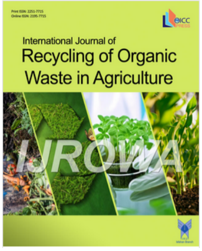

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Efficacy of organic amendments and biofertilizers on yielding, biochemical and soil nutritional attributes of radish (*Raphanus sativus* L.)

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Original Research

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Abstract:

Purpose: The current investigation was conducted at the Vegetable Research Farm of the School of Agriculture, Lovely Professional University, Phagwara, Punjab. The aim of the study was to know the effect of different combinations of organic amendments along with biofertilizers on various horticultural, biochemicals, soil profiling traits and economics of radish cultivation.
Method: The experiment followed a Factorial Randomized Block Design with three replications, two varieties, and ten treatments. The statistical data analysis was calculated from five randomly chosen plants for various horticultural, biochemical, and soil profiling traits, while the economics for the same was also calculated for analyzing the profit margin.
Results: The study found significant results across attributes. Pusa Chetki excelled in germination time, plant height, leaves, and leaf area at different stages. Pusa Shweta showed superiority in root-related factors, chlorophyll, ascorbic acid, sugars, acidity, and dry matter. T_{10} demonstrated excellence in various parameters. A combination of Pusa Chetki with 100% Vermicompost yielded notable results in plant height, soluble solids, sugars, and firmness. The VC:FYM:PM (50:25:25) treatment in Pusa Shweta displayed the highest gross return, net return, and benefit-to-cost ratio.
Conclusion: The combination of Pusa Shweta and a treatment consisting of 50% Vermicompost, 25% FYM, and 25% Poultry Manure produced positive outcomes across various parameters and had the highest economic returns in terms of benefit-to-cost ratio. These findings offer valuable insights for farmers and researchers interested in improving radish cultivation by utilizing organic amendments and biofertilizers.

Keywords: Economics; Available nitrogen; Soil profiling; Varieties; Leaf area index

1. Introduction

Radish (*Raphanus sativus* L.) is a diploid plant species with a chromosome number of eighteen (Kumar et al., 2023). It is widely cultivated in Asia due to its nutritional and medicinal properties (Shao et al., 2021). This is a perennial herbaceous root crop that belongs to the Brassicaceae family. The plant is cultivated for its modified young and tender fusiform tap root (Upadhyay and Prasad, 2021), which is commonly consumed grated, garnished, or as a salad in various Asian cuisines (Kumar et al., 2023). It contains significant levels of antioxidants, phenolic compounds, vitamin C, and minerals such as potassium and calcium. Nutrient compounds offer various health benefits, such as cell protection and the reduction of high blood pressure, thereby decreasing the risk of heart disease. It is a significant source of nitrates, which can facilitate blood flow (Upadhyay and Prasad, 2021). It has potential applications in the treatment of sleeplessness, chronic diarrhea, and neurological headaches (Dulal et al., 2021). In India, the cultivated area for radish spans 2, 09,000 hectares, with a corresponding production of 3347 metric tons. Haryana is currently the leading state in horticultural production, with a total output of 550,070 tonnes. West Bengal has the highest cultivated area per hectare, estimated at 41,360 hectares (NHB, 2021). The popularity of radish cultivation may be attributed to its wide adaptability, low production costs, short crop duration, and ability to thrive in various soil types with minimal care. However, it is important to ensure uninterrupted root growth and development. Radish exhibits a lower incidence of diseases and pest infestations compared to other vegetable crops (Singh, 2021).

To ensure optimal nutrition, it is essential to supply a balanced combination of organic, inorganic, and bio-fertilizers. The repeated use of chemical fertilizers is costly and can lead to degradation of soil and water quality, thereby negatively impacting overall environmental health. The application of organic fertilizers enhances soil structure, microbial activity, and nutrient content, leading to improved crop quality (Upadhyay and Prasad, 2021). Organic manures are environmentally friendly and can be obtained in either bulk or concentrated forms. Organic fertilizers exhibit reduced analytical value in comparison to inorganic fertilizers, and their chemical composition lacks definitiveness (Bilong et al., 2022). Farmyard manure (FYM) offers the primary benefit of efficient and low-loss nutrient recycling, while also contributing to the preservation of humus. Humic substances play a crucial role in maintaining soil fertility and ensuring the long-term stability of soil (Shahwar et al., 2023). Vermicompost is a valuable source of essential macronutrients (nitrogen, phosphorus, potassium, calcium, and magnesium) as well as micronutrients (iron, manganese, zinc, and copper). Poultry manure is estimated to contain approximately 60% organic nitrogen, which undergoes rapid mineralization (Iqbal et al., 2019; Bilong et al., 2022). It is widely acknowledged as a valuable plant nutrient for various crop types. Azotobacter plays a significant role in the process of atmospheric nitrogen fixation, contributing to the supply of nitrogen to plants. This, in turn, enhances soil fertility and improves crop productivity. Specifically, it enhances enzymatic activity and improves the translocation of plant growth-promoting substances (Bilong et al., 2022). Sumbul et al. (2020) noted that Azotobacter can improve the availability of nitrogen, phosphorus, and potassium in certain vegetables. Given the elevated expenses associated with inorganic fertilizers and their detrimental effects on soil and water quality, it is crucial to consider alternative and more cost-effective options such as organic manures. This approach can help mitigate expenses and meet the nutritional needs of crops to some extent. The purpose of this study was to examine the impact of organic amendments and biofertilizers on the growth and yield of radish (*Rhaphanus sativus* L.).

2. Materials and method

Geographical situation and location

The research study was conducted from October to December at the Experimental Farm of Lovely Professional University, Phagwara, situated in Kapurthala district. The experimental site is located at coordinates 31.13 N and 75.47 E, with an average elevation of 234 meters. It is situated near Mount Everest, within the River Ganga region. Phagwara is a region with a flat topography, which is representative of the Indo-Gangetic plains.

Climatic conditions

The climate of this region is generally categorized as semi-arid. During the peak months of May and June, summers are characterized by high temperatures ranging from 30 to 45 °C (86 to 113 °F), accompanied by dry conditions. Winter temperatures in December and January typically reach a low of approximately 5 °C (41 °F). The monsoon season, spanning from July to September, brings substantial rainfall, offering respite from the high temperatures of summer (Fig. 1).

Experimental details

The research experiment followed a Factorial Randomized Block Design with three replications during the Rabi season of 2022. The study utilized two varieties of radish, Pusa Shweta and Pusa Chetki, obtained from IARI in New Delhi. Various combinations of three organic manures (FYM, poul-

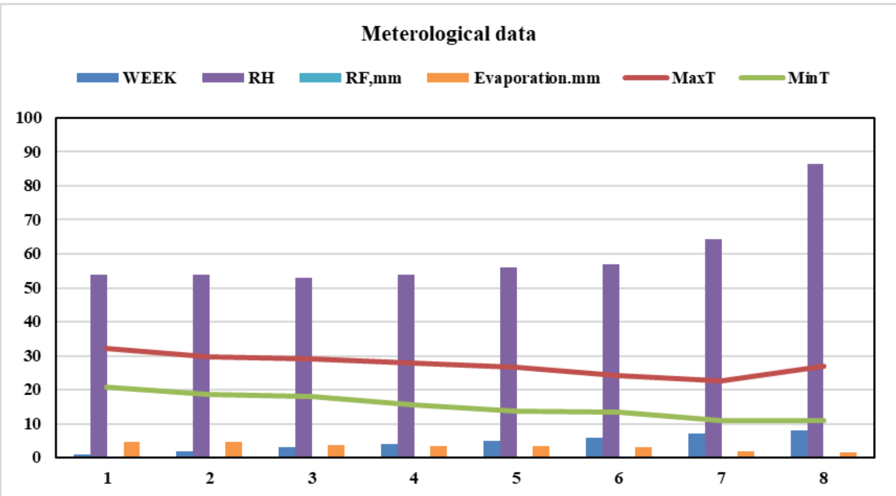

Figure 1. Graphical representation of weather data of Rabi season 2022.

try manure, and vermicompost) and two biofertilizers (Azotobacter and PSB) were applied at different doses during the investigation. Organic manures and biofertilizers were obtained from the Department of Horticulture, School of Agriculture, Lovely Professional University, located in Phagwara, Punjab, India. A total of nine treatment combinations were utilized, including one control group. The treatments consisted of Control (T1), 100% well-rotted FYM (T2), 100% vermicompost (T3), 100% poultry manure (T4), 50% poultry manure + 50% PSB (T5), 75% well-rotted FYM + 25% poultry manure (T6), 75% well-rotted FYM + 25% Azotobacter (T7), 75% vermicompost + 25% well-rotted FYM (T8), 50% vermicompost + 50% azotobacter (T9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T10). Field preparation was done in the month of October. According to the cultivation guidelines provided by Punjab Agricultural University (PAU), the recommended seed rate for Pusa Shweta and Pusa Chetki radish varieties is 5 kg per acre or 185 g per 150 m^2. Sowing in the Rabi season, specifically in October, is conducted on ridges with a row-to-row spacing of 45 cm and a plant-to-plant spacing of 7.5 cm. The seeds are sown at a depth of 1.5 cm. No synthetic fertilizers have been used in the field. The recommended basal doses of organic manures, including FYM (25 t/ha), vermicompost (12.5 t/ha), and poultry manure (2.5 t/ha), were incorporated into the soil during ridge preparation. In addition, the seed treatment involved the application of biofertilizers, specifically *Azotobacter*, and phosphorus solubilizing bacteria, at a concentration of 4 kg/ha each. Biofertilizers were prepared by creating a slurry through the mixing of biofertilizers with water at the appropriate concentration. The seeds were then soaked in this slurry overnight and subsequently dried under partial shade conditions before being sown. Radish roots were harvested when they reached horticultural maturity, specifically at the tender stage. The harvest was conducted manually, with careful attention to avoid damaging the roots.

Growth traits

To reduce potential errors caused by border effects, a total of five plants were randomly chosen from the middle rows of each unit plot. Observations were then recorded on a plot-wise basis. Data was collected for various growth traits, including the number of days for germination and harvest, plant height, number of leaves per plant, and leaf area. The average of these traits was calculated for five plants, and measurements were taken at 15, 30, and 45 days after sowing (DAS). The study involved recording the number of days from sowing to germination and from sowing to harvest for fresh radish roots. These values were then used to calculate the mean average for statistical analysis. Plant height was measured at intervals of 15, 30, and 45 days using a measuring scale. The number of leaves per plant was recorded at three different day intervals (15, 30, and 45 days after sowing). The mean value was calculated from selected plants. The leaf area at the same intervals was also measured using LICOR 3000. The average leaf area was then calculated and expressed as the leaf area index of the plant.

Yield traits

Data on yield parameters, including root length (cm), root width (cm), root fresh weight, root yield per plot, and total root yield per hectare (q/ha), were collected from five randomly selected plants. In addition, root length and width were measured using a vernier caliper, with measurements recorded in centimeters. The fresh weight of the roots of five plants per plot was measured using a digital weighing balance, and the average values were calculated at the time of harvest. The cumulative root yield in kilograms was determined for a specific plot until the final harvest. The total root yield (q/ha) was determined by summing the individual root yield values obtained from each plot.

Biochemical traits

The biochemical content of randomly selected plants was analyzed according to the standard analysis procedure provided by the Association of Official Agricultural Chemists (AOAC). The total soluble solids content was determined by crushing the sample using a pestle and mortar and measuring it with a Hand Refractometer. The ascorbic acid content was determined using a volumetric method involving the use of 2,6-dichlorophenol indophenol dye. The determination of reducing sugars was conducted using the Lane-Eynon method, as described by Lane and Eynon (1923). The estimation of total soluble sugars was conducted using the phenol-sulfuric acid method, following the procedure outlined by Sadasivam and Manickam (1992). Titrating is the most frequently employed technique for assessing the titratable acidity of radish vegetables (AOAC, 1990). Non-reducing sugars were determined by subtracting the amount of reducing sugars from the total sugar content. The chlorophyll content in the leaves of five randomly selected plants was estimated using a SPAD chlorophyll meter. The instrument was clamped over the leaf tissue during harvest to obtain the SPAD value. The dry matter content and moisture percentage of leaves and roots were determined by separately taking 20 g of each sample, wrapping them in paper, and drying them in a hot air oven (Ievinsh, 2011). The formulas for calculating dry matter and moisture percentages are as follows:

Dry matter percentage = $(FW - DW)/DW \times 100$
Moisture percentage = $(FW - DW)/FW \times 100$
where, FW = Fresh weight, which is 20 g DW = Dry weight

Soil profiling and nutrient analysis

Soil samples were collected randomly before and after the trial. An auger is used to extract a 6-inch deep and 1-inch thick layer of soil. A total of seven to eight samples were taken from the field in a zigzag arrangement. The samples were blended into a fine mixture and fully dried in the air. Then the samples were sieved thoroughly using a 2 mm sieve. The collected soil samples were used for analysis of soil nutrient status using various standardized methods. The findings of several assessments were conducted on the soil sample before and after the start of the experiment (Table 1, 2). The physicochemical analysis of the organic amendments has also been done by using various methods, as mentioned in Table 3.

Table 1. Initial soil profiling values (before seed sowing).

S.no.	Properties of soil	readings	Procedure used
1	Soil pH	6.90	Using a pH meter, given by Thomas (1996)
2	Electrical conductivity (dSm^{-1} at 25 °C)	0.18	Jackson (1973)
3	Organic carbon (%)	0.39	Walkley and Black (1934)
4	Available Nitrogen (kg/ha)	152.83	Kjeldahl method (Bradstreet, 1954)
5	Available Phosphorus (kg/ha)	28.97	Olsen's method Olsen and Sommers (1982)
6	Available potassium (kg/ha)	138.36	Flame photometer (Metson, 1956)

Table 2. Ratings of the soil chemical properties.

Rating	pH	EC (dsm^{-1})	OC %	N ($kg\ ha^{-1}$)	P ($kg\ ha^{-1}$)	K ($kg\ ha^{-1}$)
Low	< 6.5	< 0.8	< 0.5	< 250	< 28	< 140
Medium	6.5 – 7.5	0.8 – 2.5	0.5 – 0.75	250 – 500	28 – 56	140 – 280
High	> 7.5	> 2.5	> 0.75	> 500	> 55	> 280

Table 3. Characteristics of organic amendments.

Traits	Farm yard manure	Vermicompost	Poultry manure	Method used
Water holding capacity	96.56	98.15	97.89	Keen's cup method (Piper, 2002)
Organic carbon (%)	12.16	21.96	21.67	Walkley and Black (1934)
C: N ratio	10.39	18.20	9.38	-
Nitrogen (%)	0.57	1.17	2.31	Kjeldahl method (Bradstreet, 1954)
Phosphorus (%)	0.22	0.81	1.64	Olsen's method Olsen and Sommers (1982)
Potassium (%)	0.55	9.97	2.41	Flame photometer (Metson, 1956)

Economics

The total cost of cultivation was calculated by considering all expenses related to cultural activities and input expenditures for each experimental plant. The analysis focused on net returns per hectare and the economic aspects of different treatments. The B:C ratio was calculated to assess the commercial potential of the treatments within the investigation. The economic details of all the combinations were calculated.

Total cost of cultivation = fixed cost + variable cost

Gross return from crops (Rs/ha) = total yield × market price of crop (Rs/kg)

Net returns = Gross return - Total cost of cultivation

B:C ratio : net return/total cost of cultivation.

3. Results and discussion

Growth parameters

It was observed that there was a significant influence of different varieties, treatments of organic amendments, and biofertilizer, and their interactions were seen on days taken for germination (Fig. 2). Between both the varieties, the minimum days taken for germination were recorded in Pusa Chetki and the maximum was recorded in Pusa Shweta (Table 4). Whereas, amongst the treatments, the lowest value was noticed in the treatment vermicompost 100% and the highest value was noticed with VC + FYM (75:25). In between the two-way interaction of varieties and treatments, Pusa Chetki + vermicompost 100% had recorded minimum value and Pusa Shweta coupled with VC + FYM (75:25) had recorded maximum value. When the interactions were compared with the control, the interactions Pusa Chetki VC + PM (75:25) were recorded as superior, while all treatment combinations with Pusa Shweta except Pusa Shweta coupled with the sole application of vermicompost had shown superiority. As per the calculated data, a positively significant amount of variation was found amongst the varieties, organic amendments, biofertilizer, and in between their interactions, for various growth, yield, quality traits, and soil nutrient status. Different varieties, treatments of organic amendments, biofertilizers, and their interactions have a significant influence on plant height at 15 DAS (Table 4). Among the varieties, Pusa Chetki exhibited the highest plant height at 15 DAS while Pusa Shweta had the lowest plant height. Regarding the treatments, the highest plant height was observed in the sole application of vermicompost, while the lowest plant height was recorded in the control treatment. Considering the interaction between varieties and treatments, the combination of Pusa Chetki coupled with the sole application vermicompost 100% exhibited the maximum plant height at 15 DAS. On the other hand, the combi-

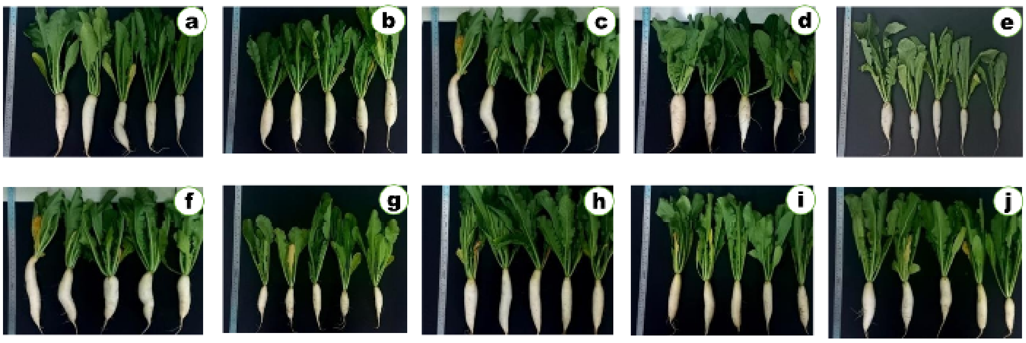

Plate 1: V1: Pusa Shweta ; a: Control; b: Well rotten FYM 100%; c: Vermicompost 100%; d: Poultry manure 100%; e: Poultry manure 50% + PSB 50%; f: Well rotten FYM 75% + Poultry manure 25%; g: Well rotten FYM 75% + *Azotobacter* 25%; h: Vermicompost 75% + Well rotten FYM 25%; i: Vermicompost 50% + *Azotobacter* 50%; j: Vermicompost 50% + Well rotten FYM 25% + Poultry manure 25%

Plate 2: V2: Pusa Chetki; a: Control, b: Well rotten FYM 100%; c: Vermicompost 100%; d: Poultry manure 100%; e: Poultry manure 50% + PSB 50%; f: Well rotten FYM 75% + Poultry manure 25%; g: Well rotten FYM 75% + *Azotobacter* 25%; h: Vermicompost 75% + Well rotten FYM 25%; i: Vermicompost 50% + *Azotobacter* 50%; j: Vermicompost 50% + Well rotten FYM 25% + Poultry manure 25%

Figure 2. Pictorial representation of the harvested radish of different treatments.

Table 4. Effect of organic amendments, biofertilizers, and their combinations on days taken for germination (days), plant height at 15, 30, and 45 days after sowing, and number of leaves per plant (15 DAS) in radish.

Code	Days taken for germination			Plant height 15 DAS			Plant height 30 DAS			Plant height 45 DAS			Number of leaves per plant (15 DAS)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	9.57	8.23	8.90	4.32	6.13	5.22	15.73	16.34	16.04	26.67	29.04	27.86	3.48	4.14	3.81
T_2	9.53*	8.54	9.04	5.81*	7.56*	6.68	16.25	17.58	16.92	25.41	29.80*	27.60	3.88	4.36*	4.12
T_3	9.01	8.13	8.57	7.05*	7.87*	7.46	17.60	18.24	17.92	27.91	29.57*	28.74	3.56	4.70*	4.13
T_4	9.32*	8.87	9.10	6.18*	6.78*	6.48	16.43	17.10	16.77	26.36	28.84*	27.60	3.64	4.38*	4.01
T_5	9.46*	8.26	8.86	6.76*	6.59*	6.68	16.83	17.19	17.01	27.47	29.51*	28.49	3.76	4.52*	4.14
T_6	9.45*	8.63	9.04	6.80*	6.07*	6.44	16.65	17.51	17.08	27.57	29.28*	28.43	3.84	4.55*	4.20
T_7	9.26*	8.64	8.95	6.03*	6.54*	6.28	16.41	17.44	16.92	26.55	28.24	27.40	3.74	4.51*	4.12
T_8	9.66*	8.66	9.16	7.04*	7.13*	7.09	17.09	17.66	17.37	27.86	29.83*	28.84	3.86	4.52*	4.19
T_9	9.43*	8.74	9.09	6.68*	7.25*	6.96	16.87	18.15	17.51	26.93	29.75*	28.34	3.55	4.76*	4.15
T10	9.25*	8.35	8.80	7.14*	7.38*	7.26	17.74	18.58	18.16	28.14	29.92*	29.03	4.17*	4.63*	4.40
Mean	9.39*	8.51	8.95	6.38	6.93	6.66	16.76	17.58	17.17	27.09	29.38	28.23	3.75	4.51	4.13
	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)
A	0.10	0.05	0.03	0.06	0.03	0.02	0.16	0.08	0.06	0.12	0.06	0.04	0.06	0.03	0.02
B	0.22	0.11	0.08	0.13	0.06	0.04	0.35	0.17	0.12	0.27	0.13	0.10	0.14	0.07	0.05
(A × B)	0.31	0.15	0.11	0.18	0.09	0.06	N/A	0.24	0.17	0.39	0.19	0.13	0.19	0.10	0.07

V_1: Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between vari-eties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of the mean;*: Superior over control; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% *Azotobacter* (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

nation Pusa Shweta in control had the minimum plant height. Furthermore, when compared to the control, all treatments in combination with both varieties showed superiority, indicating that the application of organic amendments and biofertilizers positively influenced plant height at 15 DAS. The variety Pusa Chetki exhibited the highest plant height at 30 DAS, while Pusa Shweta had the lowest plant height at 30 DAS (Table 4). Whereas, amongst the treatments the highest plant height was observed in treatment VM:FYM: PM (50:25:25) and the lowest with control treatment. The two-way interaction between varieties and treatments did not show any significant differences. This implies that the combined effect of varieties and treatments did not have a noticeable impact on the plant height at 30 DAS.

On the other hand, the maximum plant height at 45 DAS was observed with the variety namely, Pusa Chetki while the lowest was recorded in Pusa Shweta (Table 4). Regarding the treatments, the highest plant height was exhibited by treatment vermicompost 100%, while the lowest was recorded in FYM along with *Azotobacter* (75:25). When considering the interaction between varieties and treatments, the combination Pusa Chetki + VC:FYM:PM (50:25:25) exhibited the maximum plant height. Conversely, the combination Pusa Shweta + Well rotten FYM 100% had the minimum plant height. Comparing the interactions with the control, Pusa Shweta with VC:FYM: PM (50:25:25) and all treatments in combination with Pusa Chetki showed superiority over the control in terms of plant height at 45 DAS. A positively significant influence of different varieties and treatments of organic amendments and biofertilizers had been observed on the number of leaves per plant at 15 DAS (Table 4). Among the two studied varieties, Pusa Chetki exhibited the highest number of leaves per plant at 15 DAS, while the lowest value was noted with Pusa Shweta. Concerning the treatments, the maximum number of leaves was observed in treatment VC:FYM:PM (50:25:25), and the minimum was recorded in the control treatment. When considering the two-way interaction between varieties and treatments (V + T), the combination of Pusa Chetki with VC: *Azotobacter* (50:50) had the maximum number of leaves per plant at 15 DAS. On the other hand, the combination of Pusa Shweta with control had the minimum value for the studied trait. When comparing the interactions with the control, treatment Pusa Shweta with VC:FYM:PM (50:25:25) and all treatments in combination with Pusa Chetki showed superiority in terms of the number of leaves per plant at 15 DAS. Between both the varieties, the maximum number of leaves per plant at 30 DAS was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta (Table 5). Whereas, amongst the treatments, the highest value was noticed in the treatment VC: *Azotobacter* (50:50), and the lowest value was noticed with T1 (control). Among the two-way interactions of varieties and treatments (V+T), Pusa Chetki with VC: *Azotobacter* (50:50) was recorded with maximum value, and Pusa Chetki with FYM (100%) observed with the minimum value for the studied trait. When interactions were compared to control, all the treatments in combination with Pusa Shweta recorded superior except Pusa Shweta with FYM (100%).

In addition to this, amongst both varieties, the maximum number of leaves per plant at 45 DAS was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki (Table 5). However, amongst the treatments, the highest value was noticed in the treatment VC: *Azotobacter* (50:50), and the lowest value was noticed with T1 (control). It has been recorded that the two-way interaction of varieties and treatments (V + T) was found to be non-significant. However, amongst the treatments, Pusa Shweta with VC: *Azotobacter* (50:50) had recorded a maximum value and Pusa Chetki (control) had recorded a minimum value. Data performance was also calculated for leaf area index at 15, 30, and 45 DAS (Table 5). Based on observed performance

Table 5. Effect of organic amendments and biofertilizers on the number of leaves per plant (30 and 45 DAS) and leaf area (15, 30, 45 DAS) in radish.

Code	Number of leaves per plant						Leaf area(cm^2)								
	30 DAS			45 DAS			15 DAS			30 DAS			45 DAS		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	5.24	6.60	5.92	8.47	7.51	7.99	13.38	15.37	14.37	26.84	30.25	28.55	97.52	116.08	106.80
T_2	5.64	6.48*	6.06	9.09	8.03	8.56	13.88	16.85*	15.37	26.24	30.75*	28.49	98.74	116.56*	107.65
T_3	6.27*	7.32*	6.80	9.48	8.42	8.95	14.64*	17.65*	16.14	27.65	31.48*	29.57	100.44	117.16*	108.80
T_4	6.04*	7.48*	6.76	9.41	8.66	9.03	13.71	16.69*	15.20	26.33	31.85*	29.09	99.35	117.90*	108.63
T_5	6.22*	6.96*	6.59	9.52	9.12	9.32	14.32	16.66*	15.49	26.94	32.03*	29.49	99.67	118.97*	109.32
T_6	6.76*	6.94*	6.85	9.42	8.86	9.14	14.52*	17.09*	15.81	26.96	32.08*	29.52	100.74	119.76*	110.25
T_7	6.79*	7.06*	6.92	9.93	8.64	9.28	14.92*	16.12*	15.52	27.41	32.24*	29.82	101.60	118.04*	109.82
T_8	6.92*	7.19*	7.05	9.63	9.54	9.59	15.73*	16.55*	16.14	27.86	31.98*	29.92	100.46	119.49*	109.98
T_9	7.06*	7.90*	7.48	10.88	9.84	10.36	14.44	17.77*	16.11	27.00	32.05*	29.53	99.47	121.82*	110.65
T_{10}	6.73*	7.70*	7.22	10.73	9.74	10.24	14.66*	17.68*	16.17	27.30	32.14*	29.72	101.42	120.79*	111.11
Mean	6.37	7.16	6.77	9.66	8.84	9.25	14.42	16.84	15.63	27.05	31.69	29.37	99.94	118.66	109.30
	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)
A	0.03	0.02	0.01	0.19	0.10	0.07	0.09	0.04	0.03	0.06	0.03	0.02	0.19	0.09	0.07
B	0.07	0.04	0.03	0.43	0.21	0.15	0.20	0.10	0.07	0.13	0.06	0.05	0.42	0.21	0.15
A × B	0.10	0.05	0.04	N/A	0.30	0.21	0.28	0.14	0.10	0.18	0.09	0.06	0.60	0.29	0.21

V_1: Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between vari-eties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of mean; *: Superior over control; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% *Azotobacter* (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

for both the varieties, the maximum value for leaf area index at 15 DAS was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with control. In between the two-way interaction of varieties and treatments (V + T), Pusa Chetki with VC: *Azotobacter* (50:50) had recorded maximum value, and the minimum value was recorded in Pusa Shweta (control). When the interactions were compared with the control, Pusa Shweta with VC: FYM (75:25), Pusa Shweta with FYM: (75:25), Pusa Shweta with VC:FYM:PM (50:250:25), Pusa Shweta with Vermicompost (100%), Pusa Shweta with FYM:PM (75:25) and all the treatments in combination with Pusa Chetki recorded superior over control. Similarly amongst two different varieties the maximum value for leaf area index at 30 days after sowing was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM (75:25), and the lowest values were noticed with well-rotten FYM (100%). Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki with FYM: *Azotobacter* (75:25) had recorded maximum value, and the minimum value was recorded in Pusa Shweta (control). When the interactions were compared to the control, all the treatments in combination with Pusa Chetki showed superiority over the control. However, the maximum leaf area index at 45 DAS was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. However, amongst the treatments the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with T1 (control). Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki with VC: *Azotobacter* (50:50) had recorded maximum value and Pusa Shweta (control) had recorded minimum value. When the interactions were compared to the control, all the treatments in combination with Pusa Chetki showed superiority over the control. As per the presented data for varieties, the minimum days taken to harvest were recorded in Pusa Chetki and the maximum was recorded in Pusa Shweta (Table 6). Whereas, among the treatments the lowest value was noticed in the treatment FYM: *Azotobacter* (75:25). Whereas, the highest value was noticed with control. Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki, well FYM: *Azotobacter* (75:25) had recorded minimum value, whereas, Pusa Shweta with PM:PSB (50:50) had recorded maximum value. When the interactions were compared with the control, all the treatments in combination with Pusa Chetki recorded superiority over the control.

Most of the studied growth attributes of radish varieties were significantly influenced by the various treatments. Treatment of Vermicompost 100 percent applied on radish variety “Pusa Chetki” resulted from minimum days taken for germination and maximum plant height at 15 DAS. Numerous studies have reported that both solid vermicompost and vermicompost extract contain a variety of active substances, including phenolic and humic compounds. These substances have been found to have a dose-dependent effect on seed germination and the early stages of seedling development (Mishra et al., 2020). However, the maximum plant height at 30 DAS was noticed, when 50 percent of vermicompost along with 25 percent of FYM and poultry manure, each incorporated in soil of variety Pusa Chetki. The increased plant height may be due to the increased dosage and beneficiary effect of integrated nutrient management this might be due to the influence of nutrients, the chief constituent of protein which is essential for the formation of protoplasm leading to meristematic activity, cell division, and development of root (Urra et al., 2019). However, the presence of humic acids, as well as micro and macronutrients found in vermicompost, may also potentially lead to an increase in the plant’s height. It was found that applying vermicompost resulted in the highest recorded plant height

Table 6. Effect of organic amendments, biofertilizers, and their combinations on yielding attributes of radish.

Code	Root diameter (cm)			Root length (cm)			Root fresh weight (g)			Days taken to harvest			Root yield per plot (Kg)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	3.17	2.99	3.08	20.54	17.24	18.89	156.64	131.66	144.15	52.24	48.66	50.45	9.18	5.26	7.22
T_2	3.50	2.64	3.07	22.33*	17.83	20.08	173.94*	137.81	155.88	52.35	48.16*	50.25	9.74*	5.79	7.77
T_3	4.74*	2.42	3.58	23.28*	19.56	21.42	152.56*	132.51	142.54	51.22	47.89*	49.56	9.92*	5.80	7.86
T_4	3.87*	2.83	3.35	21.80*	18.23	20.01	180.19*	146.13	163.16	51.25	48.22*	49.74	10.35*	5.61	7.98
T_5	3.49	3.43	3.46	21.22*	19.70*	20.46	176.93*	132.87	154.90	52.93	47.85*	50.39	10.49*	5.83	8.16
T_6	3.78*	2.79	3.29	22.63*	19.92*	21.27	170.67*	136.37	153.52	51.36	47.55*	49.45	10.11*	5.80	7.95
T_7	3.38	3.19	3.29	24.83*	18.55	21.69	190.82*	144.92	167.87	51.36	47.06*	49.21	10.81*	5.98	8.40
T_8	3.51*	3.16	3.34	24.56*	19.51	22.04	251.18*	153.72*	202.45	52.15	48.25*	50.20	11.06*	6.17	8.62
T_9	4.08*	3.25	3.66	25.18*	17.91	21.55	232.66*	141.69	187.17	51.65	47.16*	49.40	11.27*	5.87	8.57
T_{10}	4.48*	3.27	3.87	24.51*	19.88*	22.20	241.32*	153.99*	197.66	51.82	48.22*	50.02	12.16*	6.26	9.21
Mean	3.80	3.80	3.40	23.09	18.83	20.96	192.69	131.66	166.93	51.83	47.90	49.87	10.51	5.84	8.17
	CD	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**
A	0.13	0.07	0.05	0.23	0.12	0.08	2.44	1.20	0.85	0.03	0.01	0.01	0.18	0.09	0.06
B	0.30	0.15	0.10	0.52	0.26	0.18	5.46	2.69	1.90	0.06	0.03	0.02	0.39	0.19	0.14
A × B	0.42	0.21	0.15	0.74	0.36	0.26	7.72	3.80	2.69	0.09	0.04	0.03	0.56	0.27	0.19

V_1:Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between varieties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of mean; *: Superior over control; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% *Azotobacter* (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

in radish (Khede et al., 2019). Similarly, an increase in plant height was reported when vermicompost was applied in combination with NPK integration. The results are also in conformity with the findings of Maduwanthi and Marapana (2021); Mani and Anburani (2018). Increased nutrient availability plays a crucial role in facilitating nutrient uptake by plants, which is essential for their optimal growth and development. Nitrogen, a component of chlorophyll pigment, is particularly important for photosynthesis (Patel et al., 2023). Enhanced photosynthesis, resulting from an ample supply of nitrogen, contributes to greater plant growth, specifically in terms of increased plant height. These findings were in harmony with Shilpa et al. (2022) and SRehman et al. (2023). The incorporation of a 50 percent dose of vermicompost and *Azotobacter* each in Pusa Chetki showed a positive response for the number of leaves per plant (15 and 30 DAS) and leaf area index (15 & 45 DAS). In contrast to this Pusa Chetki along with soil application of FYM 75% and seed treatment with *Azotobacter* 25%, found with highest value for the number of leaves per plant, while the minimum was noted for days to harvest. Increased number of leaves per plant was found may be due to promotive effects of macro and micronutrients on vegetative growth which ultimately lead to more photosynthetic activity. The combination of FYM and *Azotobacter* may have resulted in the improvement of cation exchange capacity and water holding capacity of the soil (Patel et al., 2023; Basnet et al., 2021). Additionally, it could have supplied all the essential primary and secondary nutrients necessary for optimal plant growth, specifically in terms of leaf development per plant. This result was confirmed by SRehman et al. (2023) and Kumar et al. (2022). The application of organic fertilizer in conjunction with vermicompost and *Azotobacter* also likely facilitated the uptake of nitrogen and other nutrients, leading to a higher leaf count. This application likely enhanced the uptake of nitrogen and other essential nutrients, resulting in a higher number of leaves. Similar findings of the maximum number of leaves due to organic manure and biofertilizers were reported by Patel et al. (2023). The combination of organic fertilizer, vermicompost, and *Azotobacter* application is believed to have contributed to the increase in leaf count. The plausible explanation for the increase in leaf area could be attributed to the enhanced uptake of nutrients, particularly iron and magnesium, from the soil (Mani and Anburani, 2018). This increased nutrient availability likely promoted greater photosynthetic activity, contributing to the expansion of leaf area (Patel et al., 2023). Furthermore, the presence of humic acid might have played a role in facilitating the increased leaf area. These findings were given conformity with the findings of SRehman et al. (2023) and Patel et al. (2023). The combination of FYM along with vermicompost has been observed to contribute to the maximum leaf area index because the availability of balanced and sufficient nutrients supports optimal leaf development and, consequently, a higher leaf area index (Shilpa et al., 2022). Increment in leaf area due to physiological parameters like photosynthesis, stomata conductance, and transpiration might have improved with the application of FYM. It enhances the absorption of nutrients from soil; and enhances carbohydrate assimilation and production of new tissue (SRehman et al., 2023).

Yield parameters

It was observed that there was a significant influence of different varieties, treatments of organic amendments, and biofertilizers, and their interactions were recorded on the root diameter. In-between both the varieties, the maximum root diameter was recorded in Pusa Chetki, and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment of VC:FYM:PM (50:25:25), and the lowest value was noticed with well rotten FYM 100%. Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki + Vermicompost (100%) had recorded maximum value. Whereas, the minimum value for the trait was recorded with a combination of Pusa Shweta treated with vermicompost (100%). When the interactions were compared with the control, the interactions of Pusa Chetki with Vermicompost (100%), Pusa Chetki treated with VC:FYM:PM (50:25:25), Pusa Chetki with VC: *Azotobacter* (50:50), Pusa Chetki with Poultry manure (100%), Pusa Chetki with FYM:PM (75:25), Pusa Chetki with VC:FYM (75:25) were recorded superior over the control. Similarly, the data has been recorded for root length and the result was revealed that, based on performance, a significant difference was found between both the varieties, the maximum root length was recorded in Pusa Shweta, and the minimum was recorded in Pusa Chetki. However, among the treatments the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with control. Among the two-way interactions of varieties and treatments (V + T), Pusa Shweta with VC: *Azotobacter* (50:50) had recorded maximum value. Whereas, Pusa Chetki (control) had recorded with minimum value. When the interactions were compared with control, all the treatments in combination with Pusa Shweta and the interactions Pusa Chetki with FYM:PM (75:25), Pusa Chetki with VC:FYM:PM (50:25:25), Pusa Chetki accompanied with PM:PSB (50:50) recorded superior over control. The maximum root fresh weight was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM (75:25), and the lowest values were noticed with Vermicompost (100%). Among the two-way interactions of varieties and treatments (V + T), Pusa Shweta with VC:FYM (75:25) had recorded a maximum. The lowest value for the trait was recorded with a combination of Pusa Chetki (control). When the interactions were compared with the control, the interactions Pusa Chetki with VC:FYM (75:25) and Pusa Chetki with VC:FYM:PM (50:25:25), and all the treatments in combination with Pusa Shweta were recorded as superior over control.

Among the varieties, the maximum root yield per plot was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki (Table 6). Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with control. In between the two-way interaction of varieties and treatments, Pusa Shweta with VC:FYM:PM (50:25:25) had recorded maximum value. Whereas, the minimum value was recorded in Pusa Chetki (control). When the interactions were compared with the control, all the treatments in combination with Pusa Shweta recorded superiority over the control.

Yielding attributes of radish varieties were also positively influenced by the various treatments of organic manures and biofertilizers. The soil application of a full dose of vermicompost (100%) in Pusa Chetki increased the root diameter, while the length was at maximum when the seed of variety Pusa Shweta was treated with Azotobacter and soil application of Vermicompost (50%). An explanation for the increase in root length and root diameter could be the result of decreased bulk density and increased porosity and water retention capacity of the soil caused by the application of organic manures (Sun et al., 2022; Patel et al., 2023). Additionally, the growth enhancement could be attributed to the process of nutrient solubilization facilitated by the addition of poultry manure and vermicompost, resulting in increased uptake of essential plant nutrients such as nitrogen, phosphorus, and potassium (Shilpa et al., 2022; SRehman et al., 2023). The major yield contributing trait i.e. highest fresh root weight of Pusa Shweta was noted, when vermicompost and well-rotten FYM at 75:25, respectively incorporated in the soil. Similarly, the variety Pusa Shweta produced maximum yield, with the incorporation of combined application of vermicompost (50%), FYM (25%), and poultry manure (25%) in the soil. The maximum fresh root weight and increment in root yield might be due to the nutrients (N.P.K.) are starting material for biological synthesis and they also play an important role in plant metabolism and being an essential constituent of diverse type metabolically active compounds like purines, pyrimidines, enzymes, coenzymes and alkaloids (Shani et al., 2017). Thus increased availability of photosynthesis, which consequently led to a desirable C:N ratio as carbohydrate supply might be helping in larger storage in the root as well as shoot. This type of situation reflected in growth and yield parameters directly led to a higher yield of radish root yield. Increased yield due to better availability of nutrients and a balanced C:N ratio might have increased the synthesis of carbohydrates which ultimately promoted greater yield (Olasekan et al., 2019). The improved effectiveness of these treatments can be attributed to the higher availability of nutrients and the gradual release of these nutrients coinciding with the stage of root development in radish. This, in turn, leads to increased root growth and improved aeration for root development. These findings were uncovered by (Shilpa et al., 2022).

Quality parameters

For quality aspects, positively significant outcomes were observed for all the studied quality traits. In between both the varieties, maximum total soluble solids were recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta (Table 7). Whereas, amongst the treatments the highest value was noticed in the treatment Vermicompost (100%) and the lowest value was noticed with Poultry manure (100%). It has been recorded that amongst the two-way interaction of varieties and treatments (V + T), Pusa Chetki with Vermicompost (100%) had recorded maximum value. The lowest value was recorded with control of Pusa Shweta. When the interactions were compared to the control, all the treatments in combination with Pusa Chetki, except Pusa Chetki, Poultry manure (100%) were recorded as superior over the control. On the other hand, there was a significant influence of different varieties, treatments of organic amendments, and biofertilizers, and their interactions were recorded on the chlorophyll content in leaves (Table 7). In between both the varieties, the maximum chlorophyll content was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. Whereas, amongst

Table 7. Effect of organic amendments, biofertilizers, and their combinations on total soluble solids, chlorophyll content, firmness, ascorbic acid, and titratable acidity in radish.

Treatments	Total Soluble Solids (°Brix)			chlorophyll content (SPAD value)			firmness (kg/cm^2)			Ascorbic acid content (mg per 100 g)			Titratable acidity (%)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	4.17	4.29	4.23	38.30	40.81	39.55	5.65	7.72	6.69	18.38	17.55	17.96	0.54	0.65	0.60
T_2	4.27	4.68*	4.47	41.24*	40.54*	40.89	5.19	7.51*	6.35	18.49	17.41	17.95	0.44	0.53	0.48
T_3	4.57	4.82*	4.69	42.67*	40.35*	41.51	5.52	7.87*	6.70	18.56	17.27	17.92	0.63	0.63	0.63
T_4	4.17	4.22	4.20	43.43*	41.53*	42.48	5.57	7.57*	6.57	18.40	17.71	18.06	0.63	0.53	0.58
T_5	4.25	4.46*	4.35	41.53*	42.53*	42.03	5.66	7.57*	6.62	18.98	18.06	18.52	0.64	0.54	0.59
T_6	4.19	4.44*	4.32	42.11*	40.20*	41.16	5.76	7.60*	6.68	18.11	17.77	17.94	0.65*	0.54	0.60
T_7	4.30	4.44*	4.37	41.33*	41.74*	41.53	5.34	7.15*	6.25	18.53	17.50	18.02	0.65*	0.55	0.60
T_8	4.29	4.42*	4.36	41.47*	40.36*	40.91	5.67	7.62*	6.64	18.27	17.34	17.81	0.53	0.56	0.54
T_9	4.25	4.36*	4.31	44.16*	40.55*	42.36	5.31	7.72*	6.52	18.74	17.71	18.23	0.73*	0.55	0.64
T_{10}	4.31	4.51*	4.41	41.47*	41.29*	41.38	5.53	7.57*	6.55	18.55	17.55	18.05	0.74*	0.54	0.64
Mean	4.28	4.46	4.37	41.77	40.99	41.38	5.52	7.59	6.56	18.50	17.59	18.05	0.62	0.56	0.59
	CD	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**
A	0.03	0.01	0.01	0.10	0.05	0.04	0.05	0.02	0.02	0.13	0.06	0.04	0.01	0.01	0.00
B	0.07	0.03	0.02	0.23	0.11	0.08	0.11	0.05	0.04	0.29	0.14	0.10	0.03	0.01	0.01
A × B	0.09	0.05	0.03	0.33	0.16	0.11	0.16	0.08	0.05	N/A	0.20	0.14	0.04	0.02	0.01

V_1: Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between varieties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of mean; *: Superior over control; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% *Azotobacter* (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

the treatments, the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with control. Among the two-way interactions of varieties and treatments (V + T), Pusa Shweta, VC: *Azotobacter* (50:50) had recorded maximum value. The lowest value was recorded in Pusa Shweta (control). When the interactions were compared with the control, all the treatments in combination with Pusa Shweta and Pusa Chetki recorded superior over the control.

The data on firmness has confirmed that a significant influence of different varieties, treatments of organic amendments, biofertilizers, and their interactions was recorded on the firmness and ascorbic acid content (Table 7). In between both the varieties, maximum firmness was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment vermicompost (100%) and the lowest value was noticed with FYM: *Azotobacter* (75:25). Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki, Vermicompost (100%) recorded maximum value, whereas, the minimum value was recorded in Pusa Shweta, well rotten FYM (100%). When the interactions were compared with the control, all the treatments in combination with Pusa Chetki recorded superior over control. In between both the varieties, the maximum ascorbic acid content was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. Whereas, among the treatments, the highest value was noticed in the treatment PM:PSB (50:50), and the lowest value was noticed with T_3 (Vermicompost 100%). Among the two-way interactions of varieties and treatments (V + T) was observed to be non-significant. However, Pusa Shweta, PM:PSB (50:50) had recorded maximum value. Whereas, the minimum value was recorded in Pusa Chetki, Vermicompost (100%). A significant influence of different varieties, treatments of organic amendments, biofertilizers, and their interactions was recorded on titratable acidity. In between both the varieties, the maximum titratable acidity was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki (Table 4). Whereas, amongst the treatments, the highest value was noticed in the treatment VC: *Azotobacter* (50:50) and VC:FYM:PM (50:25:25), and the lowest value was noticed with well-rotten FYM (100%). Among the two-way interactions of varieties and treatments (V + T), Pusa Shweta, VC:FYM:PM (50:25:25) recorded maximum value, and the minimum value was recorded in Pusa Shweta, well rotten FYM (100%). When the interactions were compared with control, the interactions, Pusa Shweta with VC: *Azotobacter* (50:50), Pusa Shweta, accompanied with FYM:PM (75:25), and Pusa Shweta with FYM: *Azotobacter* (75:25) recorded superior over control. A significant influence of different varieties, treatments of organic amendments, biofertilizers, and their interactions was recorded on the reducing sugars, non-reducing sugar, and total sugar (Table 8). In between both the varieties, the maximum reducing sugars was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment T1 (control), and the lowest value was noticed with PM:PSB (50:50). Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki, Vermicompost (100%) had recorded maximum value. Whereas, the minimum value was recorded in Pusa Shweta, FYM:PM (75:25). When the interactions were compared with the control, all the treatments in combination with Pusa Chetki recorded superior over the control. Amongst the varieties, maximum non-reducing sugars were recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki (Table 8). Whereas, amongst the treatments, the highest value was noticed in the treatment well rotten FYM (100%) and the lowest value was noticed

Table 8. Effect of organic amendments, biofertilizers, and their combinations on sugar content and moisture content percentage (leaves and roots) in radish.

Treatments	Total sugars (g 100 g^{-1})			Reducing sugars (g 100 g^{-1})			Non-reducing sugars (g 100 g^{-1})			moisture content of leaves (%)			moisture content of roots (%)		
	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean	V_1	V_2	Mean
T_1	9.86	10.32	10.09	9.65	10.14	9.89	0.22	0.18	0.20	90.78	91.23	91.01	97.31	97.66	97.49
T_2	9.83	10.54*	10.19	9.47	10.24*	9.86	0.36*	0.30*	0.33	91.71*	91.23	91.47	97.75	95.92	96.84
T_3	9.57	10.65*	10.11	9.37	10.34*	9.86	0.20	0.31*	0.26	91.17	90.28	90.73	96.72	96.26	96.49
T_4	9.72	10.53*	10.12	9.44	10.24*	9.84	0.27*	0.29*	0.28	91.30	90.52	90.91	97.18	95.68	96.43
T_5	9.65	10.26*	9.95	9.34	10.04*	9.69	0.31*	0.22*	0.26	90.22	91.27	90.75	96.85	96.18	96.51
T_6	9.48	10.45*	9.97	9.26	10.22*	9.74	0.22	0.23	0.23	90.33	91.12	90.73	95.24	94.17	94.70
T_7	9.66	10.34*	10.00	9.34	10.13*	9.74	0.32*	0.21	0.26	90.31	90.14	90.23	96.34	95.74	96.04
T_8	9.67	10.35*	10.01	9.34	10.12*	9.73	0.33*	0.23	0.28	90.30	90.38	90.34	96.79	95.39	96.09
T_9	9.64	10.35*	9.99	9.34	10.14*	9.74	0.29*	0.21	0.25	90.25	90.36	90.30	97.20	95.69	96.45
T_{10}	9.48	10.54*	10.01	9.26	10.25*	9.76	0.22	0.29*	0.26	90.80	90.82	90.81	96.54	94.94	95.74
Mean	9.66	10.43	10.04	9.38	10.19	9.78	0.27	0.25	0.26	90.72	90.74	90.73	96.79	95.76	96.28
	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)	CD	SE(d)	SE(m)
A	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.10	0.05	0.04	0.20	0.10	0.07
B	0.03	0.01	0.01	0.03	0.02	0.01	0.04	0.02	0.01	0.23	0.11	0.08	0.44	0.22	0.15
A × B	0.05	0.02	0.02	0.05	0.02	0.02	0.06	0.03	0.02	0.33	0.16	0.11	0.62	0.30	0.22

V_1: Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between varieties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of mean; *: Superior over control; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% *Azotobacter* (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

with control. It has been recorded that amongst the two-way interaction of varieties and treatments (V + T), Pusa Chetki, and Vermicompost (100%) had recorded maximum value. When the interactions were compared to control, Pusa Shweta, VC:FYM (75:25), Pusa Shweta, FYM: *Azotobacter* (75:25), Pusa Shweta VC: *Azotobacter* (50:50), Pusa Shweta, FYM (100%), Pusa Shweta, PM (100%), Pusa Shweta, PM:PSB (50:50), Pusa Chetki, VC (100%), Pusa Chetki, VC:FYM:PM (50:25:25), well rotten FYM (100%), Pusa Chetki with PM (100%), Pusa Chetki, PM:PSB (50:50) recorded superior over the control.

In between both the varieties, the maximum total sugars were recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta (Table 8). Whereas, amongst the treatments, the highest value was noticed in the treatment FYM (100%), and the lowest value was noticed with PM:PSB (50:50). Among the two-way interactions of varieties and treatments (V + T), Pusa Chetki, Vermicompost (100%) recorded maximum value. Whereas, the minimum value was recorded in Pusa Shweta, FYM:PM (75:25). When the interactions were compared with the control, all the treatments in combination with Pusa Chetki recorded superior over the control. The data on the moisture percentage of leaves and roots has confirmed a significant influence of different varieties, treatments of organic amendments, biofertilizers, and their interactions. In between both the varieties, the maximum moisture% of leaves was recorded in Pusa Chetki and the minimum was recorded in Pusa Shweta. Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with control. Among the two-way interactions of varieties and treatments (V + T), Pusa Shweta, Well-rotten FYM (100%) recorded a maximum value, and the minimum value was recorded in Pusa Chetki, FYM: *Azotobacter* (75:25). When the interactions were compared with control, Pusa Shweta, Well-rotten FYM (100%) recorded superior over control. Between both of the varieties, the maximum moisture% of roots was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki (Table 8). Whereas, amongst the treatments, the highest value was noticed in the treatment control, and the lowest values were noticed with FYM:PM (75:25). Among the two-way interaction of varieties and treatments (V + T), Pusa Shweta, Well-rotten FYM (100%) had recorded maximum value. $V_2 + T_6$ Pusa Chetki, FYM:PM (75:25) recorded with a minimum value. When the interactions were compared with control, none of the interactions showed superiority over control. A significant influence of different varieties, treatments of organic amendments, biofertilizers, and their interactions were recorded on the dry matter percentage of leaves and roots (Table 9). In between both the varieties, the maximum dry matter % of leaves was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. Whereas, amongst the treatments, the highest value was noticed in the treatment FYM: *Azotobacter* (75:25%), and the lowest value was noticed with well-rotten FYM (100%). Between the two-way interaction of varieties and treatments

Table 9. Effect of organic amendments, biofertilizers, and their interactions on dry matter content of leaves (%), dry matter content of roots (%), pH, electrical conductivity, organic carbon, nitrogen, phosphorus, and potassium (soil) in radish.

Code	Dry matter content (%) Leaves (%) V_1	Leaves (%) V_2	Leaves (%) Mean	Roots (%) V_1	Roots (%) V_2	Roots (%) Mean		pH	EC (ds/m)	OC (%)	Available N:P:K (Kg/ha) N	P	K
T_1	9.22	8.77	8.99	5.54	5.47	5.51		6.70	0.14	0.23	136.087	22.04	123.17
T_2	8.29	8.77	8.53	5.45	4.82	5.13		6.80	0.11	0.28	143.86	23.29	132.28
T_3	8.83	9.72	9.27	5.65*	4.75	5.20		6.80	0.15	0.34	146.29	22.63	131.847
T_4	8.70	9.48	9.09	5.56	4.87	5.22		6.60	0.13	0.32	142.26	21.89	134.87
T_5	9.78*	8.73	9.25	5.63*	4.76	5.20		6.70	0.16	0.25	138.83	24.24	128.65
T_6	9.67*	8.88	9.28	4.95	5.17	5.06		6.70	0.14	0.29	144.893	20.58	133.74
T_7	9.69*	9.86*	9.77	4.73	4.85	4.79		6.90	0.17	0.36	139.263	23.04	129.35
T_8	9.70*	9.62*	9.66	5.64*	4.92	5.28		7.10	0.12	0.34	143.21	21.27	131.28
T_9	9.75*	9.64*	9.70	5.56	4.86	5.21		7.00	0.19	0.32	142.537	23.01	134.26
T_{10}	9.20	9.18	9.19	5.56	5.01	5.29		7.20	0.17	0.36	146.52	23.62	133.56
Mean	9.28	9.26	9.27	5.43	4.95	5.19	**Mean**	6.70	0.14	0.23	136.087	22.04	123.17
	CD	**SE(d)**	**SE(m)**	**CD**	**SE(d)**	**SE(m)**	**C.D. (0.05)**	0.32	0.019	0.018	1.57	5.43	1.16
A	N/A	0.05	0.04	0.03	0.02	0.01	**C.V.**	2.69	7.46	3.36	136.087	2.41	3.00
B	0.24	0.12	0.09	0.07	0.03	0.02							
A×B	0.34	0.17	0.12	0.09	0.05	0.03		-	-	-	-	-	-

V_1:Pusa Shweta; V_2: Pusa Chetki; Factor (A): Varieties; Factor (B): Treatments; Factor (A × B): interaction between varieties and treatments; CD: Critical difference; SE(d): Standard Error of Difference; SE(m): standard error of mean; *: Superior over control; pH: potential of Hydrogen; EC(ds m^{-1}): Electrical conductivity; OC%: Organic carbon; N (kg ha^{-1}): Available Nitrogen; P (kg ha^{-1}): Available Phosphorus; K (kg ha^{-1}): Available potassium; C.D: Critical difference; C.V: Coefficient of variation; Control (T_1), 100% well-rotted FYM (T_2), 100% vermicompost (T_3), 100% poultry manure (T_4), 50% poultry manure + 50% PSB (T_5), 75% well-rotted FYM + 25% poultry manure (T_6), 75% well-rotted FYM + 25% Azotobacter (T_7), 75% vermicompost + 25% well-rotted FYM (T_8), 50% vermicompost + 50% *Azotobacter* (T_9), and 50% vermicompost + 25% well-rotted FYM + 25% poultry manure (T_{10}).

(V + T), Pusa Chetki, FYM: *Azotobacter* (75:25) recorded a maximum value, whereas the minimum value was recorded in Pusa Shweta, Well-rotten FYM (100%). When compared with control, among all the interactions, Pusa Shweta, PM:PSB (50:50), Pusa Shweta, FYM:PM (75:25), FYM: *Azotobacter* (75:25), Pusa Shweta, VC:FYM (75:25), Pusa Shweta, VC: *Azotobacter* (50:50), Pusa Chetki, FYM: *Azotobacter* (75:25), Pusa Chetki, VC:FYM (75:25) and Pusa Chetki, VC: *Azotobacter* (50:50) showed superiority over control. In between both the varieties, the maximum dry matter percentage of roots was recorded in Pusa Shweta and the minimum was recorded in Pusa Chetki. Whereas, amongst the treatments, the highest value was noticed in the treatment VC:FYM:PM (50:25:25), and the lowest value was noticed with FYM: *Azotobacter* (75:25). Among the two-way interaction of varieties and treatments (V + T), Pusa Shweta, Vermicompost (100%) recorded maximum value and the minimum value had been recorded in Pusa Shweta treated with Well FYM: *Azotobacter* (75:25). When the interactions were compared with control, the treatments viz., Pusa Shweta in the combination of different doses of Vermicompost (100%), VC:FYM (75:25), and FYM:PM (75:25%) shown superiority over control, respectively.

All the quality attributes were also positively influenced by the application of organic manures in combination with biofertilizers. The full dose of vermicompost (100%) in Pusa Chetki enhanced the availability of total soluble solids, firmness, total sugar, and reducing and non-reducing sugar. The potential cause behind an increase in the total soluble solids content phenomenon could be the accumulation of a greater amount of reserve substances in the roots. The significant impact of increased vermicompost application on the total soluble solids might have influenced the radish plant's response to vermicompost (Olasekan et al., 2019). This could be attributed to the insufficient organic matter present in the soil, which limits its ability to enhance the physical and chemical properties of the soil, as well as provide an ample nutrient supply (Urra et al., 2019). Vermicompost is a source of organic matter, which improves soil structure and moisture-holding capacity. Increased organic matter content can enhance root development and strengthen the plant's anchorage in the soil. This can result in firmer plant tissues (Sun et al., 2022). The adoption of safe production practices, combined with the use of farmyard manure, leads to a gradual enhancement in the quality parameters such as total sugar content, and reducing and non-reducing sugars of radish roots. This improvement can be attributed to the increased growth parameters observed in the plants, which subsequently result in improved nutrient uptake and photosynthetic activities (Kumar et al., 2022). The quality parameters of radish are positively influenced by the stimulation of enzymatic activities by plant growth components. The utilization of safe production practices, along with the incorporation of FYM, creates favorable conditions for the growth and development of radish, leading to improved nutrient absorption, efficient photosynthesis, and ultimately higher quality in the harvested radish roots (Adekiya et al., 2019). The chlorophyll content in the leaves of Pusa Shweta was positively influenced, with a reduced dose of vermicompost (soil application) and Azotobacter (seed treatment) i.e. 50 percent each. The application of poultry manure exhibited a significant influence on the leaf levels of nitrogen, phosphorus, potassium, calcium, and magnesium in radish plants. This, in turn, may contribute to an increase in chlorophyll content. Similar findings were found to be overlapped with the findings of Gamba et al. (2021). On the other hand, titratable acidity was also greatly increased with soil application of reduced dose vermicompost (50%), FYM (25%), and poultry manure (25%). The increased ascorbic content found in poultry manure can be attributed to its higher potassium content, as potassium is known to enhance the quality of crops. A quadratic relationship between poultry manure and vitamin C content was derived by Gamba et al. (2021) and Zhang et al. (2021). Furthermore, Abanto-Rodriguez et al. 2016 observed a positive correlation between ascorbic acid and the concentration of magnesium and phosphorus. The higher titratable acidity content observed in poultry manure can be attributed to its elevated potassium content. Potassium is well-known for its positive influence on crop quality. It plays a crucial role in various physiological processes within plants, including the regulation of pH and acidity levels. Adequate potassium levels can enhance enzymatic activity and metabolic processes related to organic acid synthesis, leading to increased titratable acidity in crops (Rasool et al., 2023; Wani et al., 2023). Application of recommended full dose of Well rotten FYM level up the moisture percentage of leaves and roots of radish variety " Pusa Shweta". Meanwhile, a reduction in application dose of FYM (75%) and *Azotobacter* (25%), increased the dry matter content of leaves, while in root higher availability was observed in Pusa Shweta, when vermicompost (100%) applied in full dose. More plant spread, photosynthetic area, and the availability of micronutrients may be responsible for the increase in fresh and dry matter content, which led to a greater accumulation of photosynthates in leaves of radish crop (Wani et al., 2023; Negi et al., 2023). The other possible reason might be that the organic manures release nutrients in a controlled manner.

Soil parameters

A significant effect of organic amendments and biofertilizers was observed on the chemical properties of the soil, including EC (Electrical Conductivity), organic carbon, nitrogen, phosphorus, and potassium, except for pH (Table 9). Among the treatments, the highest pH value was recorded in VC:FYM:PM (50:25:25), while the lowest pH value was observed in Poultry manure (100%). In terms of EC, the highest value was found in VC: *Azotobacter* (50:50), closely followed by FYM: *Azotobacter* (75:25), whereas the lowest value was observed in Well rotten FYM (100%). The treatment PM:PSB (50:50) had the highest organic carbon percentage, while FYM: *Azotobacter* (75:25) had the lowest. Regarding nitrogen content, the highest values were recorded in control, VC:FYM:PM (50:25:25), and Vermicompost (100%), while the lowest value was observed in PM:PSB (50:50). For phosphorus, the highest values were found in control and PM:PSB (50:50), and the lowest value was recorded in FYM:PM (75:25). Finally, control and

Poultry manure (100%) had the highest potassium values; while the lowest value was observed in PM:PSB (50:50). Soil nutrients are the major factors that greatly influence the growth and development of the plant because they directly or indirectly affect the yield and quality attributing traits of the crop. The availability of nitrogen and pH of the soil was highly influenced by the soil application of half dose of vermicompost with one-fourth dose of Well-rotten FYM and poultry manures. The electrical conductivity of the soil was also affected by the applied dose of vermicompost and *Azotobacter* fifty percent each. Additionally, the organic carbon and phosphorus content of the soil status was also improvised when the soil was incorporated with half a dose of vermicompost in combination with seed treatment of phosphorus solubilizing bacteria. In contrast to this, the full dose of poultry manures raised the availability of potassium in treated soil. The application of organic manures plays a crucial role in the secretion of growth-promoting substances and is also known as a slow releaser (Parry et al., 2021). Thereby facilitating improved root development, carbohydrate translocation to storage organs, water transportation, and the uptake and breakdown of nutrients, which also ultimately enhance the availability of organic carbon, nitrogen, phosphorus, and potassium content in the soil (Kaur et al., 2023). The utilization of organic manures affects the duration of vegetable crops by enhancing nutrient absorption by plants and promoting the growth of water-conducting tissues. A decrease in bulk density and increase in porosity and water holding capacity of the soil due to organic manures might have contributed to increasing the length of roots of the plants. The increase in the length of the root may be attributed to the solubilization of plant nutrients by the addition of poultry manure and vermicompost leading to an increased uptake of NPK (Basnet et al., 2021).

Economics

It was observed that the total cost of cultivation varied among the different treatments. The highest total cost was recorded in Vermicompost (100%). When examining the gross returns, the combination Pusa Shweta, VC:FYM:PM (50:25:25), yielded the highest returns, while the combination Pusa Chetki, VC:FYM:PM (50:25:25), generated the lowest returns. Lastly, the benefit-cost ratio was also varied among the different combinations. The combination Pusa Shweta, VC:FYM:PM (50:25:25) exhibited the highest benefit-cost ratio, indicating a favorable return on investment. On the other hand, the combination of Pusa Chetki, and Well rotten FYM (100%) showed the lowest benefit-cost ratio (Table 10). The treatment of vermicompost (50%) along with one-fourth doses of Well-rotten FYM and poultry manures in Pusa Shweta was found more profitable in radish crops. The balanced application of organic manure along with biofertilizers in integration might also help to reduce the cultivation cost as the ratio, which resulted in more benefit in terms of yield and benefit-cost ratio (Kaur et al., 2023).

4. Conclusion

Based on formal deliberation it has been concluded that the significant influence of varieties, treatments, and their interactions was observed on most of the studied attributes of radish. Whereas, the variety namely Pusa Shweta, and the treatment of VC:FYM:PM (50:25:25) followed by VC 100%, VC: *Azotobacter* (50:50) along with the interaction

Table 10. Effect of organic amendments and biofertilizers on total cost of cultivation, gross returns, net returns, and benefit-cost ratio for radish cultivation.

Code	Treatment combinations	Yield (q ha^{-1})		Total cost of cultivation (US$)		Gross returns (US$)		Net returns (US$)		Benefit-cost ratio	
		V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2	V_1	V_2
	Combinations										
T_2	**FYM 100%**	38.96	23.17	1237.33	1237.07	7014.76	4171.77	5777.70	2934.70	4.67^{b}	2.37^{b}
T_3	**Vermicompost (VC) 100%**	39.66	23.21	1465.44	1465.13	7140.80	4178.97	5675.67	2713.84	3.87^{b}	1.85
T_4	**Poultry manure (PM) 100%**	41.40	22.45	1270.34	1270.08	7454.09	4042.13	6184.01	2772.06	4.87^{ab}	2.18
T_5	**PM+PSB (50:50)**	41.95	23.33	1227.42	1227.16	7553.11	4200.58	6325.95	2973.41	5.15ab	2.42^{b}
T_6	**FYM +Poultry manure (75: 25)**	40.44	23.19	1245.58	1245.32	7281.24	4175.37	6035.92	2930.05	4.85^{ab}	2.35^{b}
T_7	**FYM+*Azotobacter* (75: 25)**	43.25	23.92	1220.22	1219.96	7787.18	4306.81	6567.22	3086.84	5.38^{ab}	2.53^{b}
T_8	**VC+FYM (75:25)**	44.26	24.67	1319.21	1318.93	7969.03	4441.84	6650.10	3122.91	5.04^{ab}	2.37^{b}
T_9	**VC+*Azotobacter* (50:50)**	45.06	23.49	1317.17	1316.89	8113.07	4229.38	6796.18	2912.50	5.16^{ab}	2.21
T_{10}	**VC+ FYM+Poultry manure (50:25:25)**	48.64	25.05	1334.13	1333.84	8757.65	4510.26	7423.81	3176.42	5.57^{ab}	2.38^{b}
Control											
T_1	**Control**	36.72	21.01	1165.29	1165.046	6611.451	3782.859	5446.405	2617.813	4.67	2.25

V_1:Pusa Shweta; V_2:Pusa Chetki; a:Superior over V_1 control; b: Superior over V_2 control; ab: Superior over both the controls; Selling price: 0.24 US$ *per* Kg combination of Pusa Chetki with Vermicompost 100% followed by Pusa Shweta with VC: *Azotobacter* (50:50) and VC:FYM:PM (50:25:25) had shown their positive influence on various horticultural and soil nutrient attributes. According to the outcome from the economic analysis, the interaction combination of Pusa Shweta with VC:FYM:PM (50:25:25) was found more profitable than others in open field conditions.

Author contributions
Conceptualization: Vandana Thakur., Pavitra Kakarla and Sunny Sharma.; methodology, data collection and original data analysis: Vandana Thakur.,and Sunny Sharma; data presentation, writing: Vandana Thakur; Sartaj Ahmed Bhat, Sunny Sharma; reviewing and editing: Vandana Thakur, Sunny Sharma and Pavitra Kakarla. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interest statement
The authors declare that they are no conflict of interest associated with this study.

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