International Journal of Plant & Soil Science

Volume 38, Issue 3, Page 17-28, 2026; Article no.IJPSS.153868
ISSN: 2320-7035

Effect of Organic Manures and Biofertilizers on the Growth and Quality of Beetroot (*Beta vulgaris* L.)

Himanshu Tiwari [a++], R. P. Srivastava [b#*], Aneeta Chaudhari [a†], Priya Barthwal [c‡], Ritika Kumari [d‡] and Rajeev Ranjan [b†]

[a] Faculty of Agriculture Sciences, Balachandra Institute of Education and Management, Lucknow, Uttar Pradesh, India.
[b] SMT School of Agriculture Sciences, Sandip University Sijoul, Madhubani, Bihar, India.
[c] Department of Forest Product's & Utilization, Veer Chandra Singh Garhwali Uttarakhand University of Horticulture and Forestry, Bharsar Pauri Garhwal, Uttarakhand, India.
[d] Department of Agronomy, Chandra Shekhar Azad University of Agriculture and technology, Kanpur, Uttar Pradesh, India.

Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i35996

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/153868

Original Research Article

Received: 15/01/2026
Published: 13/03/2026

Abstract

A field experiment was conducted during the Rabi season of 2024–25 at Lucknow, Uttar Pradesh, to assess the effect of organic manures and biofertilizers on the growth, yield, quality, and economics of beetroot (*Beta vulgaris* L.). The experiment comprised eleven treatments including control, recommended dose of fertilizers

---

[++] M.Sc. Student; [#] Associate Dean; [†] Assistant Professor; [‡] Research Scholar;
**Corresponding author: E-mail: ramprakash.srivastava@sandipuniversity.edu.in;*

Cite as: *Tiwari, H., Srivastava, R. P., Chaudhari, A., Barthwal, P., Kumari, R., & Ranjan, R. (2026). Effect of Organic Manures and Biofertilizers on the Growth and Quality of Beetroot (Beta vulgaris L.). International Journal of Plant & Soil Science, 38(3), 17–28. https://doi.org/10.9734/ijpss/2026/v38i35996*

(RDF), farmyard manure (FYM), vermicompost, neem cake, phosphate-solubilizing bacteria (PSB), and their various combinations, laid out in a Randomized Block Design with three replications. Results revealed that growth parameters such as plant height, number of leaves, leaf area, leaf biomass, and days to harvest were significantly influenced by nutrient management practices. The integrated application of vermicompost @ 2.5 t ha^{-1} + PSB @ 1.25 kg ha^{-1} recorded the highest plant height (31.45 cm), leaf area (1053.67 cm^2), and leaf biomass (5.31 g $plant^{-1}$), along with early maturity (78.52 days). Yield attributes including root length, root diameter, root weight, and root yield were maximized under the same treatment, producing the highest root yield (17.49 t ha^{-1}) and harvest index (86.33%). Quality of beetroot, measured in terms of total soluble solids, was also significantly improved, with the maximum TSS (21.13 °Brix) recorded under integrated organic treatment. Economic analysis indicated that vermicompost combined with PSB was the most profitable, recording the highest net returns (₹3,48,650 ha^{-1}) and benefit–cost ratio (3.94). The study demonstrates that integrated organic nutrient management is a sustainable and economically viable strategy for beetroot cultivation.

Keywords: Beetroot; organic manures; biofertilizers; yield; economics.

1. Introduction

Beetroot (*Beta vulgaris* L.) is an important root vegetable crop valued for its fleshy roots rich in carbohydrates, dietary fiber, minerals, vitamins, and bioactive compounds such as betalains and antioxidants. Owing to its nutritional and functional attributes, beetroot has gained increasing importance in fresh markets as well as processing industries. In India, the crop is preferred for its short duration, adaptability, and economic potential, but its productivity and root quality are strongly influenced by soil fertility and nutrient management practices (Mia & Rashid, 2023). Conventional beetroot cultivation relies heavily on chemical fertilizers to achieve higher yields. While inorganic fertilizers supply nutrients in readily available forms, their continuous and excessive use has resulted in soil nutrient imbalance, decline in soil organic carbon, reduced microbial activity, and environmental concerns such as nutrient leaching and pollution (Priya et al., 2024). Root crops like beetroot are particularly sensitive to soil physical condition and biological activity; hence, sole dependence on chemical fertilizers often compromises root development and quality. These challenges have necessitated a shift towards sustainable nutrient management approaches that integrate organic manures and biofertilizers. Organic manures such as farmyard manure (FYM), vermicompost, and neem cake play a vital role in improving soil health and crop performance. FYM enhances soil structure, water-holding capacity, and microbial activity while supplying essential nutrients in a slow and sustained manner. Vermicompost is a nutrient-rich organic input containing readily available macro- and micronutrients, beneficial microorganisms, enzymes, and growth-promoting substances, which collectively improve plant growth and yield attributes (Mia & Rashid, 2023). Neem cake serves as a valuable organic amendment that provides nutrients, improves nitrogen use efficiency through nitrification inhibition, and suppresses soil-borne pests, thereby contributing to healthier crop growth (Eraqui et al., 2023). Biofertilizers, particularly phosphate-solubilizing bacteria (PSB), have emerged as an effective biological input for improving nutrient availability and crop productivity. Phosphorus plays a crucial role in root development, energy transfer, and metabolic processes; however, a large portion of soil phosphorus remains unavailable to plants due to fixation. PSB enhance phosphorus availability by solubilizing insoluble phosphates through the secretion of organic acids and enzymes, leading to improved nutrient uptake, root growth, and overall plant vigor (Vishwakarma et al., 2020). The integration of PSB with organic manures further stimulates soil microbial activity and nutrient cycling, resulting in synergistic effects on crop growth and yield. Recent studies conducted after 2020 have demonstrated the positive influence of organic manures and biofertilizers on beetroot growth, yield, and quality. Mia & Rashid (2023) reported significant improvements in plant height, number of leaves, root diameter, and root yield under integrated organic manure management. Similarly, Eraqui et al., (2023) observed enhanced fresh root weight, dry matter accumulation, and betalain content in beetroot with the application of organic composts. Priya et al., (2024) also reported that organic nutrient sources significantly improved yield attributes and quality parameters such as total soluble solids in beetroot, highlighting the importance of sustainable nutrient inputs. Quality parameters including total soluble solids, sugar content, dry matter, and pigment concentration are critical determinants of beetroot market value and consumer acceptance. Organic manures contribute to quality enhancement by ensuring balanced nutrient supply, improving photosynthetic efficiency, and promoting effective assimilate translocation to roots (Mia & Rashid, 2023). Biofertilizers complement these effects by enhancing nutrient availability and reducing nutrient losses, thereby supporting better metabolic efficiency and quality improvement.

Economic sustainability is another important consideration in nutrient management. Although organic inputs may involve higher initial costs, their long-term benefits in improving soil fertility, reducing dependency on chemical fertilizers, and stabilizing yields often result in improved net returns and benefit–cost ratios (Kumar et al., 2022). Therefore, evaluating the agronomic and economic performance of organic manures and biofertilizers, alone and in combination with recommended chemical fertilizers, is essential for developing sustainable and farmer-friendly nutrient management strategies in beetroot cultivation. In this context, the present investigation was undertaken to comprehensively assess the effects of recommended chemical fertilizers, organic manures (FYM, vermicompost, and neem cake), biofertilizer (PSB), and their combinations on the growth, yield attributes, quality parameters, and economic viability of beetroot production under local agroclimatic conditions.

2. Materials and Methods

2.1 Experimental Site and Soil

The field experiment was conducted during the Rabi season of 2024-25 at the Faculty of Agriculture Sciences, Balachandra Institute of Education and Management, Lucknow, Uttar Pradesh. The soil of the experimental field was sandy loam in texture with neutral pH (7.2), low organic carbon, and medium available nitrogen, phosphorus, and potassium status. The site falls under a subtropical climate suitable for beetroot cultivation.

2.2 Treatments and Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with eleven treatments and three replications. Treatments included control, recommended dose of fertilizers (N 125: P_2O_5 50: K_2O 70 kg ha^{-1}), organic manures (FYM, vermicompost, neem cake), biofertilizer (PSB), and their combinations. Organic manures were incorporated into the soil before sowing, while PSB was applied as per treatment requirement. Beetroot variety ‘Atlas’ was sown at a spacing of 30 × 10 cm following standard agronomic practices.

2.3 Observations and Statistical Analysis

Growth, yield, and quality parameters were recorded from selected plants at different growth stages and at harvest. Economic analysis was carried out by calculating cost of cultivation, gross and net returns, and benefit–cost ratio. Data were analyzed statistically using analysis of variance (ANOVA) for RBD, and treatment means were compared at 5% level of significance.

3. Results and Discussion

3.1 Effect of Organic Manures and Biofertilizers on Growth of Beetroot

Growth parameters of beetroot were significantly influenced by the application of organic manures, biofertilizers and their integrated combinations. Among the treatments, the combined application of vermicompost and phosphate-solubilizing bacteria (PSB) showed superior performance compared with sole application of organic inputs or the control treatment. Integrated nutrient management improves soil fertility, microbial activity and nutrient availability, which ultimately enhances crop growth and plant development (Adesemoye & Kloepper, 2009; Vessey, 2003).

Plant height increased significantly at all growth stages (25 DAS, 50 DAS and at harvest). The maximum plant height was recorded under T_{11} (Vermicompost @ 2.5 t ha^{-1} + PSB @ 1.25 kg ha^{-1}), which was statistically at par with T_{10}, T_8, T_4 and T_7. The improvement in plant height may be attributed to the gradual release of macro- and micronutrients from vermicompost and enhanced phosphorus availability due to PSB activity. Vermicompost improves soil structure, aeration and microbial population, thereby promoting root growth and nutrient uptake. Similar positive effects of vermicompost on plant growth and development have been reported by Arancon et al. (2004) and Atiyeh et al. (2000) in horticultural crops.

The number of leaves per plant was significantly higher under integrated organic treatments. Treatment T_{11} recorded the highest number of leaves at all observation stages, while the control treatment showed the lowest values. The increased leaf production may be due to improved nitrogen availability and enhanced metabolic activity resulting from organic matter decomposition and microbial interactions in the rhizosphere.

Vermicompost is known to contain plant growth regulators such as auxins and humic substances, which stimulate vegetative growth and leaf formation (Arancon et al., 2006).

Leaf area differed significantly among treatments. The maximum leaf area was observed under T_{11} followed by T_{10} and T_4, whereas the control recorded the minimum value. Increased leaf area under vermicompost and PSB application may be attributed to enhanced nutrient mineralization and phosphorus solubilization by PSB, which improves canopy development and photosynthetic efficiency. Phosphate-solubilizing microorganisms convert insoluble phosphorus into plant-available forms, thereby improving plant nutrition and growth (Rodríguez & Fraga, 1999).

Leaf biomass was also significantly influenced by the treatments. The highest biomass was obtained under treatment T_{11} at both observation stages. Higher biomass accumulation reflects improved photosynthetic activity and efficient assimilate translocation under balanced nutrient availability. Organic amendments such as vermicompost improve soil microbial activity and nutrient cycling, which contribute to enhanced plant biomass production (Adesemoye & Kloepper, 2009).

Days taken to harvest were significantly affected by the treatments. The earliest maturity was recorded in T_{11}, whereas the control treatment required the maximum duration for harvest. Early maturity under integrated organic nutrient management may be due to improved metabolic activity and balanced nutrient supply, which accelerates plant growth and development. Enhanced nutrient availability and microbial activity under integrated nutrient management systems have been reported to shorten crop growth duration and improve crop performance (Vessey, 2003).

Overall, the results clearly indicate that the combined application of vermicompost and PSB significantly enhanced vegetative growth of beetroot, including plant height, number of leaves, leaf area and biomass accumulation, while reducing the time required for crop maturity compared to sole nutrient sources.

3.2 Effect of Organic Manures and Biofertilizers on Yield Attributes and Quality of Beetroot

Yield attributes and quality parameters of beetroot were significantly influenced by the application of organic manures and biofertilizer treatments (Table 2). Among all treatments, the integrated application of vermicompost + phosphate-solubilizing bacteria (PSB) (T_{11}) consistently produced superior results, indicating a synergistic interaction between organic nutrient supply and rhizospheric microbial activity. Organic manures improve soil fertility, nutrient availability, and microbial population, which ultimately enhances crop productivity and quality (Bhattacharyya & Jha, 2012).

3.2.1 Yield Attributes

Root length, root diameter, root weight, root yield and harvest index showed marked improvement under integrated organic treatments. The maximum root length (10.70 cm) and root diameter (6.41 cm) were recorded in T_{11}, which remained statistically at par with T_{10}, T_4, T_8 and T_7, whereas the control recorded the minimum values. Improved root growth under vermicompost-based treatments may be attributed to better soil physical properties, increased microbial activity and steady nutrient release from organic sources. Vermicompost improves soil aggregation and nutrient availability, which promotes root development and plant growth (Domínguez & Edwards, 2011).

Root weight and yield followed a similar trend. The highest root weight (154.09 g plant^{-1}), yield per plot (7.08 kg) and root yield (17.49 t ha^{-1}) were obtained under T_{11}, followed by T_{10} and T_4, while the control recorded the lowest yield. The increase in yield under integrated organic treatments may be due to improved nutrient uptake, enhanced photosynthetic activity and better partitioning of assimilates towards the storage root. Biofertilizers such as PSB enhance phosphorus availability in soil, which plays a crucial role in root development and energy transfer in plants (Sharma et al., 2013).

The harvest index also showed significant variation among treatments. The highest harvest index (86.33%) was recorded under T_{11}, indicating efficient conversion of total biomass into economic yield. Balanced nutrient supply and improved plant physiological processes under integrated nutrient management may enhance biomass partitioning and increase harvest efficiency. Similar improvements in yield attributes and harvest index due to combined application of organic manures and biofertilizers have been reported in vegetable crops (Bhattacharyya & Jha, 2012).

Table 1. Effect of organic manures and biofertilizers on growth parameters of beetroot (Beta vulgaris L.)

Treatment	Plant height at harvest (cm)	Number of leaves at harvest	Leaf area (cm^2) at 70 DAS	Leaf biomass ($g\ plant^{-1}$) at 70 DAS	Days to harvest
T_1 Control	24.26	16.05	852.00	1.86	89.99
T_2 RDF (N 125: P_2O_5 50: K_2O 70 kg ha^{-1})	30.45	15.19	943.78	3.70	79.20
T_3 FYM @ 20 t ha^{-1}	25.25	15.45	904.00	2.87	87.55
T_4 Vermicompost @ 5 t ha^{-1}	30.91	15.59	1024.04	3.59	81.84
T_5 Neem cake @ 80 kg ha^{-1}	29.47	14.01	952.81	3.72	84.14
T_6 PSB @ 2.5 kg ha^{-1}	24.45	15.90	876.53	2.66	85.13
T_7 FYM @ 10 t ha^{-1} + Vermicompost @ 2.5 t ha^{-1}	30.82	15.79	972.75	3.55	80.21
T_8 FYM @ 10 t ha^{-1} + Neem cake @ 40 kg ha^{-1}	30.99	14.56	977.48	4.50	80.36
T_9 FYM @ 10 t ha^{-1} + PSB @ 1.25 kg ha^{-1}	27.47	17.09	925.10	2.91	85.13
T_{10} Vermicompost @ 2.5 t ha^{-1} + Neem cake @ 40 kg ha^{-1}	31.16	17.49	1025.14	4.53	79.20
T_{11} Vermicompost @ 2.5 t ha^{-1} + PSB @ 1.25 kg ha^{-1}	31.45	17.49	1053.67	5.31	78.52

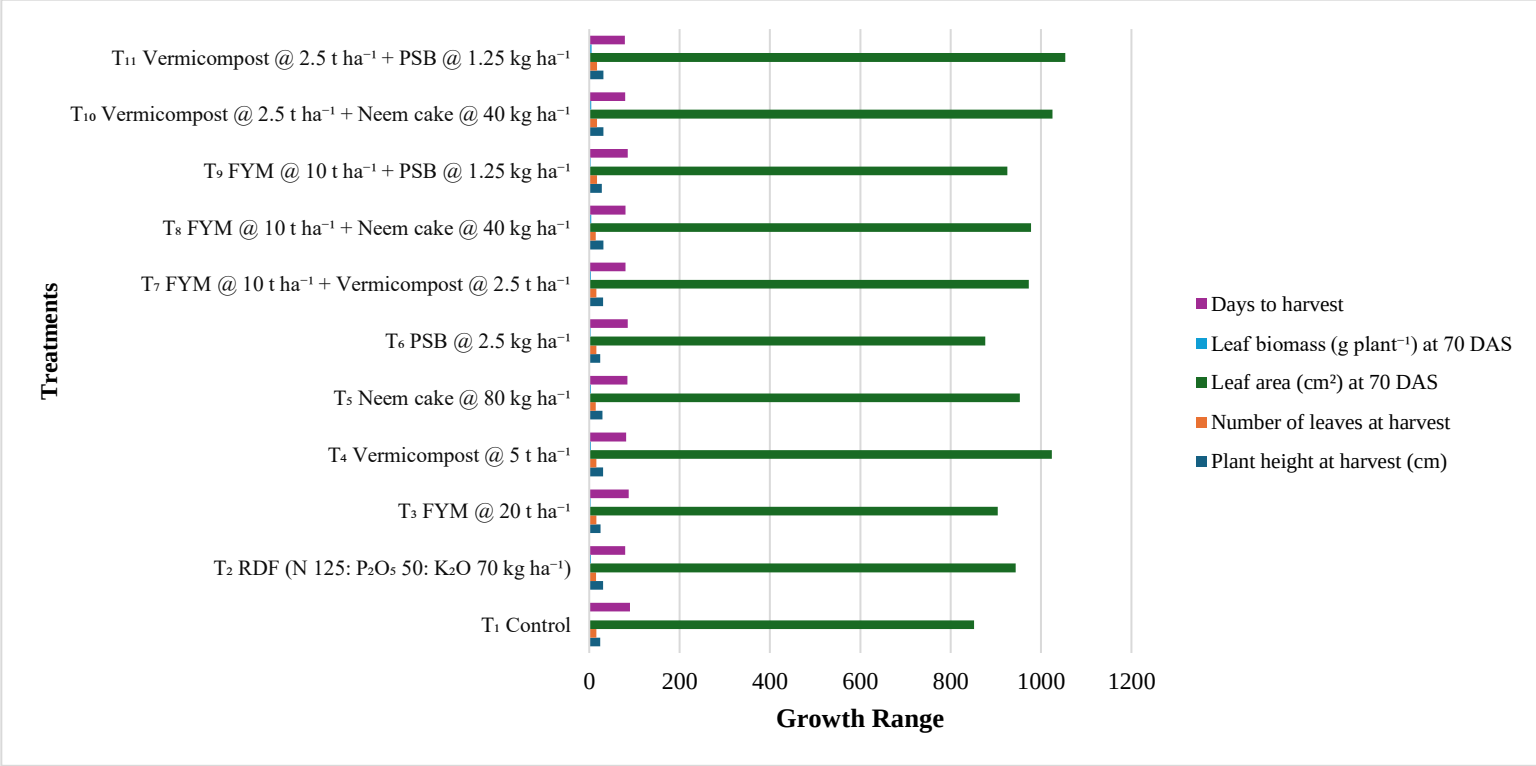

Fig. 1. Effect of organic manures and biofertilizers on growth

3.2.2 Quality Parameters

Quality parameters, particularly total soluble solids (TSS), were significantly influenced by organic nutrient management. The highest TSS (21.13 °Brix) was recorded under T_{11}, followed by T_{10} and T_4, while the control recorded the lowest value. Increased sugar accumulation under organic treatments may be attributed to balanced nutrient availability and improved carbohydrate metabolism. Organic amendments also enhance microbial activity and nutrient cycling, which positively influence biochemical composition and nutritional quality of vegetable crops.

Moisture content showed non-significant variation among treatments, although slightly higher values were recorded under integrated organic treatments. This suggests that organic nutrient management mainly influences biochemical parameters rather than water accumulation in roots.

Overall, the results clearly demonstrate that the combined application of vermicompost and PSB (T_{11}) was the most effective treatment for improving yield attributes and quality of beetroot. The improved performance may be attributed to enhanced soil fertility, improved nutrient use efficiency and increased microbial activity in the rhizosphere under integrated organic nutrient management.

3.3 Economics of Different Treatments

Economic analysis is an essential criterion for evaluating the feasibility and adoptability of different nutrient management practices in crop production. The profitability of crop cultivation depends on yield level, input costs and market price of the produce. In the present study, different organic manure and biofertilizer treatments significantly influenced root yield, cost of cultivation, gross returns, net returns and benefit–cost (B:C) ratio of beetroot (Table 3). Similar observations have been reported in several studies where integrated nutrient management practices enhanced crop productivity and profitability through improved nutrient use efficiency and soil fertility (Tilman et al., 2002; Pretty et al., 2018).

Among the treatments, T_{11} (Vermicompost 50% + PSB 50%) recorded the highest root yield (174.80 q ha^{-1}), which resulted in maximum gross returns (Rs. 4,37,000 ha^{-1}) and net returns (Rs. 3,48,650 ha^{-1}) with a B:C ratio of 3.94. The superior economic performance of this treatment may be attributed to improved nutrient availability, enhanced nutrient use efficiency and increased yield under integrated organic nutrient management. Vermicompost improves soil fertility and microbial activity, while phosphate-solubilizing bacteria enhance phosphorus availability to plants, resulting in higher crop productivity and profitability (Richardson et al., 2009; Bhardwaj et al., 2014).

The control treatment (T_1) recorded the lowest root yield (70.60 q ha^{-1}), minimum net returns (Rs. 1,17,050 ha^{-1}) and the lowest B:C ratio (1.96), indicating poor economic viability due to inadequate nutrient supply. Although the chemical fertilizer treatment T_2 (RDF) produced higher yield than the control, the economic returns were lower than integrated organic treatments due to higher input costs and comparatively lower yield advantage.

Treatments involving single organic sources such as FYM (T_3), vermicompost (T_4), neem cake (T_5) and PSB alone (T_6) showed moderate economic returns. However, integrated treatments such as T_{10} and T_{11} consistently produced higher profitability, confirming that the combined application of organic manures and biofertilizers is more remunerative than their sole application. Integrated nutrient management improves soil health, nutrient availability and crop productivity, which ultimately increases farmers' income and economic sustainability (Bhardwaj et al., 2014). Overall, the results clearly indicate that economic sustainability in beetroot cultivation is closely linked with integrated organic nutrient management. The combined use of vermicompost and PSB improves soil fertility, enhances nutrient uptake and ensures higher returns per unit investment. Therefore, T_{11} emerged as the most economically viable treatment and can be recommended for profitable beetroot cultivation under similar agro-ecological conditions.

The results of the present study clearly indicate that integrated application of organic manures and biofertilizers significantly enhanced yield and quality of beetroot. Among all treatments, vermicompost @ 2.5 t ha^{-1} + PSB @ 1.25 kg ha^{-1} (T_{11}) proved most effective, recording the highest root length (10.70 cm), root diameter (6.41 cm), root weight (154.09 g), and root yield (17.49 t ha^{-1}), along with maximum harvest index (86.33%) and TSS (21.13 °Brix). These values were markedly superior to the control, which recorded only 2.87 t ha^{-1} root yield and 9.73 °Brix TSS. The enhanced performance under T_{11} reflects improved nutrient availability, microbial activity, and efficient assimilate partitioning. Hence, integrated use of vermicompost and PSB can be recommended for achieving higher productivity, better quality, and sustainable beetroot cultivation under similar agro-climatic conditions.

Table 2. Effect of organic manures and biofertilizers on yield attributes and quality parameters of beetroot (*Beta vulgaris* L.)

Treatment	Root length (cm)	Root diameter (cm)	Root weight (g)	Root yield (t ha^{-1})	Harvest index (%)	TSS (°Brix)
T_1 Control	7.07	4.68	97.05	2.87	66.00	9.73
T_2 RDF	9.58	5.68	127.03	4.45	76.44	17.09
T_3 FYM 20 t/ha	7.30	5.16	119.78	4.21	74.33	15.04
T_4 Vermicompost 5 t/ha	10.44	6.20	141.82	13.17	83.00	18.30
T_5 Neem cake 80 kg/ha	9.78	5.79	132.02	4.64	79.21	15.08
T_6 PSB	7.53	5.11	106.71	10.26	72.00	13.53
T_7 FYM + VC	10.20	5.98	135.46	12.02	81.00	16.52
T_8 FYM + Neem cake	10.26	6.11	140.11	13.17	82.00	17.02
T_9 FYM + PSB	9.19	5.71	125.46	4.38	75.00	16.01
T_{10} VC + Neem cake	10.49	6.31	151.07	15.61	85.00	20.00
T_{11} VC + PSB	10.70	6.41	154.09	17.49	86.33	21.13

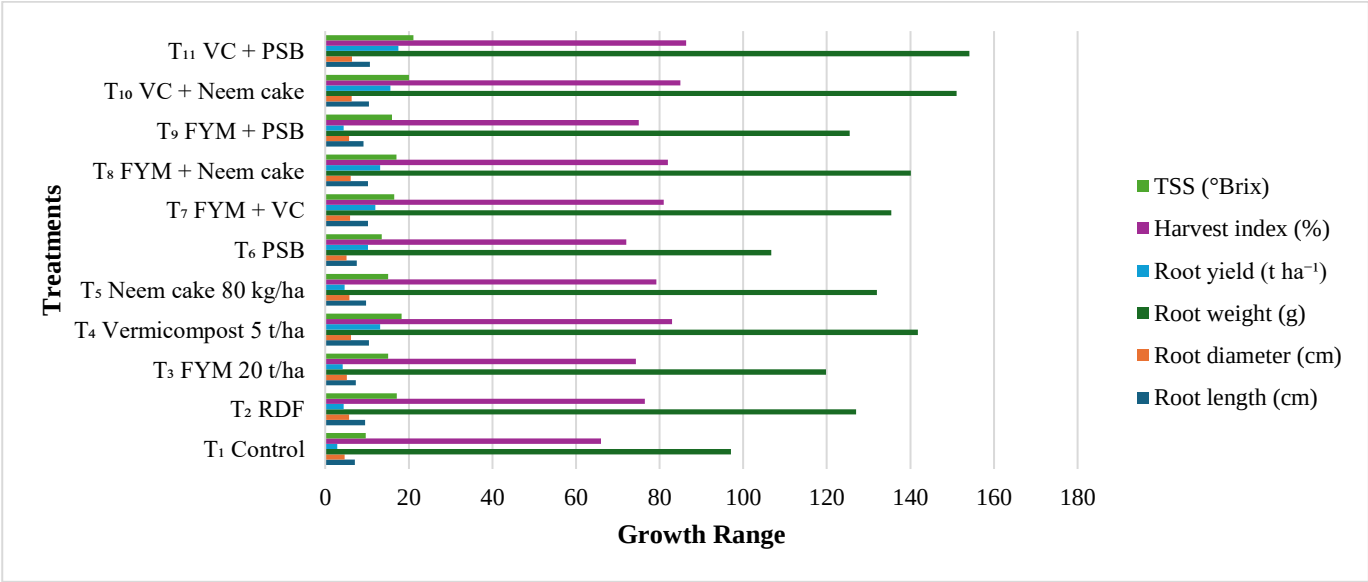

Fig. 2. Effect of organic manures and biofertilizers on yield attributes and quality

Table 3. Comparative economic analysis of different organic manure and biofertilizer treatments in beetroot *(Beta vulgaris L.)*

Treatment	Root yield (q ha^{-1})	Net returns (Rs ha^{-1})	B:C ratio
T_1 Control	70.60	1,17,050	1.96
T_2 RDF	109.36	2,07,450	3.14
T_3 FYM 20 t/ha	103.73	1,96,125	3.10
T_4 Vermicompost 5 t/ha	131.60	2,41,050	2.74
T_5 Neem cake 80 kg/ha	114.33	1,96,375	2.19
T_6 PSB	102.40	1,96,150	3.27
T_7 FYM + VC	118.20	2,03,800	2.22
T_8 FYM + Neem cake	120.06	2,06,950	2.22
T_9 FYM + PSB	107.90	2,06,150	3.24
T_{10} VC + Neem cake	156.00	2,72,050	2.30
T_{11} VC + PSB	174.80	3,48,650	3.94

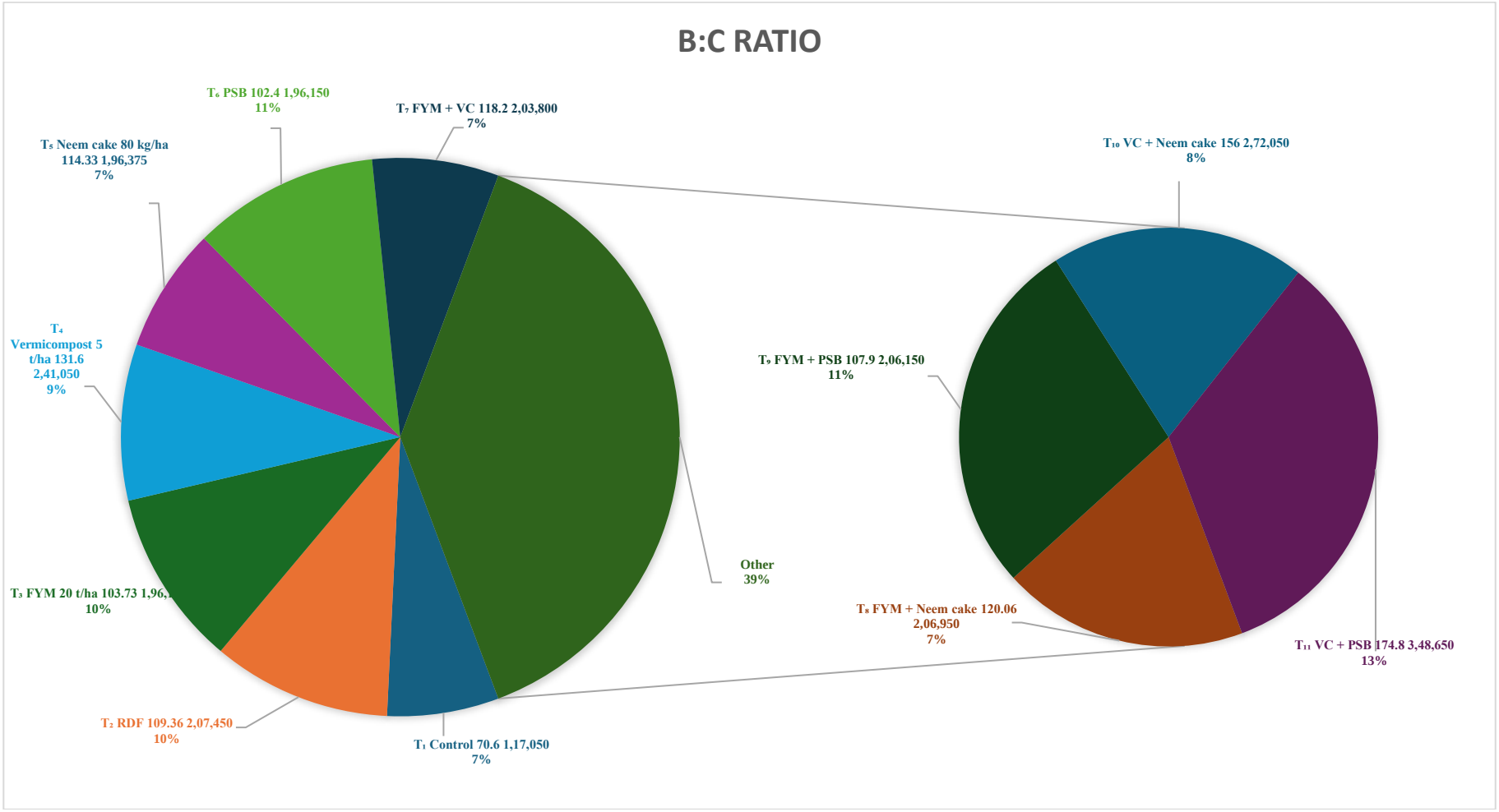

Fig. 3. B:C Ratio

4. Conclusion

The results of the present investigation indicate that organic manures and biofertilizers significantly influenced the growth, yield attributes, quality parameters, and economic returns of beetroot (*Beta vulgaris* L.). Among the evaluated treatments, the integrated application of vermicompost @ 2.5 t ha^{-1} in combination with phosphate-solubilizing bacteria (PSB) @ 1.25 kg ha^{-1} proved most effective in enhancing crop performance. This treatment recorded the highest values for plant height, leaf area, biomass accumulation, and earlier maturity, indicating improved vegetative growth and nutrient utilization. Similarly, yield attributes such as root length, root diameter, root weight, and root yield were significantly increased under the same treatment, accompanied by improved quality as reflected by higher total soluble solids (TSS). The economic analysis also revealed maximum net returns and benefit–cost ratio under this integrated nutrient management practice. Therefore, the combined application of vermicompost and PSB can be recommended as an efficient and sustainable nutrient management strategy for improving productivity, quality, and profitability of beetroot cultivation under similar agro-ecological conditions.

Disclaimer (Artificial Intelligence)

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

Acknowledgement

I sincerely acknowledge all my co-authors for their valuable contributions to this research. I am deeply grateful to Dr. R. P. Srivastava fo r his special guidance, constant support, and supervision throughout the study. I thank Priya Barthwal and Ritika Kumari for their assistance in drafting, data analysis, and manuscript preparation. Rajeev Ranjan is acknowledged for his support in data evaluation and interpretation. I also express my sincere gratitude to Dr. Aneeta Chaudhari for her overall guidance and constructive suggestions. I gratefully acknowledge the support and facilities provided by the Faculty of Agriculture Sciences, Balachandra Institute of Education and Management for successful completion of this research.

Competing Interests

Authors have declared that no competing interests exist.

References

Adesemoye, A. O., & Kloepper, J. W. (2009). Plant–microbes interactions in enhanced fertilizer-use efficiency. *Applied Microbiology and Biotechnology, 85*(1), 1–12. https://doi.org/10.1007/s00253-009-2196-0

Arancon, N. Q., Edwards, C. A., Atiyeh, R., & Metzger, J. D. (2004). Effects of vermicomposts produced from food waste on the growth and yields of greenhouse peppers. Bioresource Technology, 93(2), 139–144. https://doi.org/10.1016/j.biortech.2003.10.015

Arancon, N. Q., Edwards, C. A., Lee, S., & Byrne, R. (2006). Effects of humic acids from vermicomposts on plant growth. European Journal of Soil Biology, 42, S65–S69. https://doi.org/10.1016/j.ejsobi.2006.06.004

Atiyeh, R. M., Arancon, N. Q., Edwards, C. A., & Metzger, J. D. (2000). Influence of earthworm-processed pig manure on the growth and yield of greenhouse tomatoes. Bioresource Technology, 75(3), 175–180. https://doi.org/10.1016/S0960-8524(00)00064-X

Bhardwaj, D., Ansari, M. W., Sahoo, R. K., & Tuteja, N. (2014). Biofertilizers function as key player in sustainable agriculture by improving soil fertility, plant tolerance and crop productivity. *Microbial Cell Factories, 13*, 66. https://doi.org/10.1186/1475-2859-13-66

Bhattacharyya, P. N., & Jha, D. K. (2012). Plant growth-promoting rhizobacteria (PGPR): Emergence in agriculture. *World Journal of Microbiology and Biotechnology, 28*(4), 1327– 1350. https://doi.org/10.1007/s11274-011-0979-9

Domínguez, J., & Edwards, C. A. (2011). Biology and ecology of earthworm species used for vermicomposting. In C. A. Edwards, N. Q. Arancon & R. Sherman (Eds.), *Vermiculture Technology: Earthworms, Organic Wastes, and Environmental Management* (pp. 27–40). CRC Press. https://doi.org/10.1201/b10453

Eraqui, S., Topno, S. E., Kerketta, A., Husain, M. F., & Mishra, R. (2023). Studies on the effect of different levels of organic compost on growth, yield, betalain content and quality of beetroot (Beta vulgaris) under Prayagraj agro-climatic condition. *International Journal of Environment and Climate Change, 13*(9), 2397–2404. https://doi.org/10.9734/ijecc/2023/v13i92472

Priya, K., Ramandeep, K., Narayan, S., Vasudha, M., Ashutosh, S., & Rahul, K. (2024). Effect of organic and inorganic fertilizers on the growth, yield and quality of beetroot (Beta vulgaris L.). International Journal of Research in Agronomy, 7(2), 180–186. https://doi.org/10.33545/2618060X.2024.v7.i2c.305

Kumar, M., Shukla, I. N., Kishor, B., Nirankar, R. P., & Singh, S. (2022). Effect of organic manures and biofertilizer on growth, yield and quality of beetroot (Beta vulgaris L.) cv. Red express. *Research Trend, 10*(3), 45–50.

Mia, M. N., & Rashid, M. H. A. (2023). Yield and quality performance of beetroot (Beta vulgaris L.) as influenced by organic manure management. *Fundamental and Applied Agriculture, 8*(1 & 2), 377-389. https://doi.org/10.5455/faa.93670

Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., Goulson, D., Hartley, S., Lampkin, N., Morris, C., Pierzynski, G., Prasad, P. V. V., Reganold, J., Rockström, J., Smith, P., Thorne, P., & Wratten, S. (2018). Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability, 1*, 441–446. https://doi.org/10.1038/s41893-018-0114-0

Richardson, A. E., Barea, J. M., McNeill, A. M., & Prigent-Combaret, C. (2009). Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. *Plant and Soil, 321*(1–2), 305–339. https://doi.org/10.1007/s11104-009-9895-2

Rodríguez, H., & Fraga, R. (1999). Phosphate solubilizing bacteria and their role in plant growth promotion. *Biotechnology Advances, 17*(4–5), 319–339. https://doi.org/10.1016/S0734-9750(99)00014-2

Sharma, S. B., Sayyed, R. Z., Trivedi, M. H., & Gobi, T. A. (2013). Phosphate solubilizing microbes: Sustainable approach for managing phosphorus deficiency in agricultural soils. *SpringerPlus, 2*, 587. https://doi.org/10.1186/2193-1801-2-587

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*, 671–677. https://doi.org/10.1038/nature01014

Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil, 255*(2), 571–586. https://doi.org/10.1023/A:1026037216893

Vishwakarma, K., Kumar, N., Shandilya, C., Mohapatra, S., Bhayana, S., & Varma, A. (2020). Revisiting Plant–Microbe Interactions and Microbial Consortia Application for Enhancing Sustainable Agriculture: A Review. *Frontiers in Microbiology.* https://doi.org/10.3389/fmicb.2020.560406

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/153868