Research Article:

EFFECT OF DIFFERENT ORGANIC MANURES ON THE GROWTH, YIELD, AND QUALITY OF RADISH IN INNER TERAI, NEPAL

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ABSTRACT

A field experiment was conducted from December 2021 to February 2022 at Marin Rural Municipality, Sindhuli, Nepal to evaluate the effect of various organic manures on growth, yield, and quality of radish (*Raphanus sativus* L.) cv. 'Mino Early'. The experiment was laid out in a Randomized Complete Block Design with seven treatments and three replications. Organic manures (farmyard manure, poultry manure, pig manure, vermicompost, mustard oil cake and packaged organic manure) were applied on a nitrogen-equivalent basis to ensure uniform nutrient supply across treatments along with control. Data were collected on growth parameters, yield parameters, quality parameters, weed density were analyzed using ANOVA. The results revealed significant variation among the treatments. Poultry manure significantly ($p \leq 0.05$) improved most parameters: it produced the earliest germination (6.0 days), the highest leaf length at 40 DAS (26.17cm), the maximum root length (31.08 cm) and root diameter (3.06 cm), the greatest fresh root weight per plant (148.2 g) and the highest net plot yield (8.97 kg/plot). Poultry manure also gave the largest portion of marketable roots (80.25%), the lowest forked roots (19.75%), highest total soluble solids (5°Brix), and the greatest weed suppression efficiency (65.3%) due to rapid canopy development. Mustard oil cake ranked second for several traits. In contrast, control plots recorded the lowest growth and yield parameters. Soil analysis after harvest showed that poultry manure increased soil organic matter to 2.45%, total Nitrogen to 0.13 %, available P to 68.4 kg/ha, and available K to 178.6 kg/ha, the highest among treatments. The findings of this study concluded that poultry manure is an efficient organic nutrient supplement for enhancing radish productivity and quality in the Inner Terai region of Nepal.

Keywords: Nutrient management, poultry manure, radish quality, *Raphanus sativus*, soil fertility

INTRODUCTION

Radish (*Raphanus sativus* L.) of family Brassicaceae is a widely grown cool-season root vegetable valued for its short growing cycle, high productivity, and nutritional content (Yuan et al., 2014). On a global level, research shows that radish growth is highly sensitive to temperature and nutrient availability, with ideal day/night temperatures of approximately 24 °C/18 °C and a vital dependence on nitrogen supply for both vegetative growth and heat tolerance (Oh et al., 2022). However, the translation of these general findings into locally relevant nutrient management strategies requires detailed knowledge of the regional soil constraints and manure-specific mineralization behavior.

Radish is cultivated in different agroecological zones of Nepal, from Plain Terai to Mid-hills. But the Inner Terai is a valley region between the Siwalik hills and the Mahabharat range and presents a unique production environment. Soils in the Inner Terai, including Sindhuli district, are generally loam with pH close to neutral (6.9) but low to medium organic matter (1.5–2.0%) and limited available phosphorus and potassium (CABI, 2022). Within this zone, winter temperature is highly variable with daytime high about 15°C and night-time low about 4°C, causing cold wave condition which further limits nutrient mineralization and root growth (CABI, 2022; MoALD, 2021). These pedoclimatic characteristics differ markedly from the warmer, more fertile Plain Terai and from the cooler, steeper Mid-hill soils, and agronomic recommendations cannot be transferred directly from one zone to another.

Traditionally farmers in Sindhuli use farmyard manure (FYM) or increasingly chemical fertilizers. However, the continuous use of synthetic inputs has raised concerns about the long-term soil biological activity and the depletion of organic matter (Sharma & Dhaka, 2023). However, organic manures are an alternative and their effectiveness is dependent on mineralization pathways, i.e. rate and timing of nutrient release. Poultry manure is high in uric acid and labile organic N and mineralizes rapidly within 2-3 weeks, providing an early burst of N, P and K (Brady & Weil, 2016). Mustard oil cake also decomposes quickly, but it releases glucosinolate-derived isothiocyanates during its decomposition that can initially inhibit germination and root growth (Singh et al., 2014). Pig manure and FYM have higher content of recalcitrant organic matter and thus slow and sustained mineralization (Meena et al., 2020). Vermicompost has a medium rate of nutrient release, while packaged organic manure (e.g. Black Wonder) is designed to release nutrients steadily, but with a lower total N content. Such differences in mineralization pathways directly influence the synchrony between nutrient availability and crop demand, a key factor for radish, which requires high N during early leaf expansion and consistent P and K during root thickening.

Although organic sources offer considerable advantages, research comparing the efficacy of these particular manures for radish production in the Inner Terai is scarce. Previous Nepalese investigations have primarily examined chemical fertilizers or isolated organic inputs, without nitrogen-equivalent assessments. A key gap persists in how manure-specific mineralization rates affect yield, root quality, and weed control, especially through swift canopy development.

This study was thus carried out in Marin Rural Municipality, Sindhuli, a typical Inner Terai location marked by low soil organic matter and winter cold stress. We hypothesized that, among six organic manures applied at equivalent nitrogen rates, poultry manure would yield superior radish growth, production, and quality owing to its fast mineralization suiting the crop's early nutrient needs amid December–February chill. In contrast, slower-releasing manures were predicted to slow canopy growth, diminish weed suppression, and lower marketable yields. Objectives included: assessing each manure's influence on growth, yield, quality, and weed density; connecting these to post-harvest soil fertility shifts; and confirming manure mineralization rate as the key factor in radish success in the Inner Terai.

RESEARCH METHODS

Experimental site and climatic conditions

The field experiment was conducted from December 2021 to February 2022 at a local farmer's field in Marin Rural Municipality, Ward No. 6, Sindhuli district, Nepal, located in the inner terai region of central Nepal at 27°26′43.8″ N latitude and 85°13′10.3″ E longitude with an altitude of 297.5 m above mean sea level (Fig. 1). The site was chosen because it was agro-ecologically representative. The Inner Terai has a subtropical climate and fertile alluvial soils suitable for growing winter crops, which allows the treatments to be adequately expressed during the experimental period. Furthermore, the practice of the study under farmer field conditions enhances the practical relevance and applicability of the results as it mimics the real farming situations typical of the mid-hill to Inner Terai transition zone of Nepal (MoALD, 2021; CBS, 2019).

Fig. 1. Map of Research site

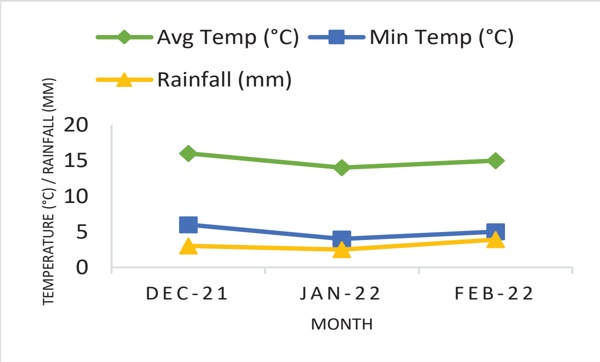

Fig. 2. Monthly weather trends during experimental period (Dec 2021-Feb 2022) Marin Rural Municipality, Sindhuli, Nepal

During the experimental period, the average temperature was 15°C during daytime, while the lowest temperature at night was around 4°C. The total rainfall recorded was 9.4 mm and the average relative humidity was 53%.

Experimental design and treatments

The experiment was designed as a Randomized Complete Block Design (RCBD) with a single factor, seven treatments (farm yard manure, pig manure, poultry manure, vermicompost, mustard oil cake, packaged organic manure and control) and three replications. The radish variety, scientifically known as *Raphanus sativus* L., and commonly known as 'Mino Early,' was used as the test crop. The total area of the experiment was 109.44 m², which was 17.1 m x 6.4 m. The area was divided into plots of 3.24 m², which was 1.8 m x 1.8 m. Each plot was provided with nine rows, each having nine plants. The population density was 81 plants, and the spacing between the plants and rows was 20 cm x 20 cm.

The organic fertilizers used as treatments were farm yard manure, pig manure, poultry manure, vermicompost, mustard oil cake, and packaged organic manure, also known as Black Wonder. The dose of the organic manures was finalized based on a nitrogen (N) equivalent approach to ensure uniform nitrogen supply across all treatments. The recommended dose of nitrogen for radish was used as the reference, and the quality of each organic manure was calculated according to its nitrogen content.

The calculation was performed using the standard formula:

Fertilizer required (Kg/ha) = Recommended N dose x 100/ % N in manure (Food and Agriculture Organization, 2000; Brady and Weil, 2016).

This approach allows for a fair comparison among the treatments by minimizing variability due to unique nitrogen supply. However, since organic manure differ in mineralization rates and nutrient release patterns, variation in crop response were expected and are discussed accordingly.

The packaged organic fertilizer ‘Black wonder’ (Double eagle brand), manufactured by Ionique Co., Ltd., Thailand and imported by Aarati Agri-Tech Pvt. Ltd., Nepal, was used in this study. According to the product level, it contains 2-2.5% nitrogen, 0.75-1% phosphorus (P_2O_5), and 2-2.5% potassium (K_2O), along with micronutrients and 20% organic matter.

The nutrient composition of the organic manures, including NPK, was analyzed before the experiment was conducted.

Land preparation and soil sampling

The experimental field was primarily ploughed followed by secondary tillage (rotavator) was performed to achieve fine tilth. The field was then leveled using a rotavator on the same date to ensure that weeds, soil clods, and stones were removed to facilitate uniform soil conditions and root development.

To assess changes in the physico-chemical properties of the soil, samples were collected before sowing and after harvesting the crops. Before sowing, samples were taken in a W-shaped pattern in each plot to obtain five subsamples. Soil samples were taken from each plot after harvest, as composite samples. The soil samples collected before sowing the seeds were collected at a depth of 15cm using a screw auger with the ‘W’ method of sampling. The collected soil was then mixed to obtain a composite sample of soil. After harvesting the crops, the soil samples were collected separately from each of the treatment plots.

Soil samples were air-dried, crushed and sieved through 2 mm and 0.2 mm sieves before laboratory analysis. Soil texture was determined using the Bouyoucos Hydrometer method. Recent modifications such as the Mwendwa Protocol have improved accuracy through specific sample pretreatments such as the use of hydrogen peroxide and 10% calgon as a dispersing agent (Mwendwa, 2020). This method is still used in recent studies to determine sand, silt and clay composition in different soil types (Fenibo et al., 2024).

The pH of the soil was determined using the electrometric method, which is an important parameter for nutrient cycling and is often measured in 1:5 soil:solution ratios for data reliability (Mosley et al., 2024). Some limitations of traditional glass electrodes have also been overcome by the development of spectrophotometric modern techniques (Bargrizan et al., 2017). Soil organic matter was determined by the Walkley and Black wet oxidation method based on the oxidation of organic carbon with potassium dichromate and sulfuric acid and still is a reference for soil carbon analysis (EI Mouridi et al., 2023).

The total nitrogen was determined by the Kjeldahl distillation method. The current study aimed to optimize the digestion temperature and distillation conditions for automatic nitrogen analyzers to improve the precision (Lee et al., 2017; Sun & Cao, 2025). Available phosphorus was determined by the Olsen’s sodium bicarbonate extraction method, modified recently to include on-line dialysis and simplified protocols for enhanced high throughput laboratory efficiency (Milham et al., 2023; Wang et al., 2023). Available potassium was estimated by flame photometry, which is still the standard quantitative method for determining soluble potassium ions in the soil extracts (Wang et al., 2022). The data of soil properties before and after harvesting are presented in Tables 1 and 2.

Organic manure analysis and application

All the organic manures were tested in the soil and fertilizer testing laboratory, Hetauda, Nepal before application for their nitrogen, phosphorus, potassium, pH, and organic matter content. The organic manures were applied one week before sowing based on the equivalence of the nutrients.

The amount of application per plot was FYM (4.0 kg), poultry manure (3.7 kg), pig manure (5.7 kg), vermicompost (1.62 kg), mustard oil cake (1.0 kg), and organic manure (1.0 kg). The fertilizer requirement was estimated using the formula:

$$F= \frac{R \times A}{C} \times 100$$

where F is fertilizer requirement (kg ha^{-1}), R is the recommended dose (kg ha^{-1}), A is area (ha), and C is nutrient concentration (%) (Dixon & Liu, 2020).

Crop establishment and cultural practices

The seeds were sown on the ridges on 4th December 2021, with a spacing of 20cm x 20cm to ensure proper root development. Two to three seeds were kept in each trench, followed by light irrigation with the help of a rose can.

The thinning of the seeds was done after ten days of germination to ensure the desired plant population.

The irrigation was applied at 7–10-day intervals depending on soil moisture conditions. Radish is a winter-season crop, and it has a relatively lower water requirement.

Weed, pest, and disease management

Weeding was done manually, and the use of herbicides was avoided. Weed flora in the experiment plots were identified based on morphological characteristics using standard weed identification manuals and field experience. The major weed species observed included Cynodon *dactylon*, *Chenopodium album*, and *Trianthema portulacastrum* L. Weed occurrence was quantified based on density (number of weeds per unit area) using quadrat method. A 1 m^2 quadrat was randomly placed in each plot, and all individual weeds within the quadrat were counted and expressed as weed density (number m^{-2}). The first weeding was done at 20 days after sowing (DAS) and 40 days after sowing (DAS).

Alternaria leaf spot disease, caused by Alternaria brassicae, was noticed during the crop growth stage. The disease was controlled by field sanitation, where the infected leaves were removed from the field.

Weed Suppression Efficiency (WSE) calculation

Weed Suppression Efficiency (WSE) can be calculated using the standard formula:

WSE (%) =Weed density in control−Weed density in treatment/Weed density in control×100 (Sharma & Chander, 2006)

Data recording and growth measurements

From each treatment of each replication, five plants were randomly selected and tagged at 25 DAS for the collection of data. Germination was recorded by counting the number of emerged seedlings at regular intervals, and the days required to reach 50%, 75% and 100% germination were calculated for each treatment.

Plant growth parameters such as the number of leaves, leaf length, leaf width, shoot length, root length, and root diameter were recorded at 30, 40, 50, and 60 DAS. Leaf length was measured from the tip of the leaf to the bottom of the petiole with the help of a ruler, and leaf width was measured at the top, middle, and bottom parts of the leaf and then averaged. Root diameter was measured with the help of a vernier caliper at three equidistant points on the root system.

Yield and biomass determination

Mino Early is an early-maturing cultivar, typically harvested at 60–75 DAS under Terai conditions, so the crop was harvested at 70 DAS, when the soil moisture was optimal. The crop was uprooted manually, and the soil that clings to the root systems was removed with care. The fresh weights of the shoot and root systems were recorded using a digital weighing balance. The dry weights were obtained by drying the samples in an oven at 70°C for 24 hours or until a constant weight is achieved (AOAC, 2016).

The net plot yield was obtained by removing the border rows to account for border effects. The net weights of the shoot and root systems were recorded individually for each plot.

Quality parameters

Marketable roots were defined as healthy and well-shaped roots to be used for consumption. The number of marketable and forked roots was counted manually and expressed as a percentage.

For quality analysis, a homogenized sample of the root was prepared by crushing 10g of root material (below 2 cm from the crown) with 10ml of distilled water. The extracted juice was filtered through muslin cloth. Total Soluble Solids (TSS) content was determined using a digital refractometer, and pH measurement was done using a calibrated digital pH meter according to AOAC (2016).

Weed density assessment

Here weed refers to the distinct types of naturally occurring plants (other than crop) that grow in the experimental plots. To analyze weed diversity (the variety and abundance of different weed species), a quadrant of 1m × 1m was placed randomly in the center of each plot at 30 DAS. All individual weed plants inside the quadrant were identified by species and counted. The quadrant-based approach allows us to record both the number of weed species present and the number of individuals per species. Weed density (the number of individual weed plants per unit area) was then calculated using the formula:

$$\text{Weed Density} = \frac{\text{No. of individual weed species that occurred}}{\text{Area of quadrant}}$$

(International Rice Research Institute, 2013; Food and Agriculture Organization, 2018).

Statistical analysis

The experiment was conducted using three replications (blocks) with five sample plants randomly selected per plot. The data was analyzed using analysis of variance (ANOVA) using MSTAT-C version 2.10 and the statistical software R version 4.2.2. The treatment means were compared using Duncan's Multiple Range Test (DMRT) at a 5% significance level, (Gomez & Gomez, 1984).

RESULTS AND DISCUSSION

Effect of different organic manures on soil properties and root quality

Initial soil (Table 1) was loam with 1.89 % SOM, pH 6.9, 0.09 % total N, 38.1 kg/ha available P and 117.6 kg/ha available K. After harvest (Table 2) all organic manures increased SOM compared to the control (1.78%) with poultry manure showing the highest SOM (2.45%), total N (0.13 %), available P (68.4 kg/ha) and available K (178.6 kg/ha) followed by vermicompost and mustard oil cake. The improved soil fertility under poultry manure treatment may have contributed to higher marketable root percentage and lower forked roots due to better nutrient availability and improved soil physical condition. Similar positive effects of poultry manure on radish growth and yield have been reported by Basnet et al. (2021).

Table 1. Physicochemical Properties of Soil sample before the experiment

S. N	Parameters	Observed values
1	Soil Texture	Loam
2	SOM%	1.89
3	Soil pH	6.9
4	Total Nitrogen%	0.09
5	Available phosphorus (Kg/ha)	38.1
6	Available potassium (Kg/ha)	117.6

Table 2. Physicochemical properties of soil after experiment with different treatments

S.N	Treatments	SOM%	Soil pH	Total Nitrogen (%)	Available phosphorus (Kg/ha)	Available potassium (Kg/ha)
1	FYM	2.10	7.1	0.11	55.2	125.3
2	Poultry manure	2.45	7.0	0.13	68.4	178.6
3	Pig manure	2.05	6.8	0.11	48.7	118.2
4	Vermicompost	2.30	6.9	0.12	62.1	142.5
5	Mustard Oil cake	2.25	6.9	0.12	58.39	135.0
6	Packaged organic manure	2.15	7.0	0.11	52.6	128.4
7	Control	1.78	6.9	0.08	36.5	109.2

Effects of different organic manure on germination percentage of radish seed

The use of various organic manures was found to have a highly significant effect ($p \leq 0.01$) on radish germination (Table 3), which took 6.0 to 13.0 DAS with a mean of 9.2 DAS. The earliest germination was observed in poultry manure (6.0 DAS), which was statistically at par with pig manure, vermicompost, and FYM, while mustard oilcake and control significantly delayed germination. Packaged organic manure was intermediate. Though moderate variability (CV = 20.19%) existed, the LSD value (3.3) ensured that the differences were significant and reliable. Early germination in poultry manure may be due to rapid decomposition, enhanced nutrient mineralization, and slightly increases in localized soil temperature generated during microbial activity which is beneficial during cool December condition in Sindhuli (Brady & Weil, 2016; Meena et al., 2020). Similar trends in pig manure, vermicompost, and FYM could be ascribed to better soil conditions and growth-promoting factors in vermicompost (Atiyeh et al., 2000). Delayed germination in mustard oilcake might be associated with the release of isothiocyanates during glucosinolate breakdown, which can temporarily inhibit seed germination when concentrated near the seed zone (Singh et al., 2014). Overall, easily decomposable manures, especially poultry manure promoted earlier and more uniform germination (Kumar et al., 2018).

Table 3. Effects of different organic manure on germination percentage of radish seed

Treatments	Germination (DAS)
FYM	8.3 ± 0.88^{bc}
Pig manure	7.0 ± 0.58^{c}
Poultry manure	6.0 ± 0.58^{c}
Vermicompost	7.7 ± 0.67^{bc}
Control	12.0 ± 0.58^{a}
Mustard oilcake	13.0 ± 0.58^{a}
Packaged organic manure	10.3 ± 0.88^{ab}
Grand Mean	9.2
F-value	14.87**
p-value	<0.01
LSD (0.05)	3.3
SEm (±)	0.99
CV%	20.19

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, **= significant at 1% level

Effects of different organic manure on leaf length of radish

The different organic manures had a highly significant (p < 0.001) effect on radish leaf length at 30, 40, 50, and 60 DAS. Poultry manure produced the maximum leaf length at early and mid-stages (30-50 DAS) due to its highly labile nitrogen and rapid mineralization (Brady & Weil, 2016; Kumar et al., 2018), but by 60 DAS its leaf length dropped sharply (from 26.92 cm to 14.67 cm) because it lacks residual effect, resulting in poor nutrient release synchrony with later crop demand. In contrast, FYM showed moderate leaf length initially but became maximum at 60 DAS (27.72 cm), attributable to its slower, sustained mineralization and prolonged effect on soil physical properties, demonstrating better synchrony with late-stage nutrient need (Meena et al., 2020). Mustard oilcake and the control showed the lowest values. For mustard oilcake, this may also involve inhibitory effect on growth (Singh et al., 2014). vermicompost and packaged organic manure yielded lower leaf lengths due to slower nutrient release (Singh et al., 2014). The coefficient of variation (8.2–16.11%) indicated acceptable experimental precision.

Table 4. Effects of different organic manure on leaf length of radish

	leaf length (cm)			
Treatments	30DAS	40DAS	50DAS	60DAS
FYM	14.18 ± 1.04^{b}	15.95 ± 1.19^{bc}	14.8 ± 1.39^{b}	27.72 ± 1.08^{a}
Pig manure	15.64 ± 1.04^{b}	16.51 ± 1.19^{b}	13.89 ± 1.39^{bc}	18.89 ± 1.08^{b}
Poultry manure	18.75 ± 1.04^{a}	26.17 ± 1.19^{a}	26.92 ± 1.39^{a}	14.67 ± 1.08^{c}
Vermicompost	12.15 ± 1.04^{c}	12.89 ± 1.19^{cd}	11.37 ± 1.39^{bc}	13.53 ± 1.08^{c}
Control	9.21 ± 1.04^{d}	10.95 ± 1.19^{d}	9.9 ± 1.39^{c}	13.2 ± 1.08^{c}
Mustard oil cake	6.77 ± 1.04^{e}	12.21 ± 1.19^{d}	15.27 ± 1.39^{b}	12.1 ± 1.08^{c}
Packaged organic Manure	10.11 ± 1.04^{d}	12.85 ± 1.19^{cd}	12.62 ± 1.39^{bc}	11.4 ± 1.08^{c}
Grand Mean	12.4	15.36	14.97	15.93
F-value	32.65***	21.65***	15.62***	21.18***
p-value	<0.001	<0.001	<0.001	<0.001
LSD (0.05)	2.18	3.37	4.30	3.34
SEm (±)	1.04	1.19	1.39	1.08
CV (%)	8.20	12.33	16.11	11.78

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, *** = highly significant at 0.1% level.

Effects of different organic manure on leaf width of radish

Leaf width of radish was significantly affected by various organic manures at all stages of growth (30, 40, 50, and 60 DAS), and the treatment values were significant to highly significant (Table 5). The average leaf width increased with age of crop, from 2.68 cm at 30 DAS to 5.32 cm at 60 DAS. Poultry manure always recorded the maximum leaf width at all stages, while the minimum leaf width was recorded in control treatment. FYM, pig manure, and mustard oilcake were of intermediate reaction. The coefficient of variation reduced from 26.38% at 30 DAS to 10.88% at 60 DAS, which showed increased precision of experiment at advanced stages. The better performance of poultry manure could be due to its faster mineralization and greater nitrogen availability, which promote cell division and leaf expansion (Brady & Weil, 2016). Greater microbial activity in poultry manure further justifies leaf development (Arshad et al., 2024). Moderate reactions in FYM and pig manure might be due to slow release of nutrients, while lower performance in vermicompost and packaged organic manure might be due to slow release of nutrients (Kamaleshwaran & Elayaraja, 2021)

Table 5. Effects of different organic manure on leaf width of radish

	Leaf width (cm)			
Treatments	30DAS	40DAS	50DAS	60DAS
FYM	2.62 ± 0.42^{bc}	5.8 ± 0.54^{b}	4.84 ± 0.40^{b}	5.15 ± 0.34^{c}
Pig manure	3.19 ± 0.42^{b}	4.96 ± 0.54^{bc}	4.02 ± 0.40^{bc}	4.69 ± 0.34^{cd}
Poultry manure	4.72 ± 0.42^{a}	7.8 ± 0.54^{a}	6.4 ± 0.40^{a}	8.11 ± 0.34^{a}
Vermicompost	1.98 ± 0.42^{bc}	4.12 ± 0.54^{c}	3.51 ± 0.40^{c}	4.45 ± 0.34^{cd}
Control	1.67 ± 0.42^{c}	3.42 ± 0.54^{c}	3.13 ± 0.40^{c}	3.8 ± 0.34^{d}
Mustard oil cake	2.61 ± 0.42^{bc}	3.46 ± 0.54^{c}	4.98 ± 0.40^{b}	6.5 ± 0.34^{b}
Packaged organic manure	1.96 ± 0.42^{bc}	3.84 ± 0.54^{c}	4.05 ± 0.40^{bc}	4.58 ± 0.34^{cd}
Grand Mean	2.68	4.77	4.42	5.32
F-value	6.24**	8.04***	7.54**	19.11***
p-value	<0.01	<0.001	<0.01	<0.001
LSD (0.05)	1.26	1.64	1.21	1.03
SEm (±)	0.42	0.54	0.40	0.34
CV (%)	26.38	19.53	15.45	10.88

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, **= significant at 1% level, ***= highly significant at 0.1% level

Effects of different organic manure on leaf number of radish

Leaf number of radish was significantly affected by various organic manures at all stages of growth (30, 40, 50, and 60 DAS) (Table 6). The average leaf number increased with age of the crop, and poultry manure always recorded the maximum leaf number, while the control and mustard oilcake treatment recorded the lowest. FYM and pig manure were moderate, especially at 30 and 40 DAS, but at 50 DAS, all treatments except poultry manure were at par. At 60 DAS, poultry manure again recorded the maximum leaf number, followed by mustard oilcake and FYM. The coefficient of variation decreased from 16% to 7.35%, which revealed greater accuracy at advanced stages. The superior performance in poultry manure is due to faster mineralization and higher availability of nitrogen, which favors active meristematic growth and continuous leaf formation (Supriya et al., 2024). Moderate performance in FYM and pig manure might be due to continuous nutrient supply and better soil properties, while lower leaf number in vermicompost, packaged organic manure, and control treatment revealed the significance of readily available organic nutrients for optimal leaf growth (Khatri et al., 2019).

Table 6. Effects of different organic manure on leaf number of radish

Treatments	leaf number 30DAS	40DAS	50DAS	60DAS
FYM	9.07 ± 1.94[abc]	11.47 ± 1.32[b]	8.07 ± 1.85[b]	10.65 ± 0.59[c]
Pig manure	10 ± 1.94[ab]	11 ± 1.32[bc]	7.53 ± 1.85[b]	10.31 ± 0.59[bc]
Poultry manure	11.47 ± 1.94[a]	13.93 ± 1.32[a]	10.73 ± 1.85[a]	13 ± 0.59[a]
Vermicompost	8.87 ± 1.94[bc]	9.73 ± 1.32[bc]	6.27 ± 1.85[b]	9.53 ± 0.59[cd]
Control	7 ± 1.94[cd]	9 ± 1.32[c]	6.13 ± 1.85[b]	8.4 ± 0.59[d]
Mustard oil cake	6.27 ± 1.94[d]	9.13 ± 1.32[c]	8 ± 1.85[b]	11.6 ± 0.59[b]
Packaged organic manure	8.33 ± 1.94[bc]	10.13 ± 1.32[bc]	6.93 ± 1.85[b]	9.87 ± 0.59[c]
Grand Mean	8.71	10.63	7.67	10.48
F-value	4.75*	6.69**	6.13**	11.18***
p-value	<0.05	<0.01	<0.01	<0.001
LSD (0.05)	2.48	2.05	1.94	1.37
SEm (±)	1.94	1.32	1.85	0.59
CV (%)	16	10.82	14.2	7.35

Note**:** Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, *= significant at 5% level, **= significant at 1% level and ***= highly significant at 0.1% level

Effects of different organic manure on shoot wt. and root wt. of radish

The application of various organic manures had a substantial effect on the shoot and root biomass of radish ($p \leq 0.01$) (Table 7). The poultry manure always recorded the highest fresh and dry weight of shoots and roots, significantly outperforming all other treatments. Mustard oilcake was the second best, while FYM, pig manure, vermicompost, packaged organic manure, and control recorded lower but relatively equal biomass. The mean values revealed moderate variability, indicating acceptable experimental precision. The superiority of poultry manure can be ascribed to its high nutrient content and rapid turnover, particularly nitrogen, phosphorus, and potassium, which promote photosynthesis, assimilation, and translocation of assimilates to roots (Gyewali et al., 2021)). The higher biomass of mustard oilcake might be due to the release of organic nitrogen and sulfur during decomposition. The lower biomass of other manures might be attributed to their slower turnover or lower availability of nutrients during key growth periods (Meena et al., 2020). The poor performance of the control treatment emphasizes the need for supplemental organic nutrient inputs. Among all, poultry manure was the most effective, followed by mustard oilcake, for maximizing radish shoot and root biomass (Pant & Oli, 2021).

Table 7. Effects of different organic manure on fresh and dry wt. of shoot and root of radish

	Shoot wt (gm)		Root wt (gm)	
Treatments	Fresh	Dry	Fresh	Dry
FYM	29.3 ± 4.87[c]	9.9 ± 1.64[bc]	53.63 ± 13.83[c]	28 ± 6.29[b]
Pig manure	23.73 ± 4.87[c]	11.23 ± 1.64[c]	49.52 ± 13.83[c]	25.33 ± 6.29[b]
Poultry manure	110.2 ± 4.87[a]	19.2 ± 1.64[a]	148.2 ± 13.83[a]	65 ± 6.29[a]
Vermicompost	26.4 ± 4.87[c]	13.13 ± 1.64[b]	55.6 ± 13.83[c]	23.17 ± 6.29[b]
Control	21.73 ± 4.87[c]	8.03 ± 1.64[bc]	53.1 ± 13.83[c]	27.67 ± 6.29[b]
Mustard oil cake	60.47 ± 4.87[b]	13.33 ± 1.64[b]	104.27 ± 13.83[b]	48.33 ± 6.29[a]
Packaged organic manure	22.23 ± 4.87[c]	10.33 ± 1.64[bc]	54.63 ± 13.83[c]	25.67 ± 6.29[b]
Grand Mean	42	12.17	74.14	34.74
F-value	45.92***	4.85**	7.48**	6.33**
p-value	<0.001	<0.01	<0.01	<0.01
LSD (0.05)	15	5.05	42.62	19.38
SEm (±)	4.87	1.64	13.83	6.29
CV (%)	20.08	23.34	32.32	31.36

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, **= significant at 1% level, ***= highly significant at 0.1% level

Effects of different organic manure on shoot length, root length and root diameter of radish

Various organic manures had a significant effect on radish shoot length ($p \leq 0.01$), root length, and root diameter ($p \leq 0.05$) (Table 8). Poultry manure produced the maximum shoot length (38.35 cm), root length (31.08 cm), and root diameter (3.06 cm) were recorded in poultry manure, which was significantly better than all other treatments. Mustard oilcake was the second-best in shoot length (27.23 cm) and root diameter (2.81 cm), whereas FYM, pig manure, vermicompost, packaged organic manure, and control had lowest but comparable values. From a source-sink perspective, the shoot act as a photosynthetic source and the taproot as the storage sink. Poultry manure's rapid mineralization and high nitrogen availability promote vigorous shoot expansion (enlarged source), which increases photosynthate supply to the root, thereby enhancing both root length and diameter (strengthened sink) (Brady & Weil, 2016). Mustard oilcake provided moderate shoot growth but its root length remained comparable to slowerrelease manures, possibly due to inhibitory compounds limiting sink allocation (Singh et al., 2014). FYM, pig manure, vermicompost, and packaged manure released nutrients more slowly (Meena et al., 2020), resulting in smaller source capacity and subsequently smaller sink development. Thus, organic manures that rapidly enhance source size (e.g., poultry manure) produce the strongest sourcesink relationship and highest overall radish growth.

Table 8. Effects of different organic manure on shoot length, root length and root diameter of radish

Treatments	Shoot length (cm)	Root length (cm)	Root diameter (cm)
FYM	17.41 ± 2.61[c]	19.92 ± 2.27[b]	2.12 ± 0.24[bc]
Pig manure	17.12 ± 2.61[c]	20.56 ± 2.27[b]	2.18 ± 0.24[bc]
Poultry manure	38.35 ± 2.61[a]	31.08 ± 2.27[a]	3.06 ± 0.24[a]
Vermicompost	18.39 ± 2.61[c]	21.20 ± 2.27[b]	2.11 ± 0.24[bc]
Control	15.36 ± 2.61[c]	21.64 ± 2.27[b]	2.08 ± 0.24[bc]
Mustard oil cake	27.23 ± 2.61[b]	22.59 ± 2.27[b]	2.81 ± 0.24[ab]
Packaged organic manure	17.23 ± 2.61[c]	21.17 ± 2.27[b]	2.02 ± 0.24[c]
Grand Mean	21.57	22.59	2.34
F-value	10.23***	2.85*	3.00*
p-value	<0.001	<0.05	<0.05
LSD (0.05)	8.04	6.93	0.74
SEm (±)	2.61	2.27	0.24
CV (%)	20.97	17.39	17.84

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, *= significant at 5% level, ***= highly significant at 0.1% level

Effects of different organic manure on net shoot wt., net root wt. and net plot wt of radish

Different organic manures had a significant effect on net shoot weight, net root weight, and net plot weight of radish (Table 9), with shoot weight being significant ($p \leq 0.01$) and root and plot weight being highly significant ($p \leq 0.01$). The mean values were 1.67 kg (shoot), 2.31 kg (root), and 3.99 kg (plot), indicating large variability among the treatments. The maximum net shoot weight (3.59 kg), net root weight (5.18 kg), and net plot weight (8.97 kg) were recorded with poultry manure, which was significantly better than other treatments. Mustard oilcake and pig manure were moderately good, while FYM, vermicompost, and packaged organic manure were intermediate. The increased biomass production in poultry manure can be attributed to faster mineralization and greater availability of nutrients, which in turn stimulate vegetative growth, root development, and productivity (Brady & Weil, 2016). Decreased productivity in other manures may be due to lower availability of nutrients because of slower release (Meena et al., 2020). Poultry manure was the most effective in maximizing radish biomass and productivity, which is in agreement with previous research work (Kumar et al., 2018).

Table 9. Effects of different organic manure on net shoot wt., net root wt., and net plot wt. of radish

Treatments	Net shoot wt. (kg)	Net root wt.(kg)	Net plot wt. (kg)
FYM	1.49 ± 0.34^{bc}	2.46 ± 0.44^{b}	3.22 ± 0.71^{bc}
Pig manure	1.60 ± 0.34^{bc}	2.55 ± 0.44^{b}	4.24 ± 0.71^{b}
Poultry manure	3.59 ± 0.34^{a}	5.18 ± 0.44^{a}	8.97 ± 0.71^{a}
Vermicompost	1.15 ± 0.34^{bc}	1.88 ± 0.44^{bc}	3.33 ± 0.71^{bc}
Control	0.82 ± 0.34^{c}	0.92 ± 0.44^{c}	1.83 ± 0.71^{c}
Mustard oil cake	1.88 ± 0.34^{b}	1.43 ± 0.44^{bc}	3.41 ± 0.71^{bc}
Packaged organic manure	1.17 ± 0.34^{bc}	1.71 ± 0.44^{bc}	2.96 ± 0.71^{bc}
Grand Mean	1.67	2.31	3.99
F-value	7.37**	9.80***	10.51***
p-value	<0.01	<0.001	<0.001
LSD (0.05)	1.03	1.37	2.19
SEm (±)	0.34	0.44	0.71
CV (%)	34.8	33.37	30.86

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, **= significant at 1% level, ***= highly significant at 0.1% level

Effects of different organic manure on marketable roots percentage and forked roots percentage of radish

Various organic manures had a significant effect on the quality of radish roots, in terms of the percentage of marketable and forked roots ($p \leq 0.01$) (Table 10). The average marketable roots for all treatments were 69.43%, and the average forked roots were 30.57%. The maximum percentage of marketable roots was obtained by poultry manure (80.25%), with the lowest percentage of forked roots (19.75%), significantly performing better than all other treatments. Mustard oilcake had moderate performance, with marketable roots of 73.25% and forked roots of 26.76%, while FYM, pig manure, vermicompost, packaged organic manure, and control had lower and comparable marketable roots (64.20-68.31%) and higher forked roots (31.68-35.80%). Better root quality in poultry manure is due to the balanced and ample availability of nutrients, particularly nitrogen and phosphorus, which cause equal development of roots and prevent root forking (Brady & Weil, 2016). The higher percentage of forked roots in other treatments might be due to the unbalanced availability of nutrients and poor soil conditions (Shrestha et al., 2021). Poultry manure increased both yield and root quality, proving its efficacy for radish growth (Meena et al., 2020).

Table 10. Effects of different organic manure on marketable roots% and forked roots% of radish

Treatments	Marketable roots%	Forked roots%
FYM	65.43 ± 2.16[c]	34.57 ± 2.16[a]
Pig manure	64.20 ± 2.16[c]	35.80 ± 2.16[a]
Poultry manure	80.25 ± 2.16[a]	19.75 ± 2.16[c]
Vermicompost	68.31 ± 2.16[bc]	31.68 ± 2.16[ab]
Control	66.26 ± 2.16[c]	33.74 ± 2.16[a]
Mustard oil cake	73.25 ± 2.16[b]	26.76 ± 2.16[b]
Packaged organic manure	68.31 ± 2.16[bc]	31.68 ± 2.16[ab]
Grand Mean	69.43	30.57
F-value	6.71**	6.68**
p-value	<0.01	<0.01
LSD (0.05)	6.55	6.56
SEm (±)	2.16	2.16
CV (%)	5.31	12.05

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, **= significant at 1% level

Effects of different organic manure on whole plant weight and root: shoot ratio of radish

Various organic manures differed significantly in radish whole plant weight and root: shoot ratio (Table 14). The maximum whole plant weight (242.93 g) and root: shoot ratio (3.93) were recorded in poultry manure, significantly higher than all other treatments. Mustard oilcake (170.27 g; 3.61) and pig manure (80.60 g; 3.15) were moderately better, while FYM, vermicompost, packaged organic manure, and control were lower. The maximum growth in radish is due to the highest nutrient release rate and higher availability of nitrogen, phosphorus, and potassium in poultry manure, thus increasing shoot and root growth (Brady & Weil, 2016). Higher root: shoot ratios in mustard oilcake and pig manure indicate better root growth in comparison to shoots, while lower ratios in other treatments indicate poor root growth due to lower nutrient release rates or poor soil conditions. Poultry manure, thus, not only maximized whole plant growth but also properly partitioned roots and shoots, as reported previously in root vegetables (Meena et al., 2020).

Table 11. Effects of different organic manure on whole plant weight and root: shoot ratio of radish

Treatments	Whole plant (gm)	Root: shoot
FYM	82.37 ± 13.53^{c}	2.68b ± 0.40^{cd}
Pig manure	80.60 ± 13.53^{c}	3.15 ± 0.40^{abc}
Poultry manure	242.93 ± 13.53^{a}	3.93 ± 0.40^{a}
Vermicompost	81.90 ± 13.53^{c}	1.75 ± 0.40^{d}
Control	74.60 ± 13.53^{c}	2.53 ± 0.40^{bcd}
Mustard oil cake	170.27 ± 13.53^{b}	3.61 ± 0.40^{ab}
Packaged organic manure	76.87 ± 13.53^{c}	2.31 ± 0.40^{cd}
Grand Mean	115.65	2.85
F-value	29.71***	4.23*
p-value	<0.001	<0.05
LSD (0.05)	41.05	1.22
SEm (±)	13.53	0.40
CV (%)	19.95	24.09

Note: Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, *= significant at 5% level, ***= highly significant at 0.1% level

Effects of different organic manure on weed density in radish field

Various organic manures had a significant effect on the density of weeds in radish crops ($p \leq 0.05$) (Table 12), with an average of 31.05 weeds m². Poultry manure had the lowest density of weeds (14 weeds m^{-2}), which was significantly lower than most other treatments, followed by mustard oilcake (15 weeds m^{-2}) and packaged organic manure (17.67 weeds m^{-2}). FYM, pig manure, and control had higher densities of weeds, with the control having the highest density of 40.33 weeds m^{-2}. Lower density of weeds in poultry manure and mustard oilcake can be related to faster canopy establishment and dense vegetative growth, which shades the soil and prevents weed emergence (Brady & Weil, 2016). Mustard oilcake can also have allelopathic properties that prevent weed germination (Kumar et al., 2018). Higher density of weeds in FYM, pig manure, and control can be related to slower initial growth and less coverage of the soil. Vermicompost moderately reduced weeds (24.33 m^{-2}) because of increased crop growth. Poultry manure and mustard oilcake have been found to be effective in reducing weed density, which improves radish growth and weed control.

Weed Suppression Efficiency (WSE) varied markedly among organic manures, from 16.5% in FYM to 65.3% in poultry manure. Poultry manure exhibited the highest WSE (65.3%), significantly outperforming most other treatments. This is attributed to its rapid mineralization and high nitrogen availability, which accelerate canopy closure and leaf area development (Brady & Weil, 2016). Dense vegetative growth shades the soil surface, reducing light penetration and inhibiting weed seed germination (Teasdale & Mohler, 2000). Mustard oil cake also showed strong WSE (62.8%), likely due to a combination of rapid crop growth and the release of glucosinolatederived isothiocyanates, which have known allelopathic effects on weed seeds (Petersen et al., 2001). Packaged organic manure and vermicompost gave moderate WSE (56.2% and 39.7%, respectively), reflecting moderate crop growth rates. In contrast, FYM and pig manure had low WSE (<20%), despite being applied on a nitrogenequivalent basis. Their slower nutrient release resulted in delayed canopy establishment, allowing weeds to emerge and compete longer (Meena et al., 2020). The control (no manure) had the lowest weed suppression (0% by definition). These results indicate that WSE is closely linked to the rate of early crop vigor. For integrated weed management in organic radish production, selecting manures with high WSE – particularly poultry manure or mustard oil cake – can reduce handweeding labor and improve overall crop productivity.

Table 12. Effects of different organic manure on weed density in radish field

Treatments	Weed density (per m^2)	Weed Suppression Efficiency (WES)
FYM	33.67 ± 9.06[ab]	16.52[ab]
Pig manure	32.67 ± 9.06[ab]	19.00[ab]
Poultry manure	14 ± 9.06[a]	65.29[a]
Vermicompost	24.33 ± 9.06[b]	39.68[b]
Control	40.33 ± 9.06[ab]	0.00[ab]
Mustard oil cake	15 ± 9.06[b]	62.81[b]
Packaged organic manure	17.67 ± 9.06[b]	56.19[b]
Grand Mean	31.05	37.07
F-value	3.86*	3.86*
p-value	<0.05	<0.05
LSD (0.05)	27.49	68.15
SEm (±)	9.06	22.46
CV (%)	49.78	60.6

Note**:** Means followed by the same letter(s) within column are non-significantly different according to Duncan's Multiple Range Test (DMRT) at 5% level of significance. SEm = Standard Error of Mean; CV= Co-efficient of Variance, LSD= Least Significant Difference, *= significant at 5% level

Effects of different organic manure on TSS and pH content of radish

Various organic manures differed in total soluble solids (TSS) and pH values of radish roots (Table 13). TSS varied from 3.0 to 5.0°Brix, and pH from 6.0 to 6.84, which revealed that the quality of roots can be affected by nutrient management. The maximum TSS (5.0°Brix) and pH (6.84) were recorded in poultry manure, which revealed that sugar content and root acidity were increased. FYM (4.0°Brix) and mustard oilcake (3.5°Brix) were moderate in TSS, while control, pig manure, vermicompost, and packaged organic manure were lowest (3.0°Brix) in TSS. The lowest pH (6.0) was recorded in pig manure, while other treatments were intermediate (6.4-6.67). Higher TSS in poultry manure can be correlated with faster availability of nutrients, particularly nitrogen and phosphorus, which increase photosynthesis and assimilate translocation to roots (Brady & Weil, 2016). Differences in pH values may be due to differences in decomposition and mineralization of organic matter. Poultry manure increased both TSS and pH, which improved root quality and palatability, while other manures were moderate in improving these quality parameters.

Table 13. Effects of different organic manure on TSS and pH content of radish

Treatments	TSS (°Brix)	pH
Control	3	6.81
FYM	4	6.67
Poultry Manure	5	6.84
Pig Manure	3	6
Vermicompost	3	6.4
Packaged O.M	3	6.8
Oil cake	3.5	6.6

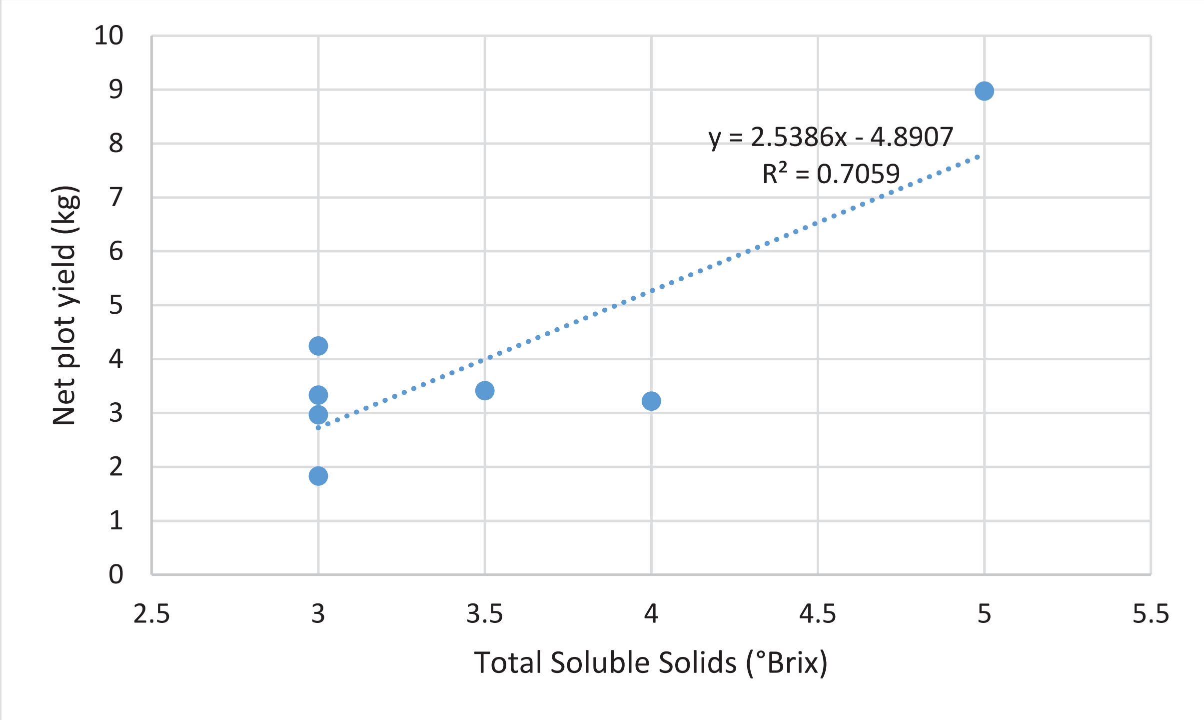

Fig. 3. Correlation between TSS and yield of radish

The scatter plot shows a clear positive linear relationship between total soluble solids (TSS, °Brix) and net plot yield, indicating that increases in TSS are associated with higher yield. The fitted regression suggests a moderately strong relationship ($R^2 = 0.7059$), meaning that about 70.6% of the variation in yield is explained by TSS. The regression equation is given as $y = 2.5386x - 4.8907$, this implies that for every unit increase in TSS, yield increases by approximately 2.54 kg per plot, reflecting improved assimilate accumulation and translocation to economic yield. Such findings are consistent with previous studies, which report that higher soluble solids often correlate with enhanced photosynthetic efficiency, better carbohydrate partitioning, and improved fruit development (e.g., Davies and Hobson, 1981; Kader, 2008). Similarly, research on vegetable crops has shown that increased TSS is associated with improved fruit quality and yield due to greater sugar accumulation and metabolic activity (Beckles, 2012). Therefore, the observed positive association supports the idea that TSS can serve as an important physiological indicator of productivity, although other environmental and management factors may also influence yield beyond what is captured in the model.

CONCLUSION

The study revealed that the growth, yield, quality and weed suppression efficiency of radish significantly influenced by different organic sources of nutrients under Inner Terai conditions of Nepal. Among the treatments, poultry manure produced the best result by improving germination, leaf growth, shoot and root biomass, root length, root diameter, marketable root percentage, total soluble solids (5°Brix) and net plot yield (8.97 kg). It also increased soil organic matter and available nutrients and decreased weed density through rapid canopy development. The higher efficiency of poultry manure was due to its fast mineralization rate, higher nutrient availability and higher microbial activity. The mustard oil cake did fairly well. Therefore, poultry manure can be recommended as an efficient and sustainable nutrient source for improving radish productivity and soil health in the Inner Terai region of Nepal.

AUTHOR CONTRIBUTIONS

DB: Conceptualization, Methodology, Investigation, Supervision, Writing – review & editing; **RM:** Data curation, Formal analysis, Writing – original draft; **SS:** Validation, Visualization; **SSK:** Resources, Writing – review & editing.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

ETHICAL APPROVAL AND PERMITS

Not applicable.

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