and sustainable. Sole dependence on inorganic fertilizers was economically inferior to integrated systems, and the control plots provided the least economic benefit. In conclusion, the study clearly demonstrates that integrated nutrient management especially the combination of reduced RDN with FYM or vermicompost not only boosts the growth and yield of *Mentha arvensis* but also supports the healthy development of Karanj trees under agroforestry systems. This system enhances soil health, productivity, and economic returns while promoting sustainable agricultural practices. Such integrated approaches are recommended for adoption in similar agro-ecological zones for long-term resource use efficiency, soil sustainability, and farmer profitability.

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