



RESEARCH ARTICLE

Effect of integrated nutrient management on growth and fresh root yield of radish (*Raphanus sativus* L.)

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Abstract

Radish (*Raphanus sativus* L.) cv. Japanese white is a widely cultivated root vegetable known for its rapid growth, high nutritional value and strong consumer preference. Its productivity is closely influenced by nutrient availability, while long-term dependence on chemical fertilisers has contributed to soil degradation and ecological imbalance. Integrated nutrient management (INM), which integrates organic materials with inorganic fertilisers, has emerged as a promising approach to improving soil health and ensuring sustainable yield enhancement. Despite its potential, limited information is available on how Japanese white radish responds to different INM combinations. Therefore, the present study evaluated the impact of various nutrient sources and their integrations on growth and yield of radish performance. The study included or consisted 9 treatments, T₁- nitrogen, phosphorus and potassium (NPK) (Recommended dose of fertilisers)-80:60:80 kg ha⁻¹, T₂- vermicompost at 4 tons ha⁻¹, T₃- farmyard manure (FYM) at 15 tons ha⁻¹, T₄- poultry manure at 3 tons ha⁻¹, T₅- NPK (50 %) + vermicompost (50 %), T₆- NPK (50 %) + FYM (50 %), T₇- NPK (50 %) + poultry manure (50 %), T₈- vermicompost (50 %) + FYM (50 %) and T₉- vermicompost (50 %) + poultry manure (50 %). The evaluation was done using a randomized block design (RBD) with 3 replications per treatment and the cultivar "Japanese white" was selected for the study. Among all treatments, T₅ (NPK 50 % + vermicompost 50 %) consistently exhibited superior performance by producing greater plant height, more leaves and longer foliage across all observation stages. The superior performance of T₅ (50 % NPK + 50 % vermicompost 50 %) may be attributed to the synergistic effect of organic and inorganic nutrient sources, ensuring both immediate and sustained nutrient availability. This combination also improved soil health, microbial activity and nutrient use efficiency, resulting in better growth and yield, including higher root fresh and dry weight, larger root dimensions and the maximum yield. Overall, substituting 50 % of the recommended NPK with 50 % vermicompost significantly improved vegetative growth, root development and soil health while reducing fertiliser dependence. This integrated nutrient strategy represents a sustainable cost-efficient and productive approach for radish cultivation particularly for Japanese white.

Keywords: integrated nutrient management; Japanese white; nutrient substitution; poultry manure; soil health; sustainable production; vermicompost

Introduction

Radish (*Raphanus sativus* L.) is an important root vegetable of the Brassicaceae family, widely cultivated during the rabi season (1). The plant has a racemose inflorescence with small flowers that are typically white to pale purple. Its fruit is a silique (pod) that is either indehiscent or slightly dehiscent and contains multiple seeds. Propagation is primarily through seeds which germinate and establish quickly under favourable conditions. These botanical traits are consistent among commonly cultivated varieties including the Japanese white radish. It has high nutritional value because it contains vitamin C and appreciable amounts of minerals, such as calcium, phosphorus, iron and possesses several medicinal properties, including digestive stimulation, diuretic effects and liver detoxification. It has a chromosome count of 2n = 18 and exhibits

both annual and biennial growth characteristics. Its rosette leaves, ranging from 10–45 cm depending on the cultivar, contribute to its distinct morphology (2).

This adaptable root vegetable thrives in tropical and temperate climates, making it suitable for diverse agricultural regions. Both the leaves and roots of radish are commonly consumed in salads and culinary dishes and the edible root develops from the primary root and hypocotyl (3, 4). Additionally, its immature pods known as moongre can be eaten raw or cooked as a standalone vegetable or combined with other ingredients. Medicinally, radish is beneficial for conditions such as piles, liver disorders and jaundice (5). Its leaves, rich in minerals and vitamins A and C, can also be utilised as a leafy vegetable due to their high nutritional and antioxidant potential (6).

In India, radish is cultivated over an area of approximately 204.00 ha, with a total production of approximately 3236.00 metric tons during 2021–2022. Major leading states under radish cultivation in India are West Bengal, Andhra Pradesh, Uttar Pradesh, Tamil Nadu, Maharashtra, Haryana, Chhattisgarh and Bihar (7). In Uttar Pradesh, radish is cultivated over an area of approximately 30000–35000 ha with a production of approximately 500–550 qt during the same period. Integrated nutrient management (INM) is a crucial approach for enhancing radish production while maintaining soil health and environmental sustainability. The INM optimises crop yields through a balanced application of inorganic, organic and biological fertilisers, ensuring both agronomic feasibility and commercial viability (8). Given the rising costs of chemical fertilisers, adopting INM strategies including the use of farmyard manure (FYM), poultry manure and vermicompost is essential. Vermicompost is highly effective in improving soil fertility and enhancing plant growth due to its superior microbial activity, aeration, porosity and water retention properties (9). Vermicompost plays a vital role in nutrient availability by providing balanced macro- and micronutrients, along with beneficial microbial populations and humic substances that enhance nutrient uptake and improve soil fertility (10). Poultry manure further enhances soil fertility by improving aeration and water-holding capacity (11) while FYM provides essential nutrients and enhances soil structure (12).

Recent studies highlight integrating organic and synthetic fertilisers in reduced quantities can optimise radish growth while minimising chemical dependency (13, 14). The application of vermicompost leachates or foliar sprays has improved crop establishment, as observed in tomatoes (15) and strawberries (16). Furthermore, combining vermicompost with chemical fertilisers has shown enhanced yield in crops like brinjal (17). These findings emphasise the importance of sustainable nutrient management practices in radish cultivation (Fig. 1).

By promoting soil fertility through organic inputs and reducing excessive reliance on chemical fertilisers, INM contributes to food sustainability and long-term agricultural resilience. Sustainable radish production ensures improved food security by maintaining soil health, reducing environmental degradation and increasing the availability of nutritious food. Thus, integrating organic and biological fertilisers in radish cultivation serves as a

model for balancing productivity with ecological responsibility, ultimately strengthening food systems for future generations.

Materials and Methods

The study area and weather conditions

The study was conducted during the rabi season of 2021–2022 at the Horticulture Research Farm, Department of Horticulture, Babasaheb Bhimrao Ambedkar Central University Lucknow, Uttar Pradesh, India. Seeds of radish (*R. sativus*) were procured from the Indian Institute of Vegetable Research (IIVR), Varanasi, India. Sown during July still rabi crop: harvesting time: October to December in the cropping years 2021–2022. The experimental site was situated between latitudes 23°15'58.04" N and 23°15'19.44" N and longitudes 87°50'34.29" E and 87°50'43.95" E. The soil at the site was classified as silt loam, with a composition of approximately 27.5 % sand, 47.4 % silt and 25.1 % clay. At a soil depth of 15–30 cm, the particle density ranged from 2.60–2.65 mg m⁻³, the bulk density ranged from 1.30–1.40 mg m⁻³ and the porosity ranged from 45–50 % all within normal ranges. The average soil pH and conductivity were around 6.8 and 0.3 dsm. The average atmospheric temperature for the rabi season of cropping year 2021–2022 was 15–25 °C, with a minimum temperature of 10–15 °C and a maximum temperature of 33.92 °C and a relative humidity of 92.37 %. Although it can tolerate moderate day lengths, high temperatures are detrimental, leading to tough, pungent and misshapen roots. The best sowing times are during the cooler months, such as November to December in India to avoid heat stress.

Experimental design and details

The experiment was laid out in a randomized block design (RBD) comprising 9 treatments with 3 replications. The treatments included:

- T₁- NPK (RDF)-80:60:80 kg ha⁻¹
- T₂- vermicompost at 4 tons ha⁻¹
- T₃- FYM at 15 tons ha⁻¹
- T₄- poultry manure at 3 tons ha⁻¹
- T₅- NPK (50 %) + vermicompost (50 %)
- T₆- NPK (50 %) + FYM (50 %)

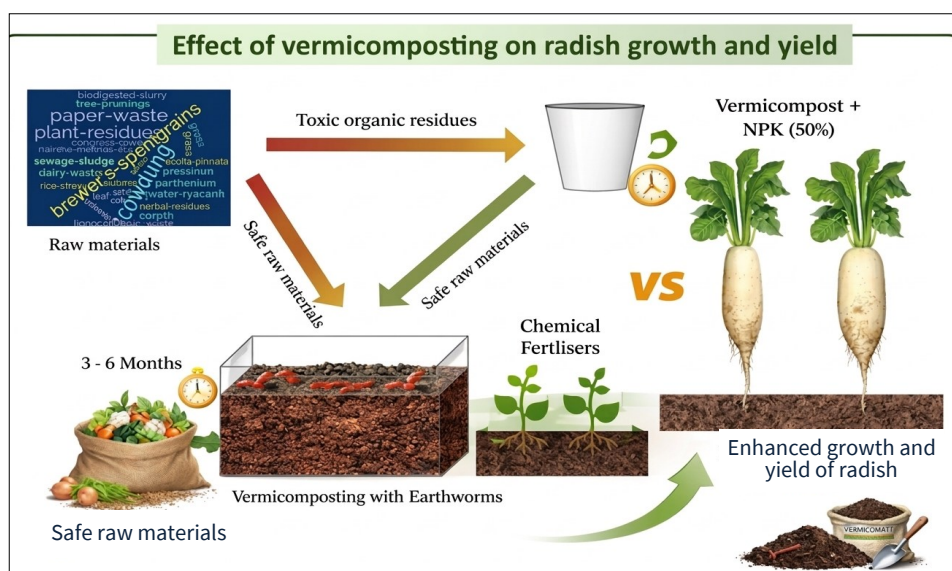


Fig. 1. Conceptual overview of vermicompost-based integrated nutrient management and its influence on growth and yield of radish.

T₇- NPK (50 %) + poultry manure (50 %)

T₈- vermicompost (50 %) + FYM (50 %)

T₉- vermicompost (50 %) + poultry manure (50 %)

In treatment T₅ half of the recommended NPK dose was applied using inorganic fertilisers, with the remaining half supplied through vermicompost. This substitution was not based on strict nutrient equivalence instead, vermicompost was used as an organic supplement to enhance nutrient supply while also improving the soil's physical, chemical and biological properties within an INM approach. The experimental field underwent extensive ploughing and cultivation, utilising a combination of a cultivator and disc harrow, followed by planking and levelling to achieve optimal soil texture.

Plant material, seed treatment and crop establishment

The seeds of radish the cultivar “Japanese white” of radish was used in the present study. It is a widely cultivated variety known for its long, cylindrical, smooth, white roots with mild pungency, rapid growth and good market acceptability. were procured from the IIVR, Varanasi, India as the institute is a premier national centre dedicated to the improvement, conservation and distribution of vegetable crop germplasm. The IIVR maintains genetically pure, well-characterised and regionally adapted cultivars of radish, ensuring high-quality seed material for research purposes. Procuring genotypes from IIVR not only guarantees authenticity and traceability of the plant material but also provides access to varieties widely accepted for their agronomic performance, market preference and suitability for scientific evaluation. This ensures reliability and reproducibility of experimental results while aligning the study with nationally recognised standards of seed quality. The seeds of the “Japanese white” cultivar were treated with carbendazim at a rate of 2 g kg⁻¹ seed prior to sowing to protect against seed-borne and soil-borne fungal pathogens. Planting occurred in November, with seeds spaced at 30 (row) × 15 cm (plant) on ridges measuring 1.50 × 1.50 m.

Manure and fertiliser

The recommended basal doses of phosphorus and potassium were applied as single super phosphate (SSP) and muriate of potash respectively, during field preparation. Nitrogen was applied through urea in split doses, with 50 % applied as basal and the remaining 50 % in two equal top dressings at 30 and 45 days after transplanting (DAT), as per treatment specifications. Organic amendments, including FYM and vermicompost, were applied as basal doses during field preparation and thoroughly and uniformly incorporated into the soil prior to sowing to ensure enhanced nutrient availability

and improved soil health. The crop was maintained according to the recommended package of practices throughout the growing period. The N, P₂O₃ and K₂O contents of the organic sources were within the standard ranges: vermicompost contained 1.0–2.0 % N, 0.5–1.5 % P₂O₃ and 0.5–1.5 % K₂O FYM contained 0.5–1.0 % N, 0.2–0.5 % P₂O₃ and 0.5–1.0 % K₂O and poultry manure contained 1.5–3.0 % N, 1.0–2.5 % P₂O₃ and 1.0–2.0 % K₂O, varying based on the source and decomposition stage.

Observational procedure

A total of 4 plants were chosen arbitrarily within each plot and marked for the purpose of documenting information related to growth and yield characteristics. These attributes encompass plant height 30, 45 and 60 DAS (cm), number of leaves 30, 45 and 60 DAS (plant⁻¹), length of leaves (cm), fresh weight (g), dry weight (g), root length (cm), root girth (cm), root diameter (cm), root yield per plot (kg) and root yield (q ha⁻¹).

Statistical analysis

The experimental data were compiled and organised using Microsoft Excel and analysed using the OPSTAT statistical software. Analysis of variance (ANOVA) for a RBD was conducted to assess the significance of treatment effects on various growth and yield parameters. Differences among treatment means were tested using the F-test at a 5 % significance level. When the F-test indicated significance, the critical difference (CD) at 5 % was calculated as a post-hoc test to compare treatment means. Additionally, the mean standard deviation (SD) and coefficient of variation (CV) were computed for all treatments (18).

Results and Discussion

Effect of integrated nutrient management on growth attributes of radish

Plant height 30, 45 and 60 DAS (cm)

Differences in plant height were observed at 30, 45 and 60 days among various treatments (Table 1 and Fig. 2). Treatment T₅ [NPK (50 %) + vermicompost (50 %)] exhibited the highest plant height at 30 days (17.08 cm), 45 days (26.45 cm) and 60 days (38.09 cm). The increased plant height in T₅ may be attributed to the synergistic effects of organic and inorganic nutrient sources, resulting in improved nutrient availability, enhanced microbial activity and better soil health. Next best treatment nearly following T₅ was T₇ [NPK (50 %) + poultry manure (50 %)]. Conversely, the lowest plant heights at 30 days (10.06 cm), 45 days (16.32 cm) and 60 days (29.05 cm) were recorded for T₁ treatment [NPK (RDF)].

Table 1. Effect of integrated nutrient management on growth parameters of radish

Treatments	Plant height (cm)			No. of leaves (plant ⁻¹)			Length of leaves (cm)		
	30 days	45 days	60 days	30 days	45 days	60 days	30 days	45 days	60 days
T ₁ - NPK (RDF)	10.06	16.32	29.05	3.32	9.09	11.04	5.87	13.45	11.08
T ₂ - vermicompost at 4 tons ha ⁻¹	11.02	18.67	31.03	3.67	10.05	12.07	6.33	14.56	12.04
T ₃ - FYM at 15 tons ha ⁻¹	12.06	19.15	32.09	4.11	11.03	13.08	7.15	15.21	13.06
T ₄ - poultry manure at 3 tons ha ⁻¹	14.09	21.11	33.02	4.35	12.06	13.03	7.11	15.87	14.06
T ₅ - NPK (50 %) + vermicompost (50 %)	17.08	26.45	38.09	5.96	15.07	18.07	8.33	18.45	19.07
T ₆ - NPK (50 %) + FYM (50 %)	13.05	20.22	34.08	4.45	13.02	15.07	8.15	16.78	16.08
T ₇ - NPK (50 %) + poultry manure (50 %)	16.05	25.56	37.03	5.45	14.09	17.05	7.93	18.33	18.02
T ₈ - vermicompost (50 %) + FYM (50 %)	15.05	23.42	35.07	3.56	14.01	15.07	6.53	16.11	15.07
T ₉ - vermicompost (50 %) + poultry manure (50 %)	12.08	24.15	36.04	4.10	11.07	16.05	6.76	14.78	17.07
S. Em (±)	0.64	1.02	1.60	0.21	0.57	0.68	0.33	0.76	0.71
CD (p = 0.05)	1.95	3.10	4.86	0.64	1.74	2.07	1.02	2.29	2.15

DAS: days after sowing; RDF: recommended dose of fertilisers; FYM: farmyard manure; NPK: nitrogen, phosphorus and potassium. Values are mean of replicated observations. S. Em (±), standard error of mean; CD, critical difference at 5 % level of significance.

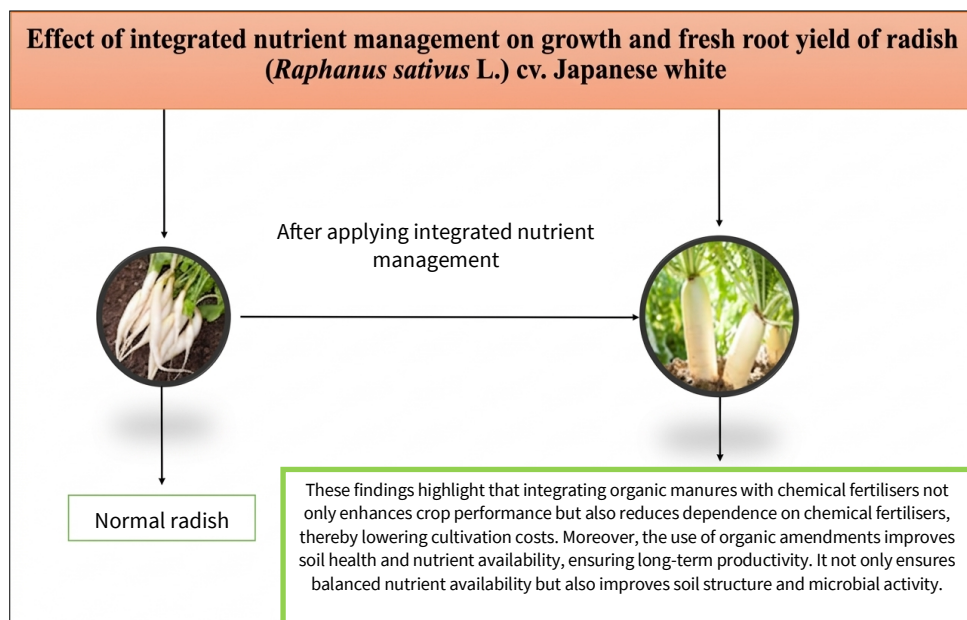


Fig. 2. Effect of integrated nutrient management on growth and fresh root yield of radish.

Number of leaves 30, 45 and 60 DAS (plant⁻¹)

Significant differences were observed in number of leaves among treatments at 30, 45 and 60 days after sowing (DAS). Treatment T₅ [NPK (50 %) + vermicompost (50 %)] produced the highest leaf counts: 5.96, 15.07 and 18.07 leaves per plant at 30, 45 and 60 DAS respectively. The next highest was T₇ [NPK (50 %) + poultry manure (50 %)], with 5.45, 14.09 and 17.05 leaves per plant. The lowest number of leaves were recorded for T₁ [NPK (RDF)], with 3.32, 9.09 and 11.04 leaves at the respective intervals. The increase in number of leaves may be attributed to the synergistic effects of combining organic and inorganic nutrients, which improved nutrient availability, soil health and vegetative growth.

Leaf length 30, 45 and 60 DAS (cm)

Significant variations in leaf length were observed among the treatments at 30, 45 and 60 DAS. Notably, there were significant variations among treatments in terms of leaf length. The T₅ treatment [NPK (50 %) + vermicompost (50 %)] exhibited the maximum leaf length of 8.33 cm, 18.45 cm and 19.07 cm at 30, 45 and 60 DAS respectively. The second-highest leaf length was recorded in plots treated with NPK (50 %) + poultry manure (50 %), with values of 7.93 cm, 18.33 cm and 18.02 cm at 30, 45 and 60 DAS respectively. In contrast, the T₁ treatment [NPK (RDF)] recorded the minimum leaf length, measuring 5.87 cm, 13.45 cm and 11.08 cm at 30, 45 and 60 DAS respectively. The increased leaf length may be attributed to enhanced cell elongation and expansion, which improves leaf area and photosynthetic efficiency, thereby supporting better root development in radish.

The combined utilisation of organic and chemical fertilisers exerts a more pronounced positive influence on microbial biomass and consequently on soil health than relying solely on organic fertilisers. Under favourable conditions for their proliferation, microorganisms demonstrate efficient nutrient dissolution, rendering them accessible to plants (19). Vermicompost is rich in bioactive substances, such as humic acids and plant growth regulators, including cytokinin, gibberellins and auxins, as recently confirmed by two studies (20, 21). However, their concentration vary depending on the source material and composting conditions and therefore cannot be expressed as fixed percentages. These compounds play a significant role in enhancing plant growth and

development. These components play a pivotal role in improving plant growth and augmenting crop yield (22). The notable enhancement in various growth characteristics may be attributed to the supplementation of primary and secondary nutrients. This supplementation, achieved through a combination of vermicompost and inorganic fertilisers, increased plant auxin levels, chlorophyll synthesis, nitrogen metabolism and photosynthetic activity. Consequently, these improvements contributed to an overall enhancement in plant height, length and leaf count. Similar outcomes have been reported by other researchers (23–27).

Yield attributes of radish

Fresh weight of roots (g)

Significant differences in fresh root weight were observed among the treatments (Table 2). Treatment T₅ [NPK at 50 % + vermicompost 50 %] achieved the highest fresh root weight of 119.08 g. This was followed by T₇ [NPK 50 % + poultry manure 50 %] with 112.08 g. The lowest fresh root weight, 90.08 g was recorded under T₁ [NPK 100 % of the recommended dose]. The increase in fresh root weight may be attributed to enhanced photosynthesis and more efficient translocation of assimilates from the leaves to storage roots, resulting in greater biomass accumulation. Moreover, integrated nutrient management improves soil structure and moisture retention, supporting better root growth and development.

Dry weight of roots (g)

Significant differences in dry root weight were observed among the treatments (Table 2). Treatment T₅ (50 % NPK + 50 % vermicompost) recorded the highest dry root weight of 21.09 g, followed by T₇ (50 % NPK + 50 % poultry manure) with 19.07 g. The lowest dry root weight was found in T₁ (100 % NPK recommended dose) at 10.09 g. The increased dry root weight is likely due to enhanced assimilate accumulation and more efficient photosynthate partitioning to the storage root, which is particularly important for Japanese white radish because greater dry matter accumulation supports better root quality and development.

Root length (cm)

Significant differences in root length were observed among the treatments (Table 2). Treatment T₅ (50 % NPK + 50 % vermicompost)

Table 2. Effect of integrated nutrient management on the yield parameters of radish

Treatments	Fresh weight of root (g)	Dry weight of root (g)	Root length (cm)	Root diameter (cm)	Root yield per plot (kg)	Root yield (q ha ⁻¹)
T ₁ - NPK (RDF)	91.22	10.57	11.08	3.14	6.13	297.7
T ₂ - vermicompost at 4 tons ha ⁻¹	95.43	12.63	12.13	3.25	6.31	312.5
T ₃ - FYM at 15 tons ha ⁻¹	96.34	13.54	13.12	3.69	7.71	321.5
T ₄ - poultry manure at 3 tons ha ⁻¹	99.07	14.43	14.06	4.11	8.43	327.1
T ₅ - NPK (50 %) + vermicompost (50 %)	119.34	21.13	19.17	4.53	9.24	401.2
T ₆ - NPK (50 %) + FYM (50 %)	111.34	17.86	17.09	3.91	8.35	370.7
T ₇ - NPK (50 %) + poultry manure (50 %)	113.1	18.76	18.05	4.10	9.02	380.7
T ₈ - Vermicompost (50 %) + FYM (50 %)	109.61	16.81	15.07	3.78	8.22	367.3
T ₉ - Vermicompost (50 %) + poultry manure (50 %)	110.18	15.88	16.10	3.38	7.24	342.6
S. Em (±)	0.42	0.33	0.02	0.01	0.02	0.80
CD (p = 0.05)	1.28	1.00	0.07	0.05	0.08	2.43

RDF: recommended dose of fertilisers; FYM: farmyard manure; NPK: nitrogen, phosphorus and potassium. Values are mean of replicated observations. S. Em (±), standard error of mean; CD, critical difference at 5 % level of significance.

resulted in the longest root length of 19.09 cm, highlighting the beneficial impact of INM on root growth. The second highest root length of 18.01 cm was recorded in treatment T₇ (50 % NPK + 50 % poultry manure). Conversely, the shortest root length of 11.09 cm occurred in treatment T₁ which used 100 % of the recommended NPK dose alone. The increased root length in the integrated treatments may be due to enhanced soil structure and aeration, promoting better root penetration and elongation. This effect is especially crucial for Japanese white radish, which develops long, cylindrical roots that require favorable soil conditions for optimal growth. These results align with previous studies that have shown that INM promotes root development in radish (28–30).

Root diameter (cm)

Significant variations in root diameter were observed among the treatments (Table 2). Treatment T₅ (50 % NPK + 50 % vermicompost) recorded the highest root diameter of 4.54 cm. This was followed by treatment T₇ (50 % NPK + 50 % poultry manure) with a root diameter of 4.11 cm. The smallest root diameter of 3.11 cm was observed in treatment T₁ which used 100 % of the recommended NPK dose alone. The increased root diameter in INM treatments may be attributed to enhanced cell division and enlargement, supported by improved nutrient availability, better

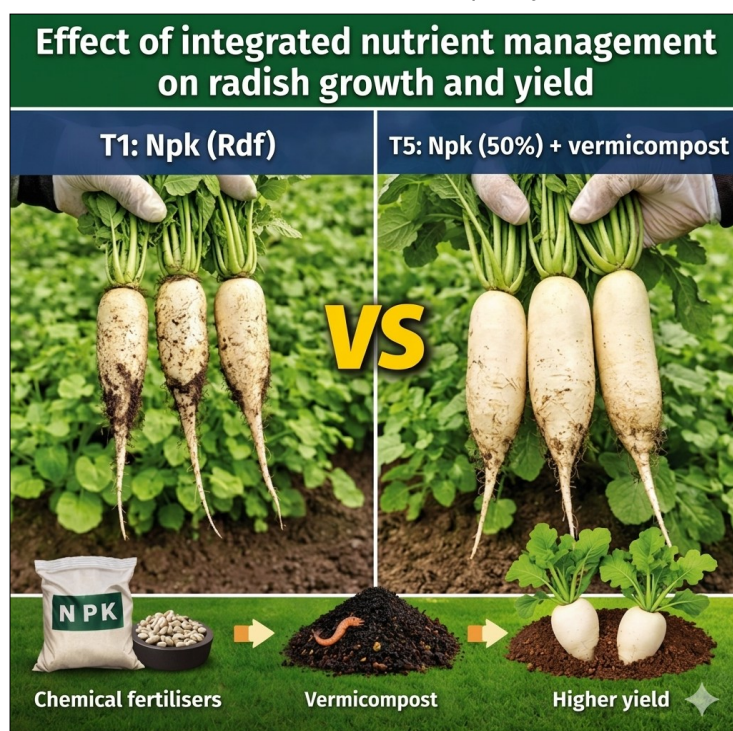
soil aeration and increased microbial activity. These findings align with those of previous studies (31–33).

Root yield per plot (kg)

Significant variations in root yield per plot were observed among the treatments (Table 2 and Fig. 3). Treatment T₅ which combined NPK at 50 % of the recommended dose with vermicompost at 50 %, recorded the highest root yield per plot at 9.24 kg. Treatment T₇ which combined NPK at 50 % with poultry manure at 50 %, yielded 9.02 kg. In contrast, the lowest yield of 6.13 kg was recorded under treatment T₁ which used 100 % of the recommended NPK dose alone. The increased root yield may be attributed to enhanced photosynthetic efficiency and improved translocation of assimilates from source to sink, leading to better root development and greater biomass accumulation. This response is particularly important for Japanese white radish, where an efficient nutrient supply supports the growth of larger, well-formed storage roots.

Root yield (q ha⁻¹)

When expressed on a hectare basis, treatment T₅ (50 % NPK + 50 % vermicompost) recorded the highest yield of 401.43 q ha⁻¹, demonstrating the superior efficiency of integrating organic inputs with reduced chemical fertiliser doses. Treatment T₇ (50 % NPK + 50 % poultry manure) achieved the next highest yield at

**Fig. 3.** Comparative effect of recommended dose of fertilisers and integrated nutrient management on growth and yield of radish.

380.46 q ha⁻¹, further supporting its effectiveness in enhancing root production. In contrast, the lowest yield of 297.09 q ha⁻¹ was recorded under treatment T₁ [NPK (100 % of the recommended dose)] indicating that the sole application of inorganic fertilisers was comparatively less effective in improving root yield. These findings align with those of previous studies (34, 35).

The application of organic fertiliser leads to elevated levels of total organic carbon in the soil, whereas the use of chemical fertiliser causes the amount of total organic carbon to decrease and basic cation contents, along with a decrease in soil pH. Consequently, this positive impact on the soil brings about modifications in soil structure, ultimately contributing to increased long-term yields (36). By breaking down and turning organic waste into beneficial compost that may help with the development of root length and root girth, earthworms significantly contribute to soil fertility and productivity (37). Vermicomposting produces chemicals that promote plant growth, which cause cell division, multiplication and elongation to occur more quickly in the meristematic zone of the plant. The availability of more nutrients and their delayed release, which coincides with the radish root's stage of development, along with the enhanced root development and root aeration, may be the reason for their greater efficacy. Similar reports were previously reported in radish (38–40).

Conclusion

The present study demonstrated that Integrated Nutrient Management (INM) practices play a vital role in enhancing the growth and yield of radish (*Raphanus sativus* L.) cv. Japanese white. Among the treatments, the combined application of 50 % NPK with 50 % vermicompost (T₅) proved to be the most effective, recording maximum plant height, number of leaves, leaf length, root weight, root length, root diameter and overall yield (401.2 q ha⁻¹). The substitution of 50 % of the recommended nitrogen, phosphorus and potassium (NPK) dose with poultry manure also produced comparable results, further emphasising the potential of organic inputs in sustainable radish cultivation.

The findings of this study can benefit farmers by showing that partially replacing chemical fertilisers with organic sources can reduce input costs, improve soil health and support sustainable crop production. Additionally, INM practices enhance nutrient use efficiency and help minimise the environmental risks associated with excessive chemical fertiliser use. Future research could explore long-term field studies to assess the sustainability of these practices under various agro-climatic conditions, with a focus on their impact on soil fertility, nutrient dynamics and economic returns in radish cultivation. Thus, incorporating organic fertilisers into conventional farming systems is a viable strategy for achieving higher yields economic sustainability and resilient farming practices.

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Authors' contributions

The conceptualisation of the study was carried out by DKM, SK and RL. The methodology was designed by DKM, RKM, RL and DSM while the implementation of experiments in the field was undertaken by DKM, VSM and SKR. The original draft of the manuscript was prepared by DKM, RL and SK, whereas RKP and VSM contributed to writing, review and editing the final version of the manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

We hereby declare that the present paper is based on the original research work. The findings, analysis and interpretations presented in this manuscript reflect independent academic effort and genuine scholarly inquiry. We further certify that the use of Artificial Intelligence (AI) tools in the preparation, writing and refinement of this manuscript has been limited to less than 10 % and solely for language improvement, formatting or proofreading purposes.

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