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Integrated nutrient management for enhancing growth, herbage and oil yield of mentha (*Mentha arvensis L.*) 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. The analyzed results showed that the 100% Farm Yard Manure (FYM) gave higher growth of Mentha such as plant height, number of leaves and branches, leaf area, dry matter accumulation, crop growth rate, fresh herbage yield, and oil content were recorded along with nitrogen uptake and content. Simultaneously, Karanj tree parameters such as diameter at breast height (DBH), total height, canopy spread, pod characteristics, seed weight, and oil content were also evaluated. Results showed that integrated nutrient management (INM) significantly enhanced 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}).

Keywords: Mentha *(Mentha arvensis*), 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. The internodes are smooth and striated, while the twigs measure 11-22 cm, bearing 6-9 nodes. The leaves are exstipulate and petiolate, with petiole lengths ranging from 0.8 cm to 1.8 cm and widths from 0.9 mm to 1.8 mm (Chawla and Thakur, 2013) [11]. The small purplish flowers are arranged in a loose cylindrical pattern with slender spikes, and the seeds are small and mucilaginous (Kirtikar and Basu).

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 (Kumar, 2016) [6]. 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*., 2014) [8].

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 (Bajeli *et al*., 2016) [12]. 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 (Bahl *et al*., 2000; Chand *et* *al*., 2004; Upadhyay *et al*., 2014) [13, 2, 8].

Mentha arvensis is a crucial essential oil-bearing plant, with its l-menthol crystals, de-mentholated oil, and specific terpene fractions extensively utilized in the food, flavour, pharmaceutical, and cosmetic industries (Singh and Khanuja, 2010) [10].

The juice of *Mentha arvensis* leaves is traditionally used to treat diarrhea and dysentery, while its leaves are also known for their effectiveness in addressing stomach ailments and allergies. The plant contains a variety of phytochemicals responsible for its therapeutic benefits, including terpenoids, alcohols, rosmarinic acids, and phenolics. One of its primary compounds, menthol, is widely used in the pharmaceutical, perfumery, and food industries. The oil extracted from the leaves contains 40-50% menthol, which possesses antiseptic, carminative, refrigerant, and analgesic properties, making it a valuable component in various medicinal and commercial applications.

The essential oil of *Mentha arvensis L*. can be diluted and applied to treat skin infections. This plant is well-known for its diverse pharmacological properties, including antimicrobial, hepatoprotective, antioxidant, antiulcer, immunomodulatory, antifertility, and anti-tumor activities. This review article provides a comprehensive overview of *Mentha arvensis Linn.* covering its taxonomic classification, phytochemical composition, traditional and modern applications, and various pharmacological benefits.

The chemical composition of *Mentha arvensis* varies based on season, climate, and processing methods. It contains key terpenoids and alcohols such as α-menthol, neomenthol, isomenthol, d-menthone, isomenthone, menthofuran, and menthyl acetate, along with aromatic compounds like p-cymene, limonene, carvacrol, and thujone. Additionally, it has flavonoids including quercetin, isorhoifolin, menthoside, vitamin K, thymol, and eugenol. Phenolic esters like caffeic acid and p-coumaric acid, as well as sugars such as 3-O-β-sitosterol-glucopyranosyl-(1α-2) fructofuranoside and sucrose, have also been identified. Linarin is present in its flowers. Essential oil yield differs across plant parts, with the highest in shoot leaves (0.62%) and negligible amounts in stems (0.2%). Menthol, the major component, is found in the highest percentage in shoot stem oil (78.16%) and the lowest in stolon stem oil (43.7%).

Material and Methods

The field experiment was meticulously planned and executed at the Herbal Garden of Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, Raipur is strategically located in the eastern-central region of Chhattisgarh, precisely positioned at a latitude of 21°16′ N and a longitude of 81°36′ E, at an elevation of approximately 289.5 meters above mean sea level, On average receives approximately 1250 mm of rainfall annually, based on an 80-year mean, with nearly 85% of the total rainfall occurring between June and September. Field specifically consists of black clayey soil, which falls under the Vertisol order and is locally referred to as "Kanhar." 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.

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.

Fig 1: Field layout and plantation, Measurement of plant height and Oil distillation of Mentha leaves

Results and Discussion

Plant height: Plant height serves as a vital biometric indicator reflecting the crop's growth and development. It is recorded from the soil surface up to the tip of the plant's tallest leaf. The crop’s vigor, robustness, and adaptability are largely influenced by the prevailing environmental conditions (Table - 1)

Table 1: Effect of nutrient on plant height (cm) of Mentha (*Mentha arvensis*) under Karanj based agroforestry system.

Treatment	Plant height (cm)														
	(2023-24)							(2024-25)							
	1st harvest				2nd harvest			1st harvest				2nd harvest			
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1 : 100% RDN (150:60:60N:P2O5:K2O Kg ha^{-1})	6.50	22.10	57.45	65.800	5.80	22.09	65.00	6.81	21.95	58.70	66.50	6.50	21.67	64.90
T2:75 % RDN	4.80	14.50	38.00	46.100	4.60	14.12	45.850	5.10	15.00	36.70	47.30	4.80	14.82	46.990
T3: 50 % RDN	4.95	15.10	38.75	47.050	4.88	14.96	46.820	4.59	14.80	39.50	46.400	3.97	14.20	45.780
T4:75% RDN+5t FYM ha^{-1}	6.30	21.70	56.10	64.20	6.10	20.67	64.170	6.50	22.40	57.30	63.50	5.87	21.40	62.10
T5:50% RDN+ 10 t FYM ha^{-1}	6.75	22.60	57.85	67.10	6.80	21.77	67.11	7.00	23.00	59.00	68.40	6.87	22.10	67.00
T6:75% RDN+1t Vermicompost ha^{-1}	6.15	16.00	39.10	47.25	6.20	15.90	48.01	6.00	16.50	40.30	46.90	6.12	15.90	47.00
T7:50% RDN+2t Vermicompost ha^{-1}	5.30	19.30	48.00	56.30	5.20	20.00	55.98	5.60	20.10	49.50	57.00	5.54	19.98	56.43
T8:control	4.50	11.90	30.60	37.40	4.45	12.00	36.80	4.70	12.30	29.90	36.80	4.40	11.78	35.60
SEm±	0.28	0.71	1.94	2.05	0.24	0.72	2.01	0.29	0.74	2.03	2.15	0.63	0.69	2.09
CD @ (P=0.05)	0.84	2.11	5.85	6.20	0.72	2.13	6.01	0.87	2.20	6.15	6.50	1.80	1.98	5.53

Number of leaves plant^{-1}: The number of leaves per plant was recorded in the range of 95.0 to 222.8 leaves by the time of harvesting (around 120 days). The highest leaf count (222.8) was observed under T_5 treatment, showing the significant role of vermicompost and organic manure in stimulating vegetative growth. The integrated use of organic and inorganic fertilizers had a strong impact on leaf development, possibly due to improved nutrient availability and better soil health.

Table 2: Effect of nutrient on number of leaves plant-1 of Mentha under Karanj based agroforestry system

Treatment	No of leaves plant^{-1}														
	(2023-24)							(2024-25)							
	1st harvest				2nd harvest			1st harvest				2nd harvest			
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1: 100 % RDN (150:60:60N:P2O5:K2O Kg ha^{-1})	14.00	43.50	119.20	218.00	29.00	85.3	240.00	16.50	41.95	121.07	126.50	20.03	89.30	193.76
T2:75 % RDN	12.37	28.00	72.70	170.67	27.00	78.00	185.60	14.8	35.00	76.20	158.30	19.80	77.04	187.70
T3: 50 % RDN	11.10	20.3	68.7	135.00	19.00	70.00	179.21	10.20	34.80	79.32	161.30	15.60	62.80	135.80
T4:75%RDN+5t FYM ha^{-1}	13.00	21.50	116.00	215.00	27.00	69.26	190.87	16.43	32.40	126.02	221.50	20.01	91.78	249.12
T5:50% RDN + 10 t FYM ha^{-1}	13.00	23.00	121.00	220.00	31.00	75.43	241.70	15.78	43.00	130.02	229.40	19.80	90.02	251.03
T6: 75 %RDN +1 t Vermicompost ha^{-1}	11.70	17.68	85.30	140.00	26.00	68.54	258.60	12.76	41.50	126.01	156.90	18.90	101.00	184.89
T7: 50 % RDN +2 t Vermicompost ha^{-1}	13.00	21.00	119.00	219.00	27.00	72.78	251.50	16.02	20.10	128.21	227.00	21.98	89.00	241.60
T8:control	7.50	13.00	50.00	95.00	17.00	47.00	182.80	10.01	15.30	69.38	93.80	18.00	88.00	101.78
SEm±	0.75	0.70	5.80	7.43	0.78	0.92	9.43	0.58	0.89	4.03	2.15	0.63	0.69	9.09
CD @ (P=0.05)	1.77	1.85	19.50	31.00	2.80	6.31	33.76	2.02	2.60	8.15	6.50	2.80	1.98	27.27

Number of Branches plant^{-1}

The branches per plant were counted in the sample plants and the analysed data are presented in Table: 3 A comparison of the number of branches per plant of Mentha at different growth stages (30, 60, 90 days, and at harvesting) over two consecutive years under the Karanj-based agroforestry system revealed a clear improvement in branching during the second year across all treatments.

Table 3: Effect of nutrient on number of branches of Mentha under Karanj based agroforestry system.

Treatment	Number of branches plant^{-1}														
	(2023-24)							(2024-25)							
	1st harvest				2nd harvest			1st harvest				2nd harvest			
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1: 100 % RDN (150:60:60N:P2O5:K2O Kg ha^{-1})	4.53	11.92	28.51	36.08	4.59	12.47	30.43	4.75	12.50	29.80	37.20	4.77	13.00	30.08
T2:75 % RDN	3.22	8.61	15.20	22.77	3.45	12.09	16.90	3.40	9.11	16.01	24.04	3.58	10.06	18.04
T3: 50 % RDN	3.42	8.81	15.40	23.97	3.47	9.02	17.60	3.60	9.30	16.08	24.10	3.99	10.19	19.07
T4:75%RDN+5t FYM ha^{-1}	4.10	11.49	28.08	35.65	4.50	12.38	30.04	4.30	12.01	29.20	36.90	4.56	14.05	31.70
T5:50% RDN + 10 t FYM ha^{-1}	4.98	12.37	28.96	36.53	5.05	12.87	30.01	5.21	13.03	30.02	38.00	5.50	14.02	32.80
T6: 75 %RDN +1 t Vermicompost ha^{-1}	3.88	10.27	16.86	24.43	4.01	11.07	17.02	4.05	10.80	17.80	25.5	4.43	11.90	27.00
T7: 50 % RDN +2 t Vermicompost ha^{-1}	4.03	11.42	22.01	29.58	4.17	12.89	25.04	4.30	12.00	23.20	31.08	4.89	15.70	30.00
T8:control	3.11	5.98	9.57	15.17	3.48	6.01	18.03	3.25	6.40	10.20	16.00	4.01	8.01	18.00
SEm±	1.32	0.58	1.60	2.20	1.38	0.62	1.87	0.29	0.55	1.32	1.91	0.37	1.47	2.02
CD @ (P=0.05)	3.96	1.71	2.68	5.46	4.14	2.78	2.86	0.87	1.57	2.68	4.01	1.11	4.41	6.06

Leaf area (cm^2)

The highest leaf area was recorded under the treatment T_6 (75% inorganic +1tvermicompost ha^{-1}), as compared to the control treatment (T_8) which received no fertilizer input. This demonstrates the beneficial effect of integrated nutrient management on vegetative growth. Additionally, the number of branches showed a significant positive correlation with soil moisture content, suggesting that adequate water availability supports better canopy development.

Table 4: Effect of nutrient on leaf area of Mentha under Karanj based agroforestry system.

Treatment	Leaf Area (cm^2)													
	(2023-24)							(2024-25)						
	1st harvest				2nd harvest			1st harvest				2nd harvest		
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1: 100 % RDN (150:60:60N:P2O5:K2O kg ha^{-1})	26.00	44.90	53.20	66.00	26.80	47.80	55.30	27.01	54.00	64.01	70.50	27.90	55.10	73.28
T2:75 % RDN	22.40	45.60	59.30	67.20	23.80	47.00	61.00	23.50	47.10	61.30	69.80	25.10	48.00	71.05
T3: 50 % RDN	24.10	48.50	58.00	61.40	25.00	50.05	60.01	25.00	50.01	60.00	65.00	26.90	52.00	67.18
T4:75%RDN+5 t FYM ha^{-1}	21.80	51.20	62.40	74.30	24.90	52.59	65.00	28.40	53.20	66.80	72.00	30.00	58.00	74.47
T5:50% RDN+10 t FYM ha-1	19.50	49.80	67.40	71.60	21.30	52.70	70.30	21.02	52.10	69.00	74.07	24.70	56.20	76.89
T6: 75 %RDN +1 t Vermicompost ha^{-1}	25.20	41.20	65.10	72.50	26.90	43.01	72.20	26.50	43.20	67.40	74.00	28.50	45.90	76.80
T7: 50 % RDN +2 t Vermicompost ha^{-1}	23.90	47.60	63.80	69.80	25.20	50.02	65.90	25.50	49.50	66.50	72.30	27.00	52.70	75.00
T8: control	18.70	39.50	50.30	59.80	19.00	42.70	53.10	19.50	41.00	52.00	61.20	21.20	43.20	61.40
SEm±	0.42	0.78	0.95	1.03	0.78	1.01	1.08	0.75	0.84	0.88	0.98	0.89	1.03	1.01
CD @ (P=0.05)	1.30	2.40	2.85	3.10	2.34	2.51	3.10	2.18	2.16	2.60	2.95	2.20	2.78	2.98

Dry Matter Accumulation (g/m^2)

At harvesting, the highest dry matter accumulation was recorded under T_4 (75 % inorganic + 5 t FYM/ha) in the second year (80.12 g/m^2), followed by T_6 (74.50 g/m^2). Treatments involving partial replacement of RDN with organic sources like vermicompost (T_6 and T_7) also demonstrated substantial improvement in biomass accumulation at harvest. Across all stages, dry matter accumulation was consistently higher in the second year, reflecting improved soil conditions and possible cumulative effects of organic amendments. The control plot (T_8) recorded the lowest values throughout, emphasizing the importance of nutrient management for sustained Mentha productivity under agroforestry systems

Table 5: Effect of nutrient on dry matter accumulation of Mentha plant under Karanj based agroforestry system

Treatment	Dry matter accumulation (g/m2)													
	(2023-24)							(2024-25)						
	1st harvest				2nd harvest			1st harvest				2nd harvest		
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1: 100 % RDN (150:60:60N:P2O5:K2O $kgha^{-1}$)	27.50	46.07	68.50	72.00	26.00	44.80	70.16	28.30	51.40	71.40	74.70	24.80	51.10	68.07
T2:75 % RDN	26.00	51.00	63.20	69.20	23.90	49.60	66.80	27.90	52.50	69.90	71.34	25.77	50.03	66.10
T3: 50 % RDN	24.00	48.50	61.00	68.00	22.13	47.00	63.00	25.60	48.00	64.60	66.90	26.80	46.81	65.22
T4:75%RDN+5t FYM ha^{-1}	24.50	54.01	76.00	80.00	24.01	51.79	77.36	24.90	55.70	77.50	80.12	23.02	52.33	75.03
T5:50% RDN + 10 t FYM ha^{-1}	22.01	52.00	74.01	76.04	20.80	50.17	71.81	23.60	54.60	72.60	75.51	21.60	52.11	70.18
T6: 75 %RDN +1 t $Vermicompostha^{-1}$	26.50	45.50	74.50	77.20	23.70	44.80	70.99	27.80	46.60	75.70	79.61	25.01	42.91	77.20
T7: 50 % RDN +2 t $Vermicompostha^{-1}$	25.02	50.13	72.00	74.90	22.70	49.19	70.05	26.70	51.70	73.40	70.00	24.30	49.04	68.39
T8:control	20.12	41.11	61.00	63.80	18.30	40.37	59.00	21.30	42.60	60.60	61.00	20.10	40.08	58.02
SEm±	0.49	0.81	1.15	1.05	0.41	0.6	1.04	0.87	1.54	1.99	2.41	0.50	1.51	2.39
CD @ (P=0.05)	1.50	2.41	3.25	3.25	1.48	2.37	3.18	2.61	4.62	5.97	7.93	1.28	2.72	6.99

Crop growth rate

At the harvest stage, maximum growth was recorded in T_7 (0.275 g m^{-2} day^{-1} in 2023-24), which increased from 0.250 in 2024-25. Treatments T_3, T_4, and T_6 followed closely, also showing progressive increases over the years. This suggests a cumulative benefit of organic matter application over time. Conversely, the control treatment remained the least productive (0.065 in 2024-25). The present study evaluated the crop growth rate (CGR) of Mentha under a Karanj-based agroforestry system with different nutrient management treatments.

Table 6: Effect of nutrient on the crop growth rate of Mentha plant under Karanj based agroforestry system.

Treatment	Crop growth rate (g m-2 day-1)													
	(2023-24)							(2024-25)						
	1st harvest				2nd harvest			1st harvest				2nd harvest		
	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS	90 DAS	At Harvest	30 DAS	60 DAS	At Harvest
T1: 100 % RDN (150:60:60N:P2O5:K2O Kg ha^{-1})	0.050	0.36	0.071	0.25	0.055	0.36	0.26	0.055	0.35	0.078	0.25	0.057	0.35	0.083
T2:75 % RDN	0.042	0.32	0.063	0.24	0.050	0.32	0.24	0.046	0.34	0.069	0.24	0.047	0.25	0.078
T3: 50 % RDN	0.033	0.22	0.057	0.22	0.045	0.30	0.19	0.036	0.33	0.063	0.23	0.038	0.20	0.072
T4:75% RDN+5t FYM ha^{-1}	0.037	0.18	0.061	0.23	0.040	0.18	0.20	0.041	0.20	0.067	0.25	0.045	0.201	0.076
T5:50% RDN + 10 t FYM ha^{-1}	0.028	0.11	0.055	0.20	0.030	0.19	0.21	0.031	0.13	0.062	0.25	0.032	0.134	0.067
T6: 75 % RDN +1 t Vermicompost ha^{-1}	0.045	0.26	0.067	0.22	0.046	0.26	0.21	0.050	0.28	0.074	0.22	0.052	0.291	0.083
T7: 50 % RDN +2 t Vermicompost ha^{-1}	0.055	0.34	0.073	0.25	0.057	0.34	0.22	0.06	0.37	0.080	0.24	0.063	0.379	0.086
T8:control	0.013	0.12	0.483	0.059	0.010	0.12	0.012	0.014	0.13	0.053	0.27	0.016	0.146	0.065
SEm±	0.42	0.78	1.03	0.95	0.30	0.81	0.93	0.45	1.04	0.99	0.024	0.47	1.06	0.032
CD @ (P=0.05)	1.26	2.34	3.09	2.85	0.90	2.43	2.79	1.35	3.12	2.97	0.072	1.41	2.19	0.96

Yield Parameters

Fresh Herbage (q ha^{-1})

The results from the pooled data over two years clearly demonstrate the significant impact of integrated nutrient management on fresh herbage yield of mentha under agroforestry systems. Among the various treatments, T_6 (75 % RDN + 1 t vermicompost ha^{-1}) recorded the highest pooled fresh herbage yield of 419.4 q/ha, show casing the most effective combination of organic and inorganic nutrient sources. This was closely followed by T_7 (50 % RDN + vermicompost ha^{-1}) and T_1 (100% RDN) with yields of 418.4 q/ha and 408.2 q/ha respectively, highlighting the beneficial role of integrating FYM and vermicompost with chemical fertilizers. T_5 (50% inorganic+10t FYM ha^{-1}) also showed a commendable yield of 389.8 q/ha, further reinforcing the advantage of combined nutrient application over sole reliance on chemical inputs.

Table 7: Effect of nutrient on fresh herbage (q ha^{-1}) of Mentha under Karanj based agroforestry system.

Treatment	Fresh herbage (q ha-1)						Pooled
	2023-24			2024-25			
	1st Har.	2nd Har.	Total	1st Har.	2nd Har.	Total	q ha^{-1}
T1:100% RDN	159.7	226.1	386.8	172.5	257.1	429.6	408.2
T2:75% RDN	112.9	171.2	284.1	126.5	198.9	325.4	304.7
T3:50% RDN	104.2	161.3	265.5	118.2	192.3	310.5	288.0
T4:75% RDN+5 t FYM ha^{-1}	167.2	216.7	383.9	176.3	245.1	421.4	390.1
T5:50% RDN+10 t FYM ha-1	145.8	205.6	351.4	157.6	240.4	397.6	389.8
T6:75% RDN+1t Vermicompost ha^{-1}	167.7	234.6	402.3	180.3	256.2	436.5	419.4
T7:50% RDN+2t Vermicompost ha^{-1}	155.7	211.8	367.5	168.5	243.5	411.1	418.4
T8: control	105.5	118.2	223.7	114.2	149.4	463.6	243.6
SEm±	7.63	8.26	12.25	8.06	9.05	11.51	11.88
CD @ (P=0.05)	21.65	25.48	36.20	24.09	27.4	33.11	34.15

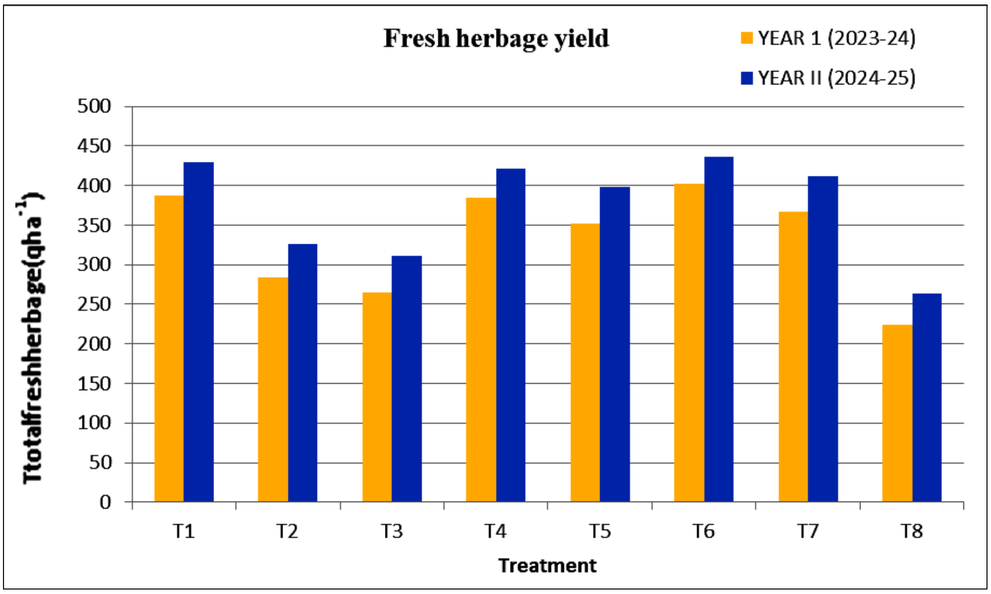

Fig 2: Effect of nutrient on fresh herbage (q ha^{-1}) of Mentha under Karanj based agroforestry system

Oil content

The influence of various nutrient management treatments on the oil content of mentha under a Karanj-based agroforestry system is presented in Table 4.8. The data reveals significant variations in both the quantity (Kg ha^{-1}) and percentage (%) of oil content across different treatments.

The oil content (%) of Mentha varied significantly across different treatments and between both years of the study, highlighting the influence of nutrient management under the Karanj-based agroforestry system.

Table 8: Effect of nutrient on Oil content of Mentha under Karanj based AFS

Treatment	Oil content %			
	2023-24		2024-25	
	1st Harvest (7 mar.)	2nd Harvest (17 may)	1st Harvest (7 mar.)	2nd Harvest (17may)
T1:100% RDN (150:60:60 N:P2O5:K2O kg ha^{-1})	0.75	0.56	0.73	0.53
T2:75% RDN	0.76	0.55	0.74	0.52
T3:50% RDN	0.75	0.56	0.73	0.54
T4:75% RDN+5t FYM ha^{-1}	0.81	0.56	0.78	0.60
T5:50% +10t FYM ha^{-1}	0.80	0.62	0.77	0.59
T6:75% RDN+1t Vermicompost ha^{-1}	0.80	0.61	0.78	0.58
T7: 50 % RDN + 2 t Vermicompost ha-1	0.77	0.61	0.75	0.57
T8: control	0.76	0.59	0.74	0.55
SEm±	0.015	0.017	0.012	0.015
CD@(P=0.05)	0.041	0.051	0.039	0.054

Table 9: Effect of nutrient on Oil yield of mentha under Karanj based agroforestry system

Treatment	Oil yield kg ha^{-1}						Pooled
	2023-24			2024-25			
	1st Har.	2nd Har.	Total	1st Har.	2nd Har.	Total	Kg ha^{-1}
T1:100% RDN	123.7	131.6	255.3	137.3	153.7	291.0	273.1
T2:75% RDN	84.9	96.4	181.3	94.26	115.4	209.7	195.5
T3:50% RDN	78.3	91.2	169.5	88.8	111.5	200.3	182.8
T4:75% RDN+5t FYM ha^{-1}	122.8	131.2	254.0	134.5	148.2	278.0	268.3
T5:50% RDN +10t FYM ha-1	121.3	128.9	250.2	127.8	150.2	302.9	264.1
T6: 75% RDN + 1t Vermicompost ha^{-1}	134.5	135.7	270.2	145.3	157.6	291.6	286.5
T7: 50% RDN + 2t Vermicompost ha^{-1}	128.9	136.1	265.0	140.2	151.4	174.0	278.3
T8: control	87.7	57.5	145.2	97.4	76.6	174.0	159.6
SEm±	8.0	7.89	15.89	7.87	8.7	16.57	6.88
CD@(P=0.05)	24.0	21.32	46.92	22.5	25.8	49.30	18.43

Conclusion

The yield parameters such as fresh herbage yield and oil content of Mentha were notably influenced by nutrient treatments. The highest pooled herbage yield was recorded in T_6 (419.4 q ha^{-1}), followed closely by T_7 and T_1 (100% RDN). Oil yield was also highest in T_6 (286.5 kg ha^{-1}), highlighting the synergistic effect of vermicompost with reduced chemical input. Moreover, the crop growth rate (CGR) and dry matter accumulation were higher in the second year of study, indicating a cumulative positive impact of organic amendments on soil fertility and crop performance.

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