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Influence of Integrated Nutrient Management on Growth Attributes, Yield and Soil Chemical Parameters of Turmeric (*Curcuma longa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

There is a growing need for Integrated Nutrient Management (INM) in turmeric cultivation due to declining soil fertility, the excessive use of chemical fertilizers, and the increasing demand for sustainable agricultural practices. To evaluate the effectiveness of INM in turmeric, a field study

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was conducted during the *kharif* season of 2022–2023 at the Regional Research Station (Vegetable Science), CCS HAU, Karnal. The study focused on assessing the impact of various INM treatments on soil fertility and yield of turmeric (*Curcuma longa* L.) grown on clay loam soil. The experiment consisted of ten treatments *viz.,* control, recommended dose of fertilizer (N:P:K-100:50:50), 50% recommended dose of fertilizer (RDF), 75% recommended dose of fertilizer (RDF), FYM @ 25 t ha^{-1}, 50% RDF + FYM @ 25 t ha^{-1}, 75% RDF + FYM @ 25 t ha^{-1}, vermicompost @ 5 t ha^{-1}, 50% RDF + vermicompost @ 5 t ha^{-1} and 75% RDF + vermicompost @ 5 t ha^{-1}. Significantly higher number of tillers per plant (3.67) were recorded in the treatment with 75% RDF+ FYM @ 25 t ha^{-1}. Maximum plant emergence (84.66%), leaf area index, plant height (14.04 cm), and yield were observed with 75% RDF + vermicompost @ 5 t ha^{-1}. The physico-chemical properties of the soil such as bulk density, electrical conductivity, organic carbon, and pH were not significantly affected by the different integrated nutrient management treatments. However, available nitrogen and phosphorus were found to be significantly highest, i.e., 192.60 kg ha^{-1} and 25.8 kg ha^{-1} respectively, in the treatment with 75% RDF + vermicompost @ 5 t/ha. In contrast, the highest available potassium (186.81 kg ha^{-1}) was recorded in the treatment receiving 75% RDF + FYM @ 25 t/ha.

Keywords: Integrated nutrient management; fertilizer; manure; growth; turmeric.

1. INTRODUCTION

"Turmeric (*Curcuma longa* L.) belongs to family Zingiberaceae is one of the important herbaceous plant grown and used in India since ancient times as spice or condiment. India is the largest producer and consumer of turmeric in the world with an area of 3.24 lakh hectare and production of 11.61 lakh metric tonnes according to first advanced estimates of 2022-23" (Anonymous, 2023). "In Haryana, turmeric is cultivated in 1.27 thousand hectare area having production of 3.17 thousand metric tonnes" (Anonymous 2022). "Commercial turmeric is a dried subterranean rhizome that is mostly utilized in the textile, cosmetic, pharmaceutical, and culinary industries. According to Choudhary and Rahi, (2018), turmeric's curcuminoids have anti-inflammatory, antimutagen, anticancer, antibacterial, anti-oxidant, antifungal, antiparasitic, and detoxifying qualities. 1.8–5.4 percent curcumin, 69.49 percent carbohydrates, 6.30 percent protein, 5.10 percent oil, 3.50 percent minerals, and other significant components are found in its rhizome" (Bulbula, 2021). These substances provide the plant its antibacterial, anti-inflammatory, and antioxidant qualities, which have been thoroughly investigated for possible medical uses.

"Although turmeric takes a long time to mature (8–9 months), it reacts well to feeding. Peter et al. (2000) have reported turmeric to be an exhaustive crop that responds well to judicious application of fertilizers and manures. Low soil fertility and suboptimal farming practices lead to decreased turmeric yield and productivity" (Das et al. 2020). "Therefore, getting an appropriate amount of nutrients is crucial for a healthy production. Balanced plant nutrition including micronutrients *viz*. Zn and B increases the rhizome yield, growth and curcumin content" (Halder et al. 2007). "After rhizome sprouting, the crop undergoes phases of moderate growth, active growth, slow growth, and a phase-approaching senescence" (Sivaraman, 2007).

"The continuous use of high dose of chemical fertilizer has an adverse effect not only on soil health and but also on environment. The combined use of organic and inorganic fertilizer known as Integrated Nutrient Management not only increases the yield but also improves the physical, chemical and biological property of soil which further improves fertility, productivity and water holding capacity of soil. FYM is an organic fertilizer rich in nutrients such as nitrogen, phosphorus and potassium, and it also improves the soil's physical and biological properties, including soil structure, water-holding capacity and microbial activity. A study conducted in India reported that the application of FYM at a rate of 10 t ha^{-1} significantly increased the turmeric yield compared to chemical fertilizers alone" (Jena et al*.,* 2016). "Vermicompost is a nutrient-rich organic fertilizer produced by the process of decomposition of organic waste by earthworms. Vermicompost contains a wide range of beneficial microorganisms and nutrients, making it an ideal organic fertilizer for turmeric cultivation. a study conducted in India found that the application of vermicompost at a rate of 5 t ha^{-1} significantly increased the turmeric yield compared to the control" (Sharma et al*.,* 2017).

"Similarly, another study in Iran reported that the application of vermicompost at a rate of 10 t ha^{-1}resulted in higher turmeric yield and quality compared to chemical fertilizers" (Hosseini et al., 2020). "Moreover, effective management of chemical, organic and biological nutrients has shown promising results in meeting crop fertilizer requirements" (Mohanty et al. 2022).

"Exogenous application of nutrients to turmeric usually involves either exclusive application of chemical fertilizers (conventional method) or organic manures (organic method) or a combination of organic manures and chemical fertilizers (integrated method). Integrated nutrient management envisaging conjunctive use of inorganic and organic sources of nutrient is a novel system of plant nutrient use for sustaining soil health and crop productivity. The integrated nutrient management ensures the better and sustainable yield while correcting some secondary and micronutrients deficiencies and also increases the nutrient use efficiency. Moreover, integrated nutrient management is of immense importance in high value crop like turmeric and by improving the productivity and quality of this crop, socioeconomic status of farmers of the state can be improved further". In view of the above facts the present investigation was conducted to evaluate the impact of integrated nutrient management on growth, yield and soil chemical parameters of turmeric (*Curcuma longa* L.).

2. MATERIALS AND METHODS

The field experiment was carried out at the Research Farm of the Department of Vegetable Science, Regional Research Station, Karnal situated at 29° 43' N latitude, 76° 58' longitude at an elevation of 245 m above mean sea level during the cropping season of 2022-2023 (June-March). The climate of village Uchani, Karnal is semi-arid and sub-tropical with dry and hot winds during summer months, warm and humid in monsoon and dry and cold weather in winter. Both summers and winters are generally extreme. During the cropping season, the mean maximum and minimum temperatures were 43.7°C and 2.0°C, respectively. Most rainfall occurred between July and September, with occasional showers from December until early summer. Soil of the study area was clay-loam. At the start of the experiment, electrical conductivity was 0.27 dS m^{-1} soil organic carbon (SOC) was 0.42 %, and the content of available N, P, K were 168, 7.1 and 156 kg ha^{-1} and were estimated using conductivity bridge, rapid titration, micro kjeldahl, calorimetry and flame photometry, respectively. The field experiment was laid out in a randomized complete block design with ten treatments *viz.,* Control, recommended dose of fertilizer (N:P:K-100:50:50 kg h^{-1}), 50% recommended dose of fertilizer, 75% recommended dose of fertilizer, FYM @ 25 t ha^{-1}, 50% recommended dose of fertilizer + FYM @ 25 t ha^{-1}, 75% recommended dose of fertilizer + FYM @ 25 t ha^{-1}, vermicompost @ 5 t ha^{-1}, 50% recommended dose of fertilizer + vermicompost @ 5 t ha^{-1} and 75% recommended dose of fertilizer + vermicompost @ 5 t ha^{-1}. The turmeric variety used was *Punjab Haldi-1*, which was planted on June 1, 2022, at a rate of 15 quintals per hectare and a spacing of 60 cm × 15 cm. One-third of the nitrogen dose, along with the full doses of phosphorus (P_2O_5) and potassium (K_2O), was applied at planting. The remaining two-thirds of nitrogen were applied in two equal splits at 60 and 120 days after planting along with irrigation. Urea, di-ammonium phosphate and muriate of potash were used as the sources of nitrogen, phosphorus, and potassium, respectively. All other agronomic practices such as earthing up and manual weeding were carried out as needed during the crop growth period.

Observations on various growth parameters were recorded monthly after rhizome germination. Germination percentage was determined at 60 days after planting by counting the number of germinated rhizomes per plot relative to the number planted. Five plants from each treatment were randomly selected and tagged for recording growth parameters including plant height and leaf area index (LAI) at 60, 90, 120, and 150 days after planting. The leaf area index (LAI) was computed using the formula given below (Sesták et al., 1971).

$$\text{LAI} = \frac{\text{Leaf area of the entire clamp (cm2)}}{\text{Spacing provided (cm2)}} \times 100$$

The crop was harvested on 12th March, 2023 and data on yield was recorded. Soil samples (0-15 cm) were taken before starting the experiment and after the harvest of turmeric. The soil samples were air dried and ground to pass through a 2 mm sieve and were analyzed for pH, organic carbon and available N, P and K. Nutrient concentration were quantified *via* micro kjeldahl for N (Jackson, 1973), colorimetry for P (Jackson, 1973) and flame photometery for K (Black, 1965).

2.1 Statistical Analysis

The data generated were statistically analyzed following the technique of analysis of variance for randomized block design as suggested by Gomez and Gomez (1984).

3. RESULTS AND DISCUSSION

3.1 Plant Emergence at 60 Days After Planting

The perusal of the data indicates that integrated nutrient management (INM) had a significant influence on plant emergence at 60 days after planting (Table 1). The emergence percentage across treatments ranged from 69.33% to 84.66%. The highest emergence (84.66%) was recorded in the treatment receiving 75% of the recommended dose of fertilizer combined with vermicompost @ 5 t ha^{-1}. This was statistically at par with several other treatments, including the full recommended dose of fertilizer (78.66%), 50% RDF + FYM @ 25 t ha^{-1} (79.33%), 75% RDF + FYM @ 25 t ha^{-1} (82.00%), and 50% RDF + vermicompost @ 5 t ha^{-1} (80.33%). The superior plant emergence observed under the 75% RDF + vermicompost treatment may be attributed to the synergistic effect of organic and inorganic nutrient sources. Vermicompost, when combined with chemical fertilizers, likely enhanced germination by improving soil structure, increasing water-holding capacity, supplying essential nutrients, promoting beneficial microbial activity, and possibly stimulating hormone-like effects creating an optimal environment for early plant establishment. These findings are consistent with the results reported by Sahoo et al. (2020), further supporting the positive role of INM in promoting early growth and vigor in turmeric.

3.2 Number of Tillers Per Plant

The data on the number of tillers per plant ranged from 2.51 to 3.67 (Table 1), indicating a significant influence of integrated nutrient management (INM). The highest number of tillers per plant (3.67) was recorded in the treatment receiving 75% of the recommended dose of fertilizer (RDF) combined with FYM @ 25 t ha^{-1}, which was statistically at par with the treatment involving 75% RDF + vermicompost @ 5 t ha^{-1} (3.51). In contrast, the lowest number of tillers per plant (2.51) was observed in the control treatment. At 60 days after planting, the treatment with 75% RDF + FYM @ 25 t ha^{-1} consistently registered the maximum tiller count. The increase in tillering can be attributed to the combined effect of chemical fertilizers and organic manures like FYM, which not only supply essential nutrients but also improve soil structure, enhance microbial activity, and may exert positive hormonal effects ultimately promoting vigorous vegetative growth. These findings are in line with those reported by Amala et al. (2022), further supporting the beneficial role of INM in enhancing tiller production in turmeric.

3.3 Leaf Area Index

Leaf area index (LAI) was measured at different growth stages 60, 90, 120, and 150 days after planting (DAP) to assess the crop's development. Significant differences in LAI were observed among the treatments at all these stages. As shown in Table 2, LAI generally increased with plant age across all treatments. The treatment receiving 75% of the recommended dose of fertilizer (RDF) combined with vermicompost @ 5 t ha^{-1} consistently recorded the highest LAI, ranging from 0.99 at 60 DAP to 3.01 at 150 DAP. At 150 DAP, this treatment's LAI (3.01) was significantly higher than the control, which recorded the lowest LAI of 2.40. The improvement in leaf area and number of leaves per plant can likely be attributed to enhanced soil properties especially increased organic carbon content and the optimal availability of essential nutrients throughout the growth period. These factors together promoted better nutrient use efficiency and soil fertility, thereby supporting healthier, more vigorous turmeric growth. Similar observations were reported by Kumar et al. (2016), Kamal and Yousuf (2012), and Amala et al. (2022), who found higher LAI values in turmeric plants treated with organic manures like vermicompost.

3.4 Plant Height (cm)

The data presented in Table 3 show that plant height was significantly influenced by different integrated nutrient management (INM) treatments. Across all treatments, plant height increased progressively with plant age, reaching up to 150 days after planting (DAP). At 60 DAP, plant heights ranged from 14.04 cm to 17.21 cm, generally increasing with higher fertilizer doses. The tallest plants at 60 DAP were observed in the treatment receiving 75% of the recommended dose of fertilizer combined with vermicompost @ 5 t ha^{-1} (17.21 cm), followed closely by the treatment with 75% recommended dose of fertilizer + FYM @ 25 t ha^{-1} (16.66 cm). The shortest plants at this stage were found in the control treatment (14.04 cm). Throughout the growth period, the 75% RDF + vermicompost treatment consistently resulted in the greatest plant height, ranging from 17.21 cm at 60 DAP to 38.26 cm at 150 DAP. In contrast, the control treatment recorded the lowest height of 33.07 cm at 150 DAP. The increase in plant height with organic fertilizers like FYM and vermicompost can be attributed to their role in improving soil health. Organic fertilizers with a narrow carbon-to-nitrogen (C:N) ratio promote the production of humic acids and other humic substances, which can chelate phosphorus. Chelated phosphorus is more soluble and thus more readily available to plants, supporting better growth and development. Similar findings were reported by Kumar et al. (2016), who observed increased plant height in turmeric treated with organic manures such as vermicompost.

3.5 Total Yield

Adequate nutrient management in turmeric whether through inorganic sources, organic sources, or a combination of both significantly improved rhizome yield compared to plants receiving no nutrition. The yield data per hectare (Fig. 1) showed significant differences among the integrated nutrient management treatments. The highest yield was achieved with the application of 75% of the recommended dose of fertilizer combined with vermicompost @ 5 t ha^{-1}. This treatment produced significantly higher yields than the control and was statistically comparable to the full recommended dose of fertilizer, 50% recommended dose + FYM @ 25 t ha^{-1}, 75% recommended dose + FYM @ 25 t ha^{-1}, and 50% recommended dose + vermicompost @ 5 t ha^{-1}. The yield increase is likely due to enhanced growth and yield attributes promoted by these treatments. Vermicompost, being rich in nutrients such as nitrogen, phosphorus, potassium, magnesium, and calcium, supports better plant growth and development, which leads to higher biomass accumulation and increased rhizome production. These findings align with Srinivasan et al. (2016), who reported that integrated nutrient management combining chemical fertilizers and organic manures improves turmeric yield, nutrient uptake, and soil quality. Similar results were observed by Sreekala and Jayachandran (2006) in baby corn. The present results also closely correspond with the earlier findings of Sadanandan and Hamza (1998) and Nirmalatha et al. (2010).

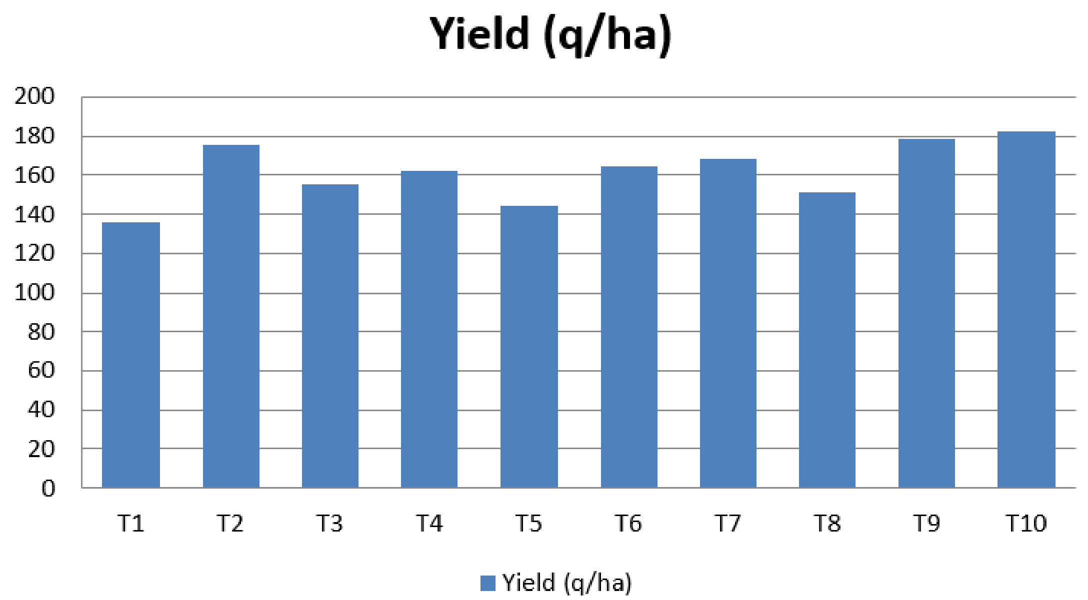

Fig. 1. Graphical representation of effect of integrated nutrient management on yield of turmeric

Where: T1: Control, T2: Recommended dose of fertilizer (N:P:K-100:50:50), T3: 50% Recommended dose of fertilizer, T4: 75% Recommended dose of fertilizer, T5: FYM @ 25 t ha^{-1}, T6: 50% Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}, T7: 75 % Recommended dose of fertilizer + FYM @ 25 t ha^{-1}, T8: Vermicompost @ 5 t ha^{-1}, T9: 50% Recommended dose of fertilizer + vermicompost @ 5 t ha^{-1}, T10: 75 % recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}.

Table 1. Effect of integrated nutrient management on plant emergence (%) and number of tillers per plant

Treatment	Plant emergence at 60 days after planting (%)	Number of tillers per plant
T_1: Control	69.33	2.51
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	78.66	2.97
T_3: 50% Recommended dose of fertilizer (RDF)	74.00	2.73
T_4: 75% Recommended dose of fertilizer (RDF)	76.66	2.84
T_5: FYM @ 25 t ha^{-1}	72.66	2.67
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	79.33	3.33
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	82.00	3.67
T_8: Vermicompost @ 5 t ha^{-1}	72.66	2.73
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	80.33	3.33
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	84.66	3.51
SEm±	2.18	0.08
CD (P = 0.05)	6.53	0.25

Table 2. Effect of integrated nutrient management on leaf area index

Treatment	Leaf area index			
	60 DAP	90 DAP	120 DAP	150 DAP
T_1: Control	0.71	1.14	2.21	2.4
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	0.90	1.44	2.40	2.81
T_3: 50% Recommended dose of fertilizer (RDF)	0.83	1.32	2.34	2.72
T_4: 75% Recommended dose of fertilizer (RDF)	0.87	1.37	2.36	2.77
T_5: FYM @ 25 t ha^{-1}	0.75	1.21	2.28	2.65
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	0.91	1.48	2.43	2.80
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	0.96	1.52	2.55	2.90
T_8: Vermicompost @ 5 t ha^{-1}	0.78	1.25	2.32	2.68
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	0.93	1.48	2.44	2.81
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	0.99	1.62	2.62	3.01
SEm±	0.02	0.03	0.06	0.07
CD (P = 0.05)	0.07	0.11	0.19	0.22

DAP: days after planting

Table 3. Effect of integrated nutrient management on plant height (cm)

Treatment	Plant height (cm)			
	60 DAP	**90 DAP**	**120 DAP**	**150 DAP**
T_1: Control	14.04	19.81	31.03	33.07
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	15.79	23.21	34.14	34.52
T_3: 50% Recommended dose of fertilizer (RDF)	14.64	22.87	33.89	34.07
T_4: 75% Recommended dose of fertilizer (RDF)	14.87	23.10	33.99	34.21
T_5: FYM @ 25 t ha^{-1}	14.57	22.38	33.64	33.88
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	16.11	23.44	34.54	34.77
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	16.66	24.01	34.98	35.17
T_8: Vermicompost @ 5 t ha^{-1}	14.62	22.51	33.76	33.98
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	16.24	23.65	34.72	34.92
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	17.21	24.85	35.97	38.26
SEm±	0.42	0.63	0.80	0.80
CD (P = 0.05)	1.28	1.88	2.39	2.40

DAP: days after planting

Table 4. Effect of integrated nutrient management on bulk density, pH, EC and O.C

Treatments	Soil physio-chemical properties			
	Bulk density	**pH**	**EC**	**O.C**
T_1: Control	1.21	8.1	0.27	0.43
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	1.18	8.1	0.28	0.44
T_3: 50% Recommended dose of fertilizer (RDF)	1.19	8.1	0.27	0.43
T_4: 75% Recommended dose of fertilizer (RDF)	1.20	8.1	0.28	0.43
T_5: FYM @ 25 t ha^{-1}	1.11	8.0	0.27	0.45
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	1.10	8.0	0.27	0.44
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	1.10	8.0	0.27	0.43
T_8: Vermicompost @ 5 t ha^{-1}	1.14	8.0	0.26	0.45
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	1.13	8.0	0.27	0.44
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	1.12	8.0	0.27	0.44
CD (P = 0.05)	NS	NS	NS	NS

Table 5. Effect of integrated nutrient management on available nitrogen, phosphorus and potassium (kg ha^{-1})

Treatments	Available nitrogen (kg ha^{-1})	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})
T_1: Control	160.0	10.47	121.82
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	175.0	15.06	159.63
T_3: 50% Recommended dose of fertilizer (RDF)	166.0	11.02	152.00
T_4: 75% Recommended dose of fertilizer (RDF)	171.8	12.56	156.23
T_5: FYM @ 25 t ha^{-1}	177.5	17.36	167.96
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	182.3	21.3	183.44
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	187.6	25.5	186.81
T_8: Vermicompost @ 5 t ha^{-1}	181.6	19.45	161.12
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	186.8	23.4	171.11
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	192.6	25.8	177.64
SEm±	4.6	0.55	4.10
CD (P = 0.05)	14.77	1.66	12.74

Table 6. Effect of integrated nutrient management on nutrient use efficiency (NUE)

Treatments	NUE-N	NUE-P	NUE-K
T_1: Control	-	-	-
T_2: Recommended dose of fertilizer (N:P:K- 100:50:50)	40.21%	80.42%	80.42%
T_3: 50% Recommended dose of fertilizer (RDF)	39.16%	78.32%	78.32%
T_4: 75% Recommended dose of fertilizer (RDF)	35.97%	71.94%	71.94%
T_5: FYM @ 25 t ha^{-1}	6.77%	12.54%	6.77%
T_6: 50%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	16.32%	30.88%	19.04%
T_7: 75%Recommended dose of fertilizer (RDF) + FYM @ 25 t ha^{-1}	16.27%	30.99%	20.02%
T_8: Vermicompost @ 5 t ha^{-1}	10.40%	31.22%	20.81%
T_9: 50% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	21.30%	56.80%	42.60%
T_{10}: 75% Recommended dose of fertilizer (RDF) + vermicompost @ 5 t ha^{-1}	20.90%	53.81%	42.57%

3.6 Bulk Density (g cm^{-3}), pH, Electrical Conductivity (dS m^{-1}) and Soil Organic Carbon (%)

A perusal of data presented in Table 4, shows that application of different integrated nutrient management practices failed to bring about significant variation in bulk density, electrical conductivity, pH and organic carbon of soil. After the harvest of crop, all the physico-chemical properties of soil were statistically similar under various integrated management practices. Similar findings were reported by Joshi et al. (2018).

3.7 Available Nitrogen, Available Phosphorus and Available Potassium

Available nitrogen, phosphorus, and potassium in the soil were significantly affected by integrated nutrient management, as shown in Table 5. After crop harvest, the highest available nitrogen (192.6 kg ha^{-1}) was recorded in the treatment receiving 75% of the recommended dose of fertilizer (RDF) combined with vermicompost @ 5 t ha^{-1}. This increase in soil nitrogen is likely because plants typically utilize only about 50% of applied nitrogen fertilizers under optimal conditions, leaving the remainder available in the soil. The lowest available nitrogen (160.0 kg ha^{-1}) was observed in the control treatment. A similar trend was seen with available phosphorus, which peaked at 25.8 kg ha^{-1} in the 75% RDF + vermicompost treatment. In contrast, the highest available potassium (186.81 kg ha^{-1}) was found in the treatment combining 75% RDF with FYM @ 25 t ha^{-1}. These findings support the observations of Satyanarayana et al. (2002), who reported that integrating organic and inorganic fertilizers enhances soil health and fertility.

3.8 Nutrient Use Efficiency

The data on nutrient use efficiency are presented in Table 6. The efficiency of nitrogen, phosphorus, and potassium use was significantly affected by the different nutrient management practices. The highest nutrient use efficiency for all three nitrogen, phosphorus and potassium was observed in the treatment receiving the recommended dose of fertilizer (N:P:K – 100:50:50). In contrast, the lowest nutrient use efficiency was recorded in the treatment with FYM @ 25 t ha^{-1} alone.

4. CONCLUSION

The present study clearly demonstrated that integrated nutrient management (INM) significantly influenced the growth, yield and nutrient use efficiency of turmeric. Among all INM treatments, the application of 75% recommended dose of fertilizer (RDF) combined with vermicompost at 5 t ha^{-1} resulted in the highest plant emergence, leaf area index, plant height, yield, and availability of nitrogen and phosphorus. In contrast, the control treatment recorded the lowest values for these parameters. While 75% RDF + vermicompost @ 5 t ha^{-1} proved most effective for enhancing overall plant performance and nutrient uptake, the combination of 75% RDF + FYM @ 25 t ha^{-1} was superior in improving available potassium levels. These findings highlight the potential of INM strategies to sustainably increase turmeric productivity and maintain soil health. The results can aid in precise planning and efficient nutrient management practices for turmeric cultivation.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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