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RESEARCH ARTICLE

# Nutrient management through organic amendments to ensure sustainable and economic cultivation of radish

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## Abstract

Radish cultivation heavily relies on fertilizers, adversely affecting soil health. Shifting to organic practices is crucial for sustainability. This study explores combinations of organic amendments (farmyard manure, vermicompost, and poultry manure) to enhance radish growth and yield economically. Ten treatments were tested using a Randomized Block Design. One-way ANOVA, correlation, and regression analyses were conducted. The combination of 50% vermicompost and 50% poultry manure yielded the best results in plant height, leaf growth, fresh and dry weights, and root size. The highest yield (280 q/ha) was achieved with this combination, followed closely by 75% vermicompost and 25% poultry manure (245 q/ha), and 50% farmyard manure with 50% poultry manure (228 q/ha). This combination also proved the most economically and environmentally sustainable, with a benefit-cost ratio of 2.48. Compared to the control, it delivered a gross return 2.44 times higher and a net return 2.85 times higher. Incorporating poultry manure and vermicompost as nutrient sources in radish cultivation is a scientifically sound and economically viable approach, contributing to sustainable agriculture and aligning with UN Sustainable Development Goals.

## Keywords

economic parameters; farm yard manure; growth; poultry manures; sustainable production; vermicompost

## Introduction

Radish (*Raphanus sativus*) is a widely cultivated root crop, thriving in regions ranging from temperate to tropical climates. The tender-fusiform roots of radish are utilized as vegetables, prized for their rich mineral content, including calcium, potassium, and phosphorus, along with substantial fiber, vitamin C (ascorbic acid), and water content (1). European radish cultivars typically yield 9-12 tons per hectare within a short cultivation period of 30-35 days. In contrast, Asiatic cultivars exhibit higher productivity, ranging from 20-30 tons per hectare over a slightly extended growth duration of 45-55 days (2). The Quantitative Evaluation of the Fertility of Tropical Soils (QUEFTS) model has provided insights into the nutritional requirements of radish plants. Predicting balanced needs for nitrogen (N), phosphorus (P), and potassium (K) at 2.15, 0.45, and 2.58 kg, respectively, the model indicates the fertilizer-intensive nature of radish cultivation. Simulated balanced removal of N, P, and K by the fleshy root to produce

1000 kg of radish is projected at 1.34, 0.30, and 1.93 kg, highlighting the resource demands of radish farming (3). The edible portion of radish, a modified taproot, is prone to nitrate accumulation, akin to other root crops such as beetroot, carrot, and turnip. Elevated nitrate levels are often attributed to nitrogen application from inorganic sources, raising concerns about potential health risks, including gastrointestinal cancer. Consequently, there is a growing trend towards the consumption of organically grown foods, driven by the promise of nutritious and safe produce. The market for organic foods is expanding at an annual rate of 12-15%, reflecting a broader societal shift towards healthier and more sustainable agricultural practices.

Intensive large-scale farming practices, coupled with the indiscriminate application of chemical fertilizers and pesticides, exert detrimental effects on soil health, contributing to the suppression of soil microbial populations and exacerbating land degradation. This phenomenon manifests in the loss of soil organic matter, decline in soil fertility, erosion, and soil toxicity (4, 5). Commonly, agroecosystems employ inorganic fertilization, primarily N, P, and K, to enhance soil fertility and crop productivity. However, this prevalent strategy has consequences for soil health, particularly in terms of soil organic carbon (SOC) and total nitrogen (TN) sequestration, crucial factors in climate change mitigation (6). The dynamic and uncertain correlation between N fertilization and soil carbon arises from the increase in crop biomass and carbon input into the soil due to N fertilization. Concurrently, N fertilization enhances microbial biomass, leading to heightened biodegradation of soil carbon (7). The resultant reduction in soil organic matter induces alterations in the physical structure of the soil, thereby influencing various associated soil physiological processes (8). This interplay underscores the intricate relationship between agricultural practices, soil health, and their implications for broader environmental considerations.

The prevailing circumstances characterized by health risks and environmental degradation, stemming from the excessive use of inorganic nutrient sources, underscore the imperative to transition from inorganic to organic agricultural practices. However, existing regulations on nitrogen-based fertilizers pose challenges to crop cultivation production and economics. Numerous studies advocate for the adoption of organic nutrient sources as a viable alternative for sustainable and economically viable crop production. Soil organic matter (SOM) stands out as a superior source of plant nutrition, with the application of soil organic amendments being an effective strategy for maintaining a robust microbial population and activities. This, in turn, leads to enhanced biomass carbon and overall soil health (9, 10). The sensitivity of soil microbial biomass as an indicator makes it crucial for assessing changes in SOM, which are contingent upon land use patterns, agricultural practices, and the application of nutrient sources, as well as the local flora (11). Categorization of SOM, based on decomposition rates, distinguishes it into labile (active), slow (medium), and stable (resistant, passive, inert) fractions. The water-extractable fraction of organic matter (WEOM), particularly the most labile component, serves as a significant energy and substrate source for soil microorganisms, contributing to soil nutrient dynamics (12). Notably, particulate organic matter (POM) and the light fraction of organic matter (LFOM) within the labile category play pivotal roles in nutrient cycling and soil structure preservation. These fractions serve as potential indicators of long-term changes in soil quality due to crop management practices such as organic matter inclusion, organic amendments, and crop rotation (13). Conversely, stable or resistant SOM fractions constitute a source of long-term carbon storage in the soil, providing plant nutrients through mineralization over an extended period (14). This scientific perspective emphasizes the intricate interplay between soil organic fractions and their response to various agricultural practices, offering insights into sustainable approaches for maintaining soil health and productivity.

In a brief-term experiment, no-till technology was observed to foster the formation of soil aggregates, providing physical protection to labile SOM against decomposition. In contrast, strip-till technology demonstrated the highest accumulation of labile SOM (15). Consequently, the experiment affirmed two viable approaches for preserving SOM. A study underscored the importance of adopting agricultural practices that contribute effectively to atmospheric carbon sequestration, manifesting as SOC (16). Noteworthy practices include agroforestry, the application of organic amendments and biochar, cover cropping, crop rotation, land-use pattern shifts from cropland to grassland, conservation agriculture, and peatland restoration (17). In another abbreviated experiment, the combination of biochar and sodium proved effective in facilitating the conversion of mineral nitrogen into SOM. This resulted in reduced nitrate content in beetroot, mitigating health risks, enhancing SOM, and increasing yield by 2.4 t/ha (18). The application of farmyard manure (FYM), cattle manure, and pig manure elevated SOC by 50%, 32%, and 41%, respectively (19). Application of organic manures demonstrated varying impacts on SOM, with rabbit manure exhibiting the highest effect, followed by cow dung, pig manure, green manure, and poultry manure. Notably, poultry manure significantly enhanced soil nutrient status, crop yield, and fruit quality in okra (20). Over the long term, FYM application was found to conserve SOM, enhance nutrient cycling through increased microbial biomass (21), and elevate enzyme activities (22). The application of vermicompost emerged as a promising organic amendment, positively affecting soil fertility by improving aeration, soil porosity, pH, electrical conductivity (EC), and SOM, thereby promoting superior crop yield (23). Additionally, vermicompost application increased microbial biomass in the rhizosphere, fostering plant growth and disease suppression (24). It further contributed to enhanced SOC, water-holding capacity, aeration, and soil porosity (25), facilitating plant nutrient uptake and vegetative growth (26).

Utilizing high-efficiency organic matter or biologically active amendments in the cultivation of radishes represents a strategic approach to ensuring sustainable production, mitigating the impacts of climate change, and fostering economic viability in alignment with the United Nations' Sustainable Development Goals, particularly those related to food and nutritional security.

To optimize radish crop yields, it is imperative to enhance soil fertility through the incorporation of organic manures or biologically active amendments with proven efficacy. Various organic amendments commonly employed in crop cultivation include FYM, vermicompost, poultry manure, mustard cake, biofertilizers, and indigenous preparations such as panchgavya and jeevamrita. However, the absence of a standardized organic practice specifically tailored for achieving a high economic yield in radish cultivation remains a gap in current scientific literature. Further research is warranted to establish a comprehensive and effective organic cultivation protocol for maximizing radish yields while ensuring long-term food security and environmental sustainability.

On the basis of the above, the following hypothesis was formulated: the application of organic amendments (FYM, vermicompost, and poultry manures) in different combinations is essential for the improvement in growth and yield of radish and to ensure the higher net return to the farmers.

## Materials and Methods

### *Location of experiment*

The investigation was conducted at CRC Farm, School of Agriculture, ITM University Gwalior (MP), located in Gwalior district at approximately 24˚10' N latitude, 74˚54' E longitude, and an altitude of 582.17 m above mean sea level. The experimental site experiences a humid subtropical climate, characterized by a sandy loam soil type, as determined through analysis of physical soil parameters. The climatic conditions are classified as subtropical, featuring a cooler period lasting more than three months and an annual rainfall of 900 mm, rendering it conducive for the cultivation of radishes. These environmental factors align with the suitability criteria for radish cultivation in the region

### *Treatments details*

The experimental design employed in this study was a Randomized Block Design (RBD) featuring ten distinct treatments. These treatments comprised organic nutrient sources, specifically farm yard manure (FYM), vermicompost, and poultry manures, either applied individually or in various combinations. The ten treatments were as follows: T1 (Control, representing no nutrient management), T2 (100% farm yard manure), T3 (100% vermicompost), T4 (100% poultry manures), T5 (75% farm yard manure + 25% vermicompost), T6 (50% farm yard manure + 50% vermicompost), T7 (75% farm yard manure + 25% poultry manures), T8 (50% farm yard manure + 50% poultry manures), T9 (75% vermicompost + 25% poultry manures), and T10 (50% vermicompost + 50% poultry manures). The experiment was structured in a manner consistent with scientific rigor, utilizing the Randomized Block Design to account for potential variability within blocks. The specified treatments allowed for the systematic examination of the impact of organic nutrient sources and their combinations on the experimental variables. The reference to the control group (T1) served as a baseline for assessing the effects of nutrient management on the observed outcomes.

### *Agronomic practices*

The experimental selection employed Mino Early Long White, an open-pollinated daikon radish cultivar well-suited for growth across spring, summer, and autumn seasons. Seed sowing occurred with a spacing of 30 cm x 25 cm following thorough land preparation to achieve fine tilth. Ten days before sowing, organic amendments, including farmyard manure, vermicompost, and poultry manure, were applied as per the treatments outlined in Table 1. To deter pest incidence, a neem oil spray (5 mL neem oil per liter of water) was administered 30 days post-seed sowing. To maintain optimal moisture levels, regular irrigation was conducted at 10-day intervals. Manual weeding activities were performed at 20 and 40 days after seed sowing, with thinning executed 15 days post-sowing. These methodological practices were designed to create conducive conditions for the cultivation of Mino Early Long White daikon radish.

**Table 1.** Quantity of organic amendments applied as per treatments (doses are given for 1 ha area).

| Treatments | Farm yard manure | Vermicompost | Poultry manure |
|---|---|---|---|
| $T_1$ [Control as no nutrients management] | - | - | - |
| $T_2$ [farm yard manure (100%) | 16 tons | - | - |
| $T_3$ [vermicompost (100%)] | - | 12 tons | - |
| $T_4$ [poultry manures (100%)] | - | - | 10 tons |
| $T_5$ [farm yard manure (75%) + vermicompost (25%)] | 12 tons | 3 tons | - |
| $T_6$ [farm yard manure (50%) + vermicompost (50%)] | 8 tons | 6 tons | - |
| $T_7$ [farm yard manure (75%) + poultry manures (25%)] | 12 tons | - | 2.5 tons |
| $T_8$ [farm yard manure (50%) + poultry manures (50%)] | 8 tons | - | 5 tons |
| $T_9$ [vermicompost (75%) + poultry manures (25%)] | - | 9 tons | 2.5 tons |
| $T_{10}$ [vermicompost (50%) + poultry manures (50%)] | - | 6 tons | 5 tons |

### Observations recorded

The study involved the acquisition of vegetative growth parameters, specifically focusing on plant height, incremental changes in plant height, leaf count per plant, and the length of leaves. Data were systematically gathered from a sample of five randomly chosen plants within each experimental plot. Plant height, measured in centimeters, was determined from ground level to the apex of the growing point using a meter scale. Leaf length, also in centimeters, was measured from the tip of the leaf to the point of connection with the leaf stem, including the lowest leaflets. The quantification of leaves per plant was conducted by direct counting. Observations were conducted at three distinct time points: 15 days after sowing (DAS), 30 DAS, and at the point of harvest. The resultant values were averaged to ensure representative data for subsequent statistical analysis. The percentage increment was calculated using a specified formula. This rigorous methodology ensures accuracy and reliability in assessing the vegetative growth dynamics across different stages of the plant's life cycle. The % increment was estimated by the given formula:

Increment in plant height =

$$\frac{\textit{Plant height at harvest - Plant height at specific day after sowing of seeds}}{\textit{Plant height at specific day after sowing of seeds}}$$

Yield-related parameters: Various parameters related to yield, including the initial fresh weight of plants, roots, and leaves, as well as root characteristics such as length, diameter, and girth, were systematically assessed for randomly selected specimens. The initial fresh weight of leaves and roots was measured in five randomly chosen plants using a digital weighing balance, and the resulting average values were employed for subsequent statistical analyses. Subsequently, the dry weight of leaves and roots was determined through hot air oven drying at a consistent temperature of 70°C for 24 hours. To gauge the root dimensions, including length, diameter, and girth, vernier calipers were employed post-harvest. The measurement of girth specifically targeted the midpoint of the radish root. Recording of root weights based on different treatments was conducted in each net plot, and the overall yield per hectare was calculated, considering that only 80% of the land was dedicated to radish cultivation, with the remaining 20% allocated for irrigation channels and bunds.

Economics of cultivation: The study assessed the input costs associated with radish cultivation, comprising fixed expenses such as land rent and machinery depreciation, as well as variable costs encompassing labor, seeds, irrigation, tillage operations, sowing, and harvesting activities, organic amendments, insecticides, and pesticides. These costs were determined based on prevailing market prices for a one-hectare area. Gross returns from the radish cultivation area were calculated by considering the yield obtained and prevailing market prices at the time of harvest. Net returns were derived by subtracting the total cost of cultivation from the gross returns. The economic viability of radish cultivation was further evaluated through the calculation of the benefit-to-cost (B:C) ratio, obtained by dividing the net returns by the cultivation cost for one hectare of radish.

### Statistical analysis

The observations recorded were analyzed for statistical significance at a 5% level of significance. The mean values of various treatments under each factor were compared by Duncan's multiple range test (DMRT) and have been represented as Mean ± Standard Deviation. The correlation and regression analysis was done to understand the contribution and impact of yield and related parameters on the yield of radish crops.

## Results and discussion

### Growth attributing characters

The recorded observations pertaining to plant height, length, and leaf number of radishes following the application of diverse organic nutrient sources reveal that, during the initial growth stage, the impact of these treatments was not statistically significant. This lack of significance may be attributed to the gradual release of nutrients from organic sources, namely FYM, vermicompost, and poultry manure (Table 2). The inherently slow nutrient release from these organic materials may explain the non-significant growth response observed at 15 days after sowing (DAS). However, as the growth progressed to the advanced stage at 30 DAS, a notable and statistically significant influence was observed. The most pronounced effects were noted after the application of nutrients through vermicompost (50%) and poultry manure (50%) in treatment T10, followed closely by FYM and poultry manure (50% each) in T8. By harvest time, when plant growth had reached senescence, the impact of nutrient sources became non-significant, indicating that the plants had already achieved maximum growth. It is worth noting that the Mino Early Long White cultivar used in this study has a senescence period that allows harvest after 50 DAS, potentially contributing to the divergence from findings in other studies reporting maximum radish plant height at 70 DAS (27). Contrary to some existing literature (27), which reported peak plant height in radishes at 70 DAS, our study emphasizes varietal variation. The Mino Early Long White cultivar used in our experiment exhibited maximum growth at 50 DAS, coinciding with the onset of senescence. Among the various nutrient sources investigated, poultry manure emerged as the most effective for radish cultivation, either in isolation or in combination with vermicompost or FYM. This effectiveness may be attributed to the presence of growth-promoting substances in poultry manure and vermicompost (27).

While the statistical analysis affirms a non-significant percentage increment in plant height at both levels (Fig. 1), the acceleration of growth during the early stage (between 15 and 30 days after sowing) is primarily

**Table 2.** Impact of organic nutrient sources on plant growth attributes (plant height, length, and number of leaves per plant) of radish at 30 days of sowing.

| Treatments | Plant height (cm) | Length of leaves (cm) | Number of leaves |
|---|---|---|---|
| $T_1$ | $14.133^{e} \pm 1.229$ | $13.127^{d} \pm 1.110$ | $10.400^{c} \pm 1.514$ |
| $T_2$ | $14.873^{e} \pm 0.770$ | $13.340^{cd} \pm 0.805$ | $13.333^{abc} \pm 1.981$ |
| $T_3$ | $15.493^{de} \pm 1.749$ | $13.720^{cd} \pm 1.665$ | $11.133^{bc} \pm 1.768$ |
| $T_4$ | $19.087^{abcd} \pm 1.997$ | $16.800^{abcd} \pm 1.929$ | $13.000^{abc} \pm 2.117$ |
| $T_5$ | $16.960^{bcde} \pm 1.925$ | $15.000^{bcd} \pm 1.893$ | $11.067^{bc} \pm 2.204$ |
| $T_6$ | $16.460^{cde} \pm 1.549$ | $15.120^{bcd} \pm 1.420$ | $13.333^{abc} \pm 1.048$ |
| $T_7$ | $19.100^{abcd} \pm 0.501$ | $17.487^{abc} \pm 0.503$ | $14.933^{a} \pm 0.636$ |
| $T_8$ | $20.560^{ab} \pm 0.881$ | $18.987^{ab} \pm 1.144$ | $14.400^{a} \pm 0.611$ |
| $T_9$ | $20.260^{abc} \pm 1.365$ | $18.713^{ab} \pm 1.625$ | $14.200^{ab} \pm 1.629$ |
| $T_{10}$ | $21.173^{a} \pm 0.646$ | $19.727^{a} \pm 0.923$ | $15.600^{a} \pm 2.274$ |
| SE(m)± | 1.378 | 1.423 | 1.076 |
| C.D. at 0.05 | 4.126 | 4.260 | 3.222 |

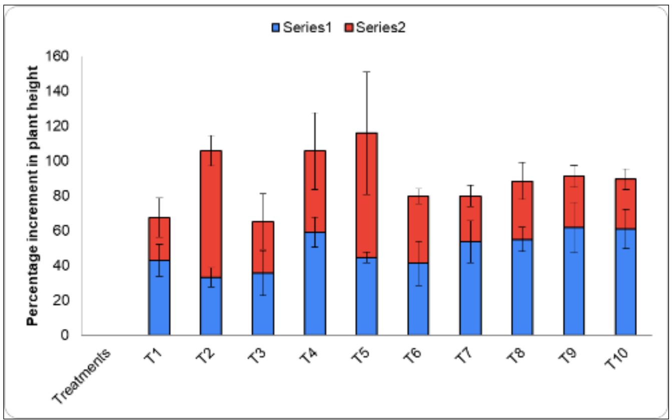


**Fig. 1.** Impact of organic nutrient sources on increment in plant height between 15 days to 30 days of sowing (Series 1) and between 30 days of sowing to harvest (Series 2).

attributed to the application of poultry manures. However, during the later stage of growth (between 30 days after sowing and harvest), the influence on growth is more pronounced with the application of FYM. This phenomenon can be rationalized by the relatively slower release of nutrients from FYM compared to poultry manures. Poultry manures exhibit rapid release of nitrogen and potassium, with 40 to 70% of total nitrogen becoming available within the first six weeks (28). This rapid nutrient availability is identified as the primary reason for the significant increase in plant height during the early phase of growth after the application of poultry manure in treatments T10, T9, and T4. Despite the constraint of poultry manure having a high concentration of ammonia, volatile fatty acids, and antibiotics, which may negatively impact anaerobic microorganisms (29), the co-decomposition of poultry manure with other feedstocks can mitigate these effects by providing additional nutrients required for anaerobes (30). This approach significantly improves the stability of microbial communities and subsequent microbial augmentation (31). The combined application of poultry manure with vermicompost (T10 and T9) or FYM (T8) in various treatments is considered responsible for the rapid decomposition and release of nutrients (32). Furthermore, the application of poultry manure and vermicompost ensures efficient absorption and assimilation of nitrogen by the plant, contributing to the enhancement of growth attributes, photosynthetic potential, and radish yield (33). Poultry manure, with its lowest C:N ratio among all organic manures used, facilitates quick mineralization and nutrient release to the soil compared to other soil amendments. The combination of poultry manure with vermicompost or FYM ensures a balanced C:N ratio and lignin:N, promoting organic matter accumulation and humus formation, thereby sustaining nutrient release over an extended period (34).

### *Fresh and dry weight of plants*

The investigation into the post-harvest fresh weight of radish plants revealed a significant influence arising from the application of diverse nutrient sources, as outlined in Table 3. Statistical analyses affirm that the utilization of vermicompost and/or poultry manures led to a substantial increase in fresh weight, exemplified by treatments T10, T9, T8, T7, and T4. Notably, poultry manures emerged as a common factor in these treatments, exerting a pronounced impact on yield-related traits, such as fresh biomass. The elevated fresh weight observed can be attributed to heightened photosynthetic activities, resulting in the accumulation of substantial amounts of starch and synthetic products within the plants. Poultry manures, in particular, demonstrated efficacy in facilitating the efficient release, uptake, and utilization of nutrients during the developmental phase (35). Synchronicity between the influence of diverse nutrient sources on both leaf and root fresh weights underscores the enhanced photosynthetic activities induced by the application of organic nutrient sources, leading to starch accumulation in radish roots. The combined application of vermicompost and poultry manure notably increased the nitrogen content in the cell sap of meristematic tissues. This enhancement ensured augmented vegetative growth and the accrual of carbohydrates, contributing to increased root and leaf development (1). Furthermore, the low C: N ratio of poultry manure was identified as a factor contributing to rapid decomposition and nutrient release, consequently resulting in the highest biomass in radish (36). Observations on dry weight, obtained through sun drying followed by oven drying of radish plants, mirrored the trends observed in fresh weight at harvest. This consistency affirms the syn-

**Table 3**. Impact of organic nutrient sources on initial fresh weight of radish plants and their parts (roots and leaves).

| Treatments | Initial fresh weight (gram) | | |
|---|---|---|---|
| | Plants | Roots | Leaves |
| $T_1$ | 219.500$^{g}$ ± 7.742 | 127.557$^{f}$ ± 8.678 | 91.947$^{f}$ ± 2.900 |
| $T_2$ | 348.890$^{de}$ ± 31.347 | 204.447$^{de}$ ± 18.986 | 144.443$^{bcd}$ ± 12.372 |
| $T_3$ | 322.223$^{ef}$ ± 27.376 | 183.333$^{ef}$ ± 30.245 | 138.890$^{cd}$ ± 7.776 |
| $T_4$ | 402.223$^{bc}$ ± 24.367 | 240.000$^{bcd}$ ± 22.193 | 162.223$^{b}$ ± 4.006 |
| $T_5$ | 372.223$^{cd}$ ± 17.462 | 223.333$^{cd}$ ± 10.185 | 148.890$^{bc}$ ± 7.776 |
| $T_6$ | 286.667$^{fg}$ ± 6.667 | 171.113$^{ef}$ ± 8.678 | 115.553$^{e}$ ± 4.005 |
| $T_7$ | 402.223$^{bc}$ ± 7.287 | 250.000$^{bc}$ ± 1.923 | 152.220$^{bc}$ ± 5.879 |
| $T_8$ | 377.780$^{cd}$ ± 4.843 | 253.330$^{bc}$ ± 5.773 | 124.443$^{de}$ ± 1.113 |
| $T_9$ | 424.443$^{b}$ ± 2.940 | 272.223$^{b}$ ± 9.685 | 152.220$^{bc}$ ± 6.758 |
| $T_{10}$ | 494.957$^{a}$ ± 10.003 | 311.113$^{a}$ ± 10.944 | 183.843$^{a}$ ± 7.078 |
| SE(m)± | 14.465 | 12.695 | 6.752 |
| C.D. at 0.05 | 43.312 | 38.01 | 20.217 |

thesis of a substantial quantity of functional biomass, encompassing both organic and inorganic materials within the plants (Fig. 2). These findings underscore the heightened nutrient uptake and biomolecule synthesis in radish plants attributable to the application of organic nutrient sources, especially poultry manures and/or vermicompost (37).

### *Yield and related parameters*

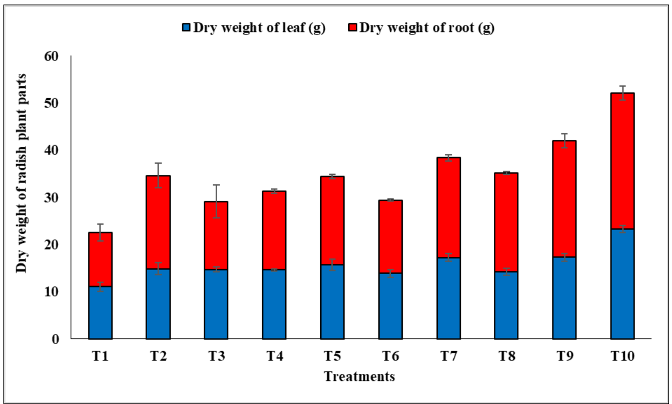


**Fig. 2.** Impact of organic nutrient sources on dry weight of radish plants.

The root morphological characteristics were markedly influenced by the application of poultry manure, either alone or in conjunction with vermicompost. This effect was particularly associated with a notable synthesis of storage products, notably starch, in the roots (Table 4). Consequently, parameters such as root length, root diameter, and root girth exhibited significant enhancements and were statistically comparable in treatments T10, T9, T8, T4, and T7. Analysis of radish root yield indicated a substantial impact ($P < 0.05$) of diverse treatments on the yield per hectare, assessed at the point of plant harvesting (Table 5). The maximum yield per hectare (280.00 q) was achieved with the incorporation of T10 [(vermicompost 50% + poultry manure 50%)], statistically on par with T9 (245.00 q), followed by T8 (228.00 q), T7 (225.00 q), and T4 (216.00 q). Conversely, the minimum yield per hectare was recorded in T1 (115.00 q) at the time of plant harvest. In root and tuber crops, the economically valuable component resides in the subterranean root or stem, formed subsequent to the translocation of photosynthates from leaves to the below-ground region. For radish, the economically significant portion is the subterranean taproot, renowned for its richness in starch, minerals, and

**Table 4.** Impact of organic nutrient sources on various root parameters of radish plants.

| Treatments | Root size related attributes | | |
|---|---|---|---|
| | Maximum root length (cm) | Diameter of root (mm) | Girth of root (cm) |
| $T_1$ | 13.333$^{d}$ ± 2.581 | 33.787$^{d}$ ± 2.023 | 9.490$^{e}$ ± 1.644 |
| $T_2$ | 21.423$^{cd}$ ± 2.252 | 36.600$^{d}$ ± 1.855 | 11.933$^{abcde}$ ± 2.319 |
| $T_3$ | 22.333$^{bcd}$ ± 1.425 | 37.777$^{cd}$ ± 2.027 | 10.000$^{de}$ ± 1.384 |
| $T_4$ | 25.257$^{ab}$ ± 1.844 | 41.110$^{abcd}$ ± 2.476 | 12.313$^{abcd}$ ± 0.357 |
| $T_5$ | 22.343$^{bcd}$ ± 1.445 | 40.537$^{bcd}$ ± 4.684 | 10.953$^{cde}$ ± 0.397 |
| $T_6$ | 24.733$^{abc}$ ± 0.313 | 39.033$^{bcd}$ ± 2.318 | 11.287$^{bcde}$ ± 0.483 |
| $T_7$ | 24.910$^{abc}$ ± 0.985 | 44.357$^{abc}$ ± 3.309 | 12.647$^{abc}$ ± 1.404 |
| $T_8$ | 26.043$^{a}$ ± 0.144 | 45.100$^{abc}$ ± 4.303 | 12.453$^{abcd}$ ± 0.451 |
| $T_9$ | 27.090$^{a}$ ± 1.118 | 45.710$^{ab}$ ± 0.511 | 13.847$^{ab}$ ± 0.612 |
| $T_{10}$ | 27.380$^{a}$ ± 0.692 | 48.543$^{a}$ ± 1.315 | 14.033$^{a}$ ± 0.852 |
| SE(m)± | 1.201 | 2.562 | 0.889 |
| C.D. at 0.05 | 3.595 | 7.671 | 2.661 |

**Table 5.** Yield and economics of different treatments and benefit: cost ratio of organic cultivation of radish.

| Treatments | Radish yield (q $ha^{-1}$)* | Gross return (a) (Rs. $ha^{-1}$)# | Cost of cultivation (b) (Rs. $ha^{-1}$) | Net return (a-b) (Rs. $ha^{-1}$) | Benefit: cost ratio [(a-b)/b] |
|---|---|---|---|---|---|
| $T_1$ | $115^{f} \pm 7.81$ | 1,26,500 | 49,640 | 76,860 | 1.55 |
| $T_2$ | $184^{de} \pm 17.09$ | 2,02,400 | 97,640 | 1,04,760 | 1.07 |
| $T_3$ | $165^{ef} \pm 27.22$ | 1,81,500 | 97,640 | 83,860 | 0.85 |
| $T_4$ | $216^{bcd} \pm 19.98$ | 2,37,600 | 79,640 | 1,57,960 | 1.98 |
| $T_5$ | $201^{cd} \pm 9.17$ | 2,21,100 | 97,640 | 1,23,460 | 1.26 |
| $T_6$ | $154^{ef} \pm 7.81$ | 1,69,400 | 97,640 | 71,760 | 0.73 |
| $T_7$ | $225^{bc} \pm 1.73$ | 2,47,500 | 93,140 | 1,54,360 | 1.60 |
| $T_8$ | $228^{bc} \pm 5.20$ | 2,50,800 | 88,640 | 1,62,160 | 1.82 |
| $T_9$ | $245^{b} \pm 8.18$ | 2,69,500 | 93,640 | 1,75,860 | 1.87 |
| $T_{10}$ | $280^{a} \pm 9.85$ | 3,08,000 | 88,640 | 2,19,360 | 2.48 |

*CD value is 34.210 with SE(m) ± as 11.426; #Rate of radish = Rs. 1100 per quintal

water content.

The enhanced yield of radish roots observed in treatments incorporating poultry manures and/or vermicompost as nutrient sources correlates with the synchronized growth and biomass production in radishes. Root yield, whether measured per plot or hectare, is intricately linked to individual plant yield and the fresh weight of radish roots, thereby exhibiting a direct correlation between these parameters. The combination of poultry manure with vermicompost (at ratios of 1:1 or 3:1) or farmyard manure (at a 1:1 ratio) appears to be accountable for the heightened availability of phosphorus, thereby exerting a positive influence on root growth. This improvement in root growth can be attributed to enhancements in cellular division, photosynthesis, carbohydrate metabolism, enzyme activation, and nutrient translocation (27). This phenomenon may be associated with the lower C:N ratio and lignin:N ratio observed in poultry manure, facilitating rapid mineralization and nutrient release conducive to the accelerated growth of short-duration crops such as radish. Consequently, the amplified biomass production in the plant contributes to a higher yield when compared to alternative amendments (20).

### *Economics of cultivation of radish*

An economic analysis was conducted to assess the efficacy of utilizing organic nutrient sources in radish cultivation (refer to Table 5). The overall cost of cultivation, encompassing both fixed and variable costs, was observed to be elevated across all treatments compared to the control. This increase was attributed to the supplementary expenses associated with acquiring nutrient sources. The variations in cultivation costs among different treatments were primarily attributed to discrepancies in the costs of organic sources, such as farmyard manure (FYM), poultry manures, and vermicompost, employed for nutrient provision. Gross returns were calculated based on prevailing market values of the produce, with disparities in gross returns among treatments being a consequence of yield variations. Notably, all treatments yielded greater net returns, except for T6 (Rs. 71760) compared to the control, T1 (Rs. 76860), which may be attributed to its higher gross return. The highest benefit-to-cost (B: C) ratio was recorded in T10 (2.48), followed by T4 (1.98), T9 (1.87), T8 (1.82), and T7 (1.60). These treatments exhibited significantly high B: C ratios owing to their elevated gross or net returns and relatively lower cultivation costs. While treatments such as T5 (1.26), T2 (1.07), T4 (0.85), and T6 (0.73) had B: C ratios lower than the control (T1, 1.55), their gross and net returns (excluding T6) were higher. It is imperative to note that treatments with a B: C ratio exceeding one are generally considered economically beneficial in production economics. However, for societal acceptance within the farming community, this ratio should surpass that of the control. Alternatively, treatments with a B: C ratio greater than one, coupled with high net returns, could also be deemed as profitable options. These economic findings align with corroborating research by various authors (38). Furthermore, the adoption of organic approaches, particularly those incorporating poultry manures alone or in conjunction with vermicompost or FYM, demonstrated higher benefit-cost ratios. This underscores the economic sustainability and profitability of organic production methods in contrast to conventional inorganic systems (39).

### *Correlation analysis*

Correlation analyses were conducted to assess the relationships among pivotal yield-related traits, with the exclusion of analogous traits (Fig. 3). The observed correlations exhibited a predominantly low magnitude for most parameters, with statistical significance tested at both the 0.05 and 0.01 levels. At a significance level of $P \leq 0.05$, notably low correlations ($r = 0.2$) were identified between the following pairs of traits: diameter of root (DOR) and plant height at 30 days (PH 30), girth of root (GOR) and plant height at 30 days (PH 30), initial fresh weight of leaves (IFWL) and plant height at 30 days (PH 30), maximum root length (MRL) and initial fresh weight of plant (IFWP), maximum root length (MRL) and initial fresh weight of root (IFWR), diameter of root (DOR) and initial fresh weight of leaves (IFWL), as well as girth of root (GOR) and initial fresh weight of leaves (IFWL).

At a significance level of $P \leq 0.01$, the correlation analysis revealed notable associations among several key

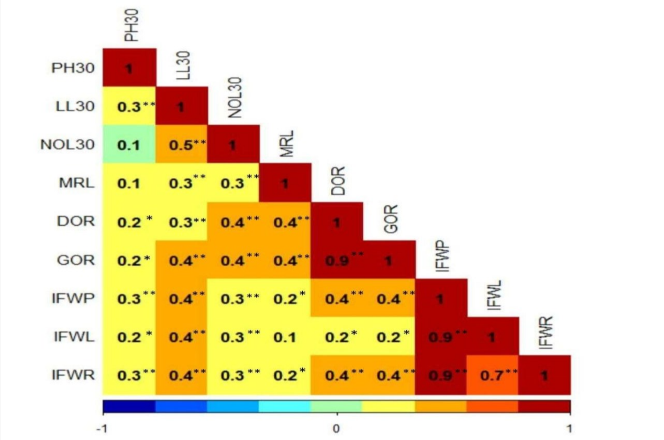


**Fig. 3.** Correlation analysis of traits significant for contributing to yield in radish [**PH30** (plant height at 30 days), **LL30** (leaf length at 30 days), **NOL30** (number of leaves at 30 days), **MRL** (maximum root length), **DOR** (diameter of root), **GOR** (girth of root), **IFWP** (initial fresh weight of plant), **IFWL** (initial fresh weight of leaves), **IFWR** (initial fresh weight of root)].

parameters in the study. Specifically, a substantial correlation coefficient (r = 0.9) was observed between the initial fresh weight of roots (IFWR) and the initial fresh weight of plants (IFWP), as well as between the initial fresh weight of leaves (IFWL) and the initial fresh weight of plants (IFWP). Additionally, a strong correlation (r = 0.7) was identified between the initial fresh weight of roots (IFWR) and the initial fresh weight of leaves (IFWL). Notably, correlations involving girth of roots (GOR) and diameter of roots (DOR) were also significant. These findings underscore the robust correlation between the initial fresh weight of roots (IFWR) and both the initial fresh weight of plants (IFWP) and leaves (IFWL). This correlation is rationalized by the pivotal role of leaves in photosynthesis, where carbohydrates are synthesized, with any excess being stored in organs such as roots in radish plants. This phenomenon likely contributes to the observed high correlation between IFWR and both IFWL and IFWP. The present study, while not supported by existing literature on organic fertilization, fills a gap in the understanding of correlations among various yield-contributing parameters. It is pertinent to note that although this study is unique in its focus on organic fertilization, prior research has elucidated the significance of leaves as the primary site of photosynthesis in enhancing dry weight in radish crops subjected to varying salt concentrations, as documented in existing literature (41).

### *Regression analysis*

The conducted regression analysis yielded statistically significant results, as indicated by the outcomes presented in Table 6. The coefficient of determination (R2) was calculated at 0.932, signifying that approximately 93.2% of the variability observed in the dependent variable, IFWR (yield of radish crops), can be elucidated by the selected independent variables. The regression model is IFWR = -7.04 + 0.068 PH30 (plant height 30 DAS) + 0.325 LL 30 DAS (Length of leaves 30 days) + 0.246 NOL 30 DAS (number of leaves 30 days) + 0.025 MRL (maximum root length) + 0.433 DOR (diameter of the root) - 1.779 GOR (girth of the root) + 0.895 IFWP (initial fresh weight of plant) -0.730 IFWL (initial fresh weight of leaves). Out of all the independent variables, variable IFWP (initial fresh weight of plant) and IFWL (initial fresh weight of leaves) were found to be significant, which confirms that these two variables or parameters have significantly influenced the yield of radish crops, which can be justified by the high degree of correlation observed.

### *Economic consideration and future scope*

The ongoing investigation presents an opportunity for the transition from chemical-intensive agriculture to organic cultivation. While a complete shift to an organic approach may initially impact crop production and economic aspects unfavorably, the application of a judicious combination of nutrient sources, such as FYM paired with poultry

**Table 6.** Various aspects of regression analysis of traits significant for contributing to yield in radish.

| Model | Sum of Squares | DF | Mean Square | F | Significance |
|---|---|---|---|---|---|
| Regression | 868517.05 | 8 | 108564.631 | 153.606 | < 0.01 |
| Residual | 57248.506 | 81 | 706.772 | | |
| Total | 925765.556 | 89 | | | |

**Regression Coefficients**

| Model | Unstandardized Coefficients | | Standardized Coefficients | t-value | Significance |
|---|---|---|---|---|---|
| | B | Std. Error | Beta | | |
| 1 (Constant) | -7.04 | 18.374 | | -0.383 | 0.703 |
| PH30 | 0.068 | 0.139 | 0.015 | 0.49 | 0.626 |
| LL30 | 0.325 | 0.937 | 0.012 | 0.347 | 0.729 |
| NOL30 | 0.246 | 0.954 | 0.009 | 0.258 | 0.797 |
| MRL | 0.025 | 0.727 | 0.001 | 0.034 | 0.973 |
| DOR | 0.433 | 0.618 | 0.041 | 0.701 | 0.485 |
| GOR | -1.779 | 1.937 | -0.056 | -0.918 | 0.361 |
| IFWP | 0.895 | 0.042 | 1.302 | 21.244 | < 0.01 |
| IFWL | -0.73 | 0.101 | -0.415 | -7.228 | < 0.01 |

[Predictors: (Constant), **IFWL** (initial fresh weight of leaves), **MRL** (maximum root length), **PH30** (plant height at 30 days), **NOL30** (number of leaves at 30 days), **DOR** (diameter of root), **LL30** (leaf length at 30 days), **GOR** (girth of root), **IFWP** (initial fresh weight of plant); Dependent Variable: **IFWR** (initial fresh weight of root)] manure or vermicompost combined with poultry manure, as delineated in the experimental findings of the current study, holds potential to mitigate these losses. The prohibitive cost associated with cultivation stands as a paramount obstacle to the widespread adoption of new technologies in crop production. Therefore, there is a critical need for research focused on devising low-cost nutrient sources utilizing biodegradable waste materials. A promising avenue for achieving cost-effectiveness in nutrient management involves biochar-based sequestration of phosphorus derived from wastewater (42) or biogas fermentation residues (43). This innovative approach transforms voluminous bio-waste into fertilizer with soil-enhancing properties (44). Another avenue worth exploring is the utilization of algae-based sequestration of nutrients from wastewater, employing organisms such as Spirulina (blue-green algae) (45), Oscillatoria (46), Anabaena (47), and Nostoc (48). These technologies show promise in developing cost-effective strategies for supplying nutrients to plants. Furthermore, the enrichment of FYM, vermicompost, and poultry manure through co-decomposition demonstrates potential as the most economical nutrient management technology for organic farming.

## Conclusion

The findings of this investigation affirm that the utilization of a combination of poultry manures and vermicompost, with each contributing 50% (T10), as organic amendments, demonstrates significant potential in promoting optimal plant growth. This is evidenced by increased biomass in terms of both fresh and dry weight, enhanced root development, and the attainment of the highest yield (280 ± 9.85 q/ha) and benefit-cost ratio (2.48) in radish cultivation. Based on the outcomes of this study, the following treatments are identified as the most economically viable combinations for radish cultivation: T10 [Vermicompost (50%) + Poultry manures (50%)], followed by T4 [Poultry manures (10 t/ha)], T9 [Vermicompost (75%) + Poultry manures (25%)], and T8 [Farmyard manure (50%) + Poultry manures (50%)]. These results underscore the economic advantages of incorporating organic amendments, specifically combinations of vermicompost, poultry manures, and farmyard manure, for enhancing radish growth and yield, ultimately leading to increased net returns for farmers. Given the detrimental impact of inorganic nutrients on both the environment and soil health, further research is warranted to delve into the efficacy and sustainable practices related to the use of organic amendments in agricultural systems.

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## Authors' contributions

SS conducted field trials from cultivation to data collection. SKS was involved in drafting of manuscript and approval of the final manuscript and performed the data analysis. DB participated in the design of the study and participated in its design and coordination. All authors read and approved the final manuscript.

## Compliance with ethical standards

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

**Ethical issues**: None.

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