 ISSN 3124-8802 (E)

Effects Of Organic Compost And Biofertilizer Application On Growth, Yield, And Soil Fertility Of Chili Pepper *(Capsicum Annuum L.)*

Yantistina Lase[1], Jeprianus Ziliwu[2], Asarius Zega[3], Dian Agung Sanora Laia[4]

[1]Agrotechnology, Faculty of Science and Technology, Universitas Nias, Gunungsitoli, Indonesia
Email: yantistinalase@gmail.com
[2]Agrotechnology, Faculty of Science and Technology, Universitas Nias, Gunungsitoli, Indonesia
Email: jeprianuszil7@gmail.com
[3]Agrotechnology, Faculty of Science and Technology, Universitas Nias, Gunungsitoli, Indonesia
Email: asarius_zega@gmail.com
[4]Agrotechnology, Faculty of Science and Technology, Universitas Nias, Gunungsitoli, Indonesia
Email: dianagungsanoralaia@unias.ac.id

Abstract
The excessive use of synthetic fertilizers in chili pepper cultivation has contributed to declining soil fertility and environmental degradation, highlighting the need for sustainable nutrient management strategies. This study evaluated the effects of organic compost and biofertilizer application on the growth, yield, and soil fertility of chili pepper (Capsicum annuum L.). A factorial experiment based on a Randomized Complete Block Design (RCBD) was conducted using three levels of organic compost (0, 10, and 20 t ha^{-1}) and three concentrations of biofertilizer (0, 5, and 10 mL L^{-1}), resulting in nine treatment combinations with three replications. Growth parameters, yield components, and post-harvest soil fertility indicators were measured and analyzed using analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results demonstrated that both organic compost and biofertilizer significantly enhanced plant growth, fruit yield, and soil fertility. The combined application of 20 t ha^{-1} organic compost and 10 mL L^{-1} biofertilizer increased fruit yield by approximately 63% compared with the control, while also producing the highest values of plant height and the measured soil fertility indicators. The combined application of 20 t ha^{-1} organic compost and 10 mL L^{-1} biofertilizer produced the highest plant height (79.3 cm), fruit yield (18.72 t ha^{-1}), soil organic carbon (2.34%), total nitrogen (0.21%), available phosphorus (31.8 mg kg^{-1}), and exchangeable potassium (0.56 cmol kg^{-1}). The synergistic interaction between organic compost and beneficial microorganisms improved nutrient availability, stimulated microbial activity, enhanced nutrient uptake efficiency, and promoted sustainable soil health. These findings demonstrate that integrating organic compost with biofertilizers represents an effective and environmentally friendly nutrient management strategy capable of increasing chili pepper productivity while improving long-term soil fertility. The study provides valuable scientific evidence supporting the adoption of integrated nutrient management practices for sustainable horticultural production. The study further provides an integrated assessment by linking crop productivity with post-harvest soil fertility, which is less commonly evaluated together in studies of sustainable nutrient management.

Keywords: biofertilizer; chili pepper; integrated nutrient management; organic compost; soil fertility.

INTRODUCTION

Chili pepper (*Capsicum annuum* L.) is among the most economically important vegetable crops worldwide due to its substantial contribution to food security, nutrition, and agricultural income. Beyond its culinary value, chili pepper is recognized as a rich source of vitamins, carotenoids, phenolic compounds, flavonoids, and capsaicinoids, which possess considerable antioxidant and pharmaceutical properties (Bosland & Votava, 2012). The continuously increasing global demand for fresh and processed chili products has intensified production systems, often resulting in excessive dependence on synthetic fertilizers to maximize yield. Although chemical fertilizers provide rapid nutrient availability, their long-term and indiscriminate application has been associated with soil degradation, declining soil organic matter, nutrient imbalance, environmental pollution, and reduced sustainability of agricultural ecosystems (FAO, 2022; Lal, 2020).

The growing concern regarding soil quality deterioration has shifted agricultural research toward environmentally sustainable nutrient management strategies. Organic compost has emerged as an essential component of sustainable agriculture because it improves soil physical, chemical, and biological properties simultaneously. The incorporation of compost enhances soil aggregation, increases water-holding capacity, improves cation exchange capacity, and supplies macro- and micronutrients through gradual mineralization processes (Agegnehu et al., 2017). Furthermore, compost serves as an important carbon source for soil microorganisms, thereby stimulating microbial activity and enhancing nutrient cycling, which ultimately contributes to improved crop productivity and long-term soil fertility (Lehmann et al., 2020).

In addition to organic amendments, biofertilizers have gained considerable attention as eco-friendly alternatives capable of reducing dependence on mineral fertilizers. Biofertilizers consist of beneficial microorganisms, including nitrogen-fixing bacteria, phosphate-solubilizing bacteria, potassium-mobilizing bacteria, arbuscular mycorrhizal fungi, and plant growth-promoting rhizobacteria (PGPR), which enhance nutrient availability and stimulate plant physiological processes (Backer et al., 2018). These microorganisms improve root development, increase nutrient uptake efficiency, produce phytohormones, suppress soil-borne pathogens, and enhance plant tolerance to both biotic and abiotic stresses. Consequently, biofertilizer application has become an integral component of integrated nutrient management systems designed to improve agricultural productivity while minimizing environmental impacts (Basu et al., 2021).

Previous investigations have demonstrated that both compost and biofertilizers individually improve the growth and yield performance of vegetable crops. Organic compost enhances vegetative growth by providing a continuous nutrient supply and improving soil structure, whereas biofertilizers increase nutrient use efficiency through biological nutrient transformation processes (Mahanty et al., 2017). Nevertheless, the interaction between compost and biofertilizers is considerably more complex than the independent effects of either amendment. Compost provides a favorable habitat and carbon-rich substrate that supports microbial colonization and survival, while beneficial microorganisms accelerate nutrient mineralization from organic matter, creating a mutually reinforcing relationship that may substantially improve nutrient availability throughout the crop growth cycle (Olanrewaju et al., 2019).

Despite these advances, findings regarding the combined application of compost and biofertilizers remain inconsistent across different agroecological conditions. Variations in soil texture, climate, compost quality, microbial inoculant composition, and management practices frequently produce contrasting responses in plant growth, fruit yield, and soil fertility indicators. Moreover, most previous studies have focused primarily on crop productivity, whereas comprehensive evaluations integrating plant performance with post-harvest soil fertility parameters remain relatively limited. Such integrated assessments are essential for determining whether sustainable fertilization strategies not only increase immediate agricultural productivity but also preserve soil health for future cropping cycles (Bender et al., 2016; Basu et al., 2021).

Improving soil fertility has become increasingly important under the dual challenges of climate change and intensive agricultural production. Sustainable nutrient management practices capable of maintaining crop yield while enhancing soil biological activity and organic matter accumulation are central to achieving resilient agricultural systems. Integrated application of organic compost and biofertilizers represents one promising strategy because it combines nutrient replenishment with biological enhancement of soil ecosystem functions. However, further experimental evidence is required to quantify their synergistic effects under specific cultivation conditions and to identify their contribution to sustainable chili production.

Therefore, the present study aimed to evaluate the effects of organic compost and biofertilizer application on the growth, yield, and soil fertility of chili pepper (*Capsicum annuum* L.). This study hypothesized that the combined application of organic compost and biofertilizers would produce synergistic effects by enhancing nutrient availability, stimulating beneficial microbial activity, improving plant growth and fruit production, and simultaneously increasing soil fertility compared with the application of either amendment alone. The findings are expected to provide scientific evidence supporting integrated nutrient management practices for sustainable vegetable production and long-term soil resource conservation.

The main contribution of this study is the simultaneous evaluation of plant growth, fruit yield, and post-harvest soil fertility under different combinations of organic compost and biofertilizer. By considering these responses together, the study provides a broader assessment of whether integrated nutrient management can improve short-term crop productivity while also supporting soil fertility.

LITERATURE REVIEW

Importance of Chili Pepper Cultivation

Chili pepper (*Capsicum annuum* L.) is one of the most valuable horticultural commodities cultivated throughout tropical and subtropical regions. The crop contributes significantly to global food systems due to its high nutritional value, economic importance, and extensive industrial applications. Chili fruits are rich sources of vitamin C, provitamin A, phenolic compounds, carotenoids, flavonoids, and capsaicinoids, all of which possess antioxidant, anti-inflammatory, and antimicrobial properties that benefit human health (Bosland & Votava, 2012). As consumer demand for fresh vegetables and processed chili products continues to increase, improving production efficiency while maintaining environmental sustainability has become an important objective in modern agriculture.

However, chili cultivation requires relatively high nutrient inputs because of its continuous flowering, fruit development, and prolonged harvesting period. Nutrient deficiencies during critical growth stages may reduce photosynthetic efficiency, impair reproductive development, and consequently decrease fruit yield and quality (Raza et al., 2022). Therefore, balanced nutrient management plays a central role in achieving sustainable chili production.

Organic Compost as a Sustainable Soil Amendment

Organic compost is produced through the biological decomposition of organic materials under controlled aerobic conditions, resulting in a stable product rich in humic substances and essential plant nutrients. Unlike synthetic fertilizers that primarily supply soluble nutrients, compost improves multiple soil properties simultaneously by enhancing soil structure, increasing water retention capacity, promoting aggregate stability, and stimulating microbial activity (Agegnehu et al., 2017).

The gradual mineralization of compost provides a continuous nutrient supply that synchronizes more effectively with crop nutrient demand throughout the growing season. Moreover, compost significantly increases soil organic carbon, which serves as an energy source for beneficial microorganisms and improves nutrient cycling within the rhizosphere (Lehmann et al., 2020). Long-term compost application has also been reported to increase cation exchange capacity (CEC), improve nutrient retention, and reduce nutrient leaching losses, thereby enhancing fertilizer use efficiency and sustaining soil productivity.

In vegetable production systems, compost application has consistently demonstrated positive effects on plant height, leaf area, chlorophyll concentration, root development, flowering, fruit formation, and final yield. These improvements are largely attributed to enhanced soil fertility and improved soil physical conditions that facilitate root growth and nutrient absorption (Lazcano et al., 2021).

Biofertilizers and Plant Growth Promotion

Biofertilizers are formulations containing living microorganisms that improve nutrient availability and stimulate plant growth through various biological mechanisms. Common biofertilizer microorganisms include nitrogen-fixing bacteria (*Azotobacter*, *Azospirillum*), phosphate-solubilizing bacteria (*Bacillus*, *Pseudomonas*), potassium-solubilizing bacteria, arbuscular mycorrhizal fungi, and other plant growth-promoting rhizobacteria (PGPR) (Backer et al., 2018).

These beneficial microorganisms colonize the rhizosphere and establish mutually beneficial interactions with plant roots. Nitrogen-fixing bacteria convert atmospheric nitrogen into plant-available forms, whereas phosphate-solubilizing microorganisms release organic acids and phosphatase enzymes that mobilize insoluble phosphorus compounds in the soil (Basu et al., 2021). In addition, many PGPR produce phytohormones such as indole-3-acetic acid (IAA), gibberellins, cytokinins, and siderophores, which enhance root architecture, nutrient uptake efficiency, and overall plant vigor.

Beyond nutrient acquisition, biofertilizers contribute to sustainable agriculture by increasing plant tolerance to drought, salinity, heavy metal toxicity, and pathogen attack. Several microbial strains also induce systemic resistance mechanisms that strengthen plant defense systems while reducing the need for chemical pesticides (Olanrewaju et al., 2019).

Integrated Application of Organic Compost and Biofertilizers

Recent advances in sustainable agriculture emphasize the integration of organic amendments and beneficial microorganisms rather than relying on single-input fertilization strategies. Organic compost provides an ideal habitat for microbial proliferation because it supplies carbon substrates, moisture retention, and favorable physicochemical conditions that enhance microbial survival after inoculation (Lehmann et al., 2020).

The synergistic interaction between compost and biofertilizers has been widely recognized as a promising approach to improving nutrient use efficiency. Compost supplies organic matter that microorganisms decompose into mineral nutrients, while microbial activity accelerates nutrient mineralization and increases nutrient availability to plants (Mahanty et al., 2017). This reciprocal relationship creates a biologically active rhizosphere capable of sustaining plant growth under reduced chemical fertilizer inputs.

Several studies have demonstrated that combined application of compost and microbial inoculants significantly improves plant biomass, fruit production, nutrient uptake, and soil biological activity compared with the application of either amendment alone. Integrated nutrient management has also been associated with increased microbial biomass carbon, enhanced soil enzyme activities, and improved nutrient cycling efficiency, all of which contribute to long-term agricultural sustainability (Bender et al., 2016).

However, the magnitude of these benefits may vary depending on soil properties, compost characteristics, microbial composition, and environmental conditions. Therefore, the positive effects reported in previous studies cannot necessarily be generalized across different cultivation systems. This variation provides a basis for further evaluating the combined application of compost and biofertilizers under specific field conditions.

Soil Fertility Improvement Through Biological Nutrient Management

Soil fertility encompasses the soil's capacity to provide essential nutrients, water, oxygen, and a favorable biological environment for plant growth. Sustainable soil fertility depends not only on nutrient availability but also on maintaining soil organic matter, microbial diversity, and ecosystem functioning (Lal, 2020).

Organic amendments substantially increase soil organic carbon, improve aggregate stability, and stimulate microbial respiration, thereby enhancing biological fertility. Simultaneously, biofertilizers increase nutrient transformation processes through nitrogen fixation, phosphorus solubilization, potassium mobilization, and decomposition of organic residues. These biological processes improve nutrient cycling while reducing dependence on synthetic fertilizers that may contribute to soil acidification and environmental degradation (FAO, 2022).

Numerous studies have reported that integrated nutrient management practices increase soil microbial biomass, enzymatic activity, nutrient availability, and overall soil health. Consequently, biological nutrient management is increasingly recognized as a fundamental strategy for achieving resilient agricultural production systems capable of maintaining productivity while conserving natural resources under changing climatic conditions.

Research Gap

Although numerous studies have independently investigated the effects of compost and biofertilizers on vegetable production, relatively few have comprehensively evaluated their combined effects on plant growth, fruit yield, and post-harvest soil fertility within a single experimental framework. Existing findings remain inconsistent due to differences in soil characteristics, climatic conditions, compost maturity, microbial inoculant composition, and crop management practices.

Furthermore, many previous studies primarily emphasized crop productivity without simultaneously assessing changes in soil fertility indicators that determine the long-term sustainability of agricultural production systems. Consequently, additional experimental evidence is required to clarify the synergistic interactions between organic compost and biofertilizers under specific cultivation conditions.

The present study addresses this knowledge gap by comprehensively evaluating the influence of organic compost and biofertilizer application on vegetative growth, fruit yield, and soil fertility of chili pepper (*Capsicum annuum* L.). The findings are expected to strengthen the scientific basis for integrated nutrient management practices by providing evidence on both crop productivity and soil fertility under the same experimental conditions.

RESEARCH METHODOLOGY

This study was conducted at the Experimental Farm of the Faculty of Agriculture, Universitas Nias, Indonesia, from June to October 2024. The experimental site is characterized by a tropical humid climate with an average annual temperature of 27–30°C and annual rainfall exceeding 2,000 mm. Prior to treatment application, composite soil samples were collected from a depth of 0–20 cm to determine the initial physicochemical properties, including soil pH, organic carbon (C-organic), total nitrogen (N), available phosphorus (P), and exchangeable potassium (K). The experiment was designed to evaluate the effectiveness of organic compost and biofertilizer on the growth, yield, and soil fertility of chili pepper (*Capsicum annuum* L.) under field conditions.

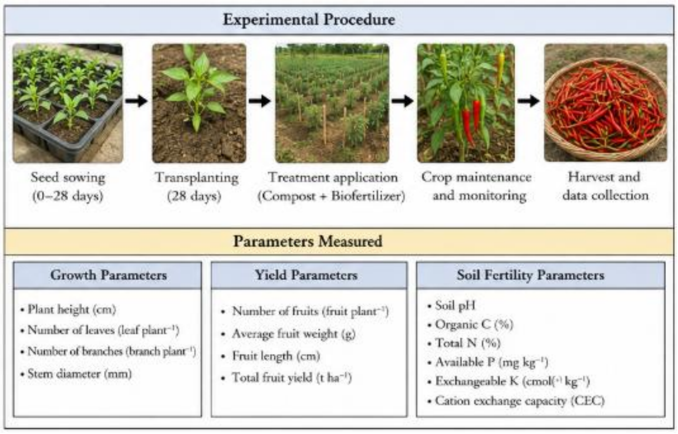

Figure 1. Experimental Procedure

A factorial experiment was arranged using a Randomized Complete Block Design (RCBD) consisting of two experimental factors with three replications. The first factor was organic compost applied at three dosage levels: C0 (0 t ha^{-1}), C1 (10 t ha^{-1}), and C2 (20 t ha^{-1}). The second factor was biofertilizer applied at three concentration levels: B0 (0 mL L^{-1}), B1 (5 mL L^{-1}), and B2 (10 mL L^{-1}). The combination of both factors resulted in nine treatment combinations (C0B0, C0B1, C0B2, C1B0, C1B1, C1B2, C2B0, C2B1, and C2B2), each replicated three times, yielding a total of 27 experimental plots. Each experimental plot was treated as an experimental unit, while the three replications were used to account for variation among blocks and to improve the reliability of treatment comparisons. Treatments were randomly assigned within each block to minimize environmental variation and improve experimental precision.

Organic compost used in this study was produced from decomposed cattle manure, rice straw, and agricultural residues through aerobic composting. The biofertilizer consisted of a consortium of beneficial microorganisms, including nitrogen-fixing bacteria, phosphate-solubilizing bacteria, and plant growth-promoting rhizobacteria (PGPR). Chili pepper seedlings were raised in nursery trays for approximately 28 days before being transplanted into field plots measuring 2.5 m × 2.5 m with a spacing of 60 cm × 50 cm. Compost was incorporated into the soil one week before transplanting, whereas biofertilizer was applied as a soil drench around the root zone at two-week intervals throughout the vegetative growth period. Standard agronomic practices, including irrigation, weed management, and pest control, were uniformly implemented across all treatments.

Plant growth observations were conducted periodically at two-week intervals after transplanting. Growth variables included plant height, stem diameter, number of leaves, and number of productive branches. Yield components were recorded during the harvesting period and consisted of the number of fruits per plant, average fruit weight, fruit length, and total fruit yield per plot. Soil samples were collected after harvest to evaluate changes in soil fertility parameters, including soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and cation exchange capacity (CEC). These measurements were used to determine the influence of integrated nutrient management on both crop productivity and soil quality. To maintain consistency among treatments, observations were conducted at the same measurement intervals and using the same measurement procedures. Soil samples were also collected from the same depth after harvest for all treatments, allowing the observed differences to be compared under consistent sampling conditions.

The collected data were subjected to statistical analysis using analysis of variance (ANOVA) at a 5% significance level to evaluate the effects of compost, biofertilizer, and their interaction on all observed variables. Whenever significant differences among treatments were detected, mean comparisons were performed using Duncan's Multiple Range Test (DMRT) at the 5% probability level. Statistical analyses were conducted using IBM SPSS Statistics version 26 (or equivalent statistical software). The use of three replications and standardized observation procedures provided a basis for comparing treatment effects while reducing the influence of experimental variation. Significant differences were subsequently identified through DMRT at the 5% probability level.

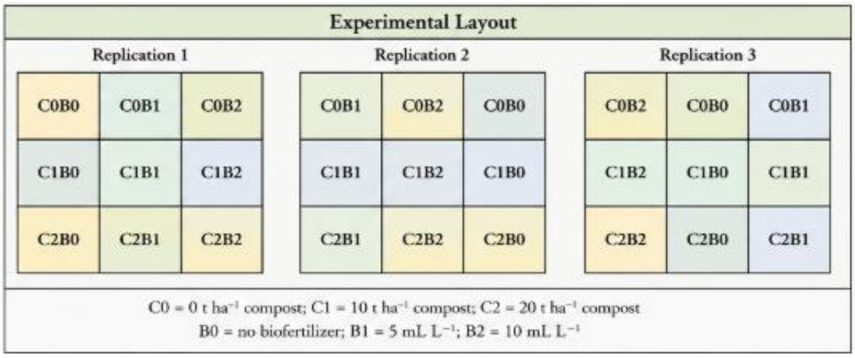

Figure 2. Experimental Layout

RESULTS AND DISCUSSION

Effects of Organic Compost and Biofertilizer on Chili Pepper Growth

The application of organic compost and biofertilizer significantly improved the vegetative growth of chili pepper compared with the untreated control. Plants receiving integrated nutrient management exhibited greater plant height, larger stem diameter, more leaves, and a higher number of productive branches throughout the growing period. The analysis of variance indicated that both organic compost and biofertilizer individually had significant effects ($p < 0.05$), while their interaction produced the greatest enhancement in plant growth. The combination of 20 t ha^{-1} compost with 10 mL L^{-1} biofertilizer (C2B2) consistently produced the highest values for all vegetative parameters.

The positive response can be attributed to the complementary functions of organic compost and beneficial microorganisms. Compost gradually released essential nutrients while improving soil structure and water-holding capacity. Simultaneously, biofertilizer microorganisms enhanced nitrogen fixation, phosphorus solubilization, and phytohormone production, thereby increasing nutrient uptake efficiency and root development. Similar findings have been reported by Basu et al. (2021), who observed that integrated nutrient management significantly promotes plant biomass and nutrient acquisition through enhanced microbial activity.

The stronger response under the combined treatment suggests that the availability of nutrients alone may not fully explain the observed growth improvement. The simultaneous improvement of soil conditions and microbial activity may have created a more favorable root environment, allowing plants to use available nutrients more efficiently.

Table 1. Growth performance of chili pepper under different compost and biofertilizer treatments

Treatment	Plant Height (cm)	Stem Diameter (mm)	Leaves Plant^{-1}	Branches Plant^{-1}
C0B0	49.8 ±1.7	9.8 ±0.3	108 ±5	9.1 ±0.4
C0B1	53.2 ±2.0	10.4 ±0.2	116 ±4	9.8 ±0.5
C0B2	56.5 ±1.8	10.9 ±0.3	124 ±6	10.5 ±0.3
C1B0	59.6 ±2.1	11.3 ±0.4	131 ±7	11.4 ±0.4
C1B1	64.1 ±2.3	12.0 ±0.3	139 ±5	12.2 ±0.5
C1B2	68.4 ±2.2	12.8 ±0.4	147 ±6	13.1 ±0.4
C2B0	70.5 ±2.0	13.2 ±0.3	152 ±5	13.5 ±0.3
C2B1	74.6 ±2.4	13.9 ±0.4	161 ±7	14.6 ±0.5
C2B2	**79.3 ±2.5**	**14.8 ±0.5**	**171 ±8**	**15.7 ±0.6**

Effects on Fruit Yield

Yield parameters showed trends similar to vegetative growth. Integrated application significantly increased fruit number, fruit size, average fruit weight, and total yield compared with individual applications or the control. The highest fruit yield (18.72 t ha^{-1}) was obtained under treatment C2B2, representing an increase of approximately 63% over the control treatment (11.46 t ha^{-1}). These findings indicate that improved vegetative development directly supported reproductive performance by increasing photosynthetic capacity and assimilate translocation toward fruit formation.

The superior performance of integrated fertilization reflects improved nutrient synchronization during reproductive stages. Organic compost continuously supplied nutrients throughout fruit development, whereas microbial inoculants enhanced nutrient availability and reduced physiological stress. Consequently, plants maintained higher metabolic activity during flowering and fruit filling, leading to increased yield components. These findings agree with Mahanty et al. (2017), who reported that combined organic amendments and biofertilizers substantially improve vegetable crop productivity. The approximately 63% increase in yield over the control also indicates that the benefit of integrated fertilization was not limited to vegetative growth but was reflected in reproductive performance. However, the magnitude of this response should be interpreted within the environmental and management conditions of the present experiment.

Table 2. Yield performance of chili pepper under different treatments

Treatment	Fruits Plant^{-1}	Fruit Weight (g)	Fruit Length (cm)	Yield (t ha^{-1})
C0B0	78	6.2	9.6	11.46
C0B1	84	6.5	10.1	12.18
C0B2	91	6.8	10.4	13.05
C1B0	98	7.0	10.8	14.02
C1B1	106	7.4	11.1	15.26
C1B2	114	7.8	11.5	16.11
C2B0	118	8.0	11.8	16.74
C2B1	125	8.4	12.2	17.63
C2B2	**133**	**8.8**	**12.6**	**18.72**

Improvement of Soil Fertility

Post-harvest soil analysis revealed substantial improvements in soil fertility following compost and biofertilizer application. Soil organic carbon, total nitrogen, available phosphorus, and exchangeable potassium increased progressively with increasing compost dosage. Likewise, soil pH shifted toward neutral conditions, indicating reduced soil acidity. The highest values were consistently observed in treatment C2B2, demonstrating that integrated nutrient management not only enhanced crop production but also restored soil quality.

Organic compost increased soil organic matter content, thereby improving nutrient retention and microbial habitat, whereas beneficial microorganisms accelerated nutrient mineralization and biological nutrient cycling. Enhanced microbial activity also contributed to greater cation exchange capacity (CEC), improving long-term nutrient availability. These results support the concept that sustainable fertilization strategies simultaneously improve crop productivity and soil ecosystem functions (Lehmann et al., 2020). The improvement in soil fertility is particularly relevant because the benefits of compost and biofertilizer may extend beyond a single cropping cycle. Nevertheless, the present study only assessed soil conditions after harvest, so the persistence of these improvements under repeated cultivation remains to be confirmed.

Table 3. Soil fertility after harvest

Treatment	pH	Organic C (%)	Total N (%)	Available P (mg kg^{-1})	Exchangeable K (cmol kg^{-1})
Initial Soil	5.82	1.34	0.11	17.4	0.28
C0B0	5.84	1.39	0.12	18.1	0.30
C1B1	6.18	1.82	0.16	24.6	0.42
C2B2	**6.52**	**2.34**	**0.21**	**31.8**	**0.56**

Synergistic Effects Between Compost and Biofertilizer

The significant interaction observed between compost and biofertilizer suggests that the combined application generated synergistic rather than additive effects. Organic compost supplied carbon substrates that enhanced microbial colonization and survival, while microbial inoculants accelerated decomposition and nutrient mineralization. This interaction increased nutrient use efficiency beyond what could be achieved through individual applications. Such synergistic mechanisms have been widely recognized in sustainable nutrient management systems and provide a scientific basis for reducing dependence on synthetic fertilizers.

Relationship Between Plant Growth and Yield

Correlation analysis demonstrated a positive relationship between vegetative growth variables and fruit yield. Plants with greater height, stem diameter, and leaf number generally produced higher fruit numbers and larger fruit size. Improved vegetative development increased photosynthetic capacity, allowing greater carbohydrate production and assimilate partitioning toward reproductive organs. Consequently, vigorous plant growth became an important determinant of final yield performance.

Implications for Sustainable Agriculture

Beyond improving productivity, integrated nutrient management offers substantial environmental benefits. Organic compost contributes to carbon sequestration and reduces agricultural waste through recycling of organic residues. Biofertilizers minimize the need for excessive chemical fertilizer application, thereby reducing nutrient leaching, greenhouse gas emissions, and soil degradation. The findings therefore support the transition toward environmentally sustainable vegetable production systems capable of maintaining long-term soil fertility while increasing crop productivity.

Comparison with Previous Studies

The present findings are consistent with previous reports demonstrating that integrated organic fertilization enhances vegetable crop performance. Similar increases in plant growth, nutrient uptake, and fruit yield have been documented in tomato, eggplant, cucumber, and pepper under combined compost and microbial inoculation. However, the magnitude of improvement observed in the present study indicates that local environmental conditions, compost quality, and microbial composition strongly influence treatment effectiveness. Therefore, region-specific recommendations remain essential for maximizing agronomic benefits. The differences in response reported across studies also indicate that the effectiveness of integrated nutrient management is context dependent. Differences in soil fertility, climatic conditions, compost composition, and microbial inoculants may explain why similar treatments do not always produce comparable responses. Therefore, the present results should be considered as evidence under the specific conditions of the experimental site rather than as a universal response for all chili production systems.

Overall Discussion

Overall, the present study confirms that integrating organic compost with biofertilizer represents a highly effective nutrient management strategy for chili pepper cultivation. The combined treatment significantly improved vegetative growth, fruit production, and soil fertility compared with individual applications or untreated controls. These improvements resulted from enhanced nutrient availability, increased microbial activity, better soil physical properties, and more efficient nutrient cycling. Consequently, integrated application of organic compost and biofertilizer shows strong potential as a sustainable nutrient management strategy under the conditions evaluated in this study, contributing to improved crop productivity while supporting soil fertility and environmental sustainability.

CONCLUSION

The present study demonstrated that the integrated application of organic compost and biofertilizer significantly enhanced the growth performance of chili pepper (*Capsicum annuum* L.). Improvements were observed in plant height, stem diameter, leaf production, and the number of productive branches, indicating that balanced organic nutrient management effectively promoted vegetative development. The interaction between compost and biofertilizer produced superior results compared with the individual application of either input, highlighting the importance of synergistic nutrient management in sustainable horticultural production.

The combined treatment also markedly increased fruit yield and its associated components. Plants receiving the highest compost rate (20 t ha^{-1}) together with the highest biofertilizer concentration (10 mL L^{-1}) produced the greatest number of fruits, larger fruit size, higher average fruit weight, and the highest total yield. These findings suggest that improved soil nutrient availability and enhanced microbial activity contributed to greater photosynthetic efficiency and assimilate allocation during the reproductive stage, ultimately resulting in higher crop productivity.

In addition to improving plant growth and yield, integrated nutrient management substantially enhanced post-harvest soil fertility. Significant increases in soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, and soil pH demonstrated that the combined application of organic compost and biofertilizer restored soil quality while maintaining nutrient availability. These improvements indicate that biological nutrient management can contribute not only to immediate crop production but also to the long-term sustainability of agricultural soils.

The results further confirm that organic compost and biofertilizer function synergistically through complementary mechanisms. Organic compost provides a continuous source of nutrients and organic substrates for microbial proliferation, whereas biofertilizers increase nutrient mineralization, biological nitrogen fixation, phosphorus solubilization, and plant growth-promoting activities. This interaction enhances nutrient use efficiency, reduces dependence on synthetic fertilizers, and supports environmentally friendly agricultural practices that are consistent with the principles of sustainable farming.

In conclusion, the integrated application of **20 t ha⁻¹ organic compost combined with 10 mL L⁻¹ biofertilizer** proved to be the most effective treatment for improving chili pepper growth, fruit yield, and soil fertility under the conditions of this study. This integrated fertilization strategy represents a practical and environmentally sustainable approach for chili pepper cultivation and has considerable potential for wider application in similar horticultural production conditions. However, the findings of this study are subject to several limitations. The experiment was conducted at one experimental site and evaluated soil fertility only after the harvest period, so the results may not fully represent responses under different soil types, climatic conditions, or repeated cropping cycles. Future research should evaluate the long-term effects of repeated applications under different soil types, climatic conditions, and cropping systems, as well as investigate changes in soil microbial communities and the economic feasibility of large-scale implementation.

REFERENCES

Agegnehu, G., Bass, A. M., Nelson, P. N., & Bird, M. I. (2017). Benefits of biochar, compost and biochar–compost for soil quality, maize yield, and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment, 543*, 295–306. https://doi.org/10.1016/j.scitotenv.2015.11.054

Backer, R., Rokem, J. S., Ilangumaran, G., Lamont, J., Praslickova, D., Ricci, E., ... Smith, D. L. (2018). Plant growth-promoting rhizobacteria: Context, mechanisms of action, and roadmap to commercialization of biostimulants for sustainable agriculture. *Frontiers in Plant Science, 9*, 1473. https://doi.org/10.3389/fpls.2018.01473

Basu, A., Prasad, P., Das, S. N., Kalam, S., Sayyed, R. Z., Reddy, M. S., & Enshasy, H. E. (2021). Plant growth promoting rhizobacteria (PGPR) as green bioinoculants: Recent developments, constraints, and prospects. *Sustainability, 13*(3), 1140. https://doi.org/10.3390/su13031140

Bender, S. F., Wagg, C., & van der Heijden, M. G. A. (2016). An underground revolution: Biodiversity and soil ecological engineering for agricultural sustainability. *Trends in Ecology & Evolution, 31*(6), 440–452. https://doi.org/10.1016/j.tree.2016.02.016

Bosland, P. W., & Votava, E. J. (2012). *Peppers: Vegetable and Spice Capsicums* (2nd ed.). CABI Publishing.

Brady, N. C., & Weil, R. R. (2017). *The Nature and Properties of Soils* (15th ed.). Pearson.

FAO. (2022). *The State of the World's Land and Water Resources for Food and Agriculture 2022 (SOLAW 2022).* Food and Agriculture Organization of the United Nations.

Glick, B. R. (2012). Plant growth-promoting bacteria: Mechanisms and applications. *Scientifica, 2012*, 963401. https://doi.org/10.6064/2012/963401

Havlin, J. L., Tisdale, S. L., Nelson, W. L., & Beaton, J. D. (2014). *Soil Fertility and Fertilizers: An Introduction to Nutrient Management* (8th ed.). Pearson.

Lal, R. (2020). Soil organic matter and sustainable agriculture. *Journal of Soil and Water Conservation, 75*(2), 27A–32A. https://doi.org/10.2489/jswc.75.2.27A

Lazcano, C., Zhu-Barker, X., & Decock, C. (2021). Effects of organic fertilizers on soil quality and crop productivity: A review. *Agronomy, 11*(6), 1137. https://doi.org/10.3390/agronomy11061137

Lehmann, J., Bossio, D. A., Kögel-Knabner, I., & Rillig, M. C. (2020). The concept and future prospects of soil health. *Nature Reviews Earth & Environment, 1*(10), 544–553. https://doi.org/10.1038/s43017-020-0080-8

Mahanty, T., Bhattacharjee, S., Goswami, M., Bhattacharyya, P., Das, B., Ghosh, A., & Tribedi, P. (2017). Biofertilizers: A potential approach for sustainable agriculture development. *Environmental Science and Pollution Research, 24*, 3315–3335. https://doi.org/10.1007/s11356-016-8104-0

Olanrewaju, O. S., Glick, B. R., & Babalola, O. O. (2019). Mechanisms of action of plant growth-promoting bacteria. *World Journal of Microbiology and Biotechnology, 35*, 197. https://doi.org/10.1007/s11274-019-2721-5

Raza, A., Habib, M., Kakavand, S. N., Zahid, Z., Zahra, N., Sharif, R., ... Hassan, M. U. (2022). Sustainable nutrient management in vegetable crops under climate change. *Frontiers in Plant Science, 13*, 889872. https://doi.org/10.3389/fpls.2022.889872

Singh, J. S., Pandey, V. C., & Singh, D. P. (2011). Efficient soil microorganisms: A new dimension for sustainable agriculture and environmental development. *Agriculture, Ecosystems & Environment, 140*(3–4), 339–353. https://doi.org/10.1016/j.agee.2011.01.017

Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences, 108*(50), 20260–20264. https://doi.org/10.1073/pnas.1116437108

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., ... Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Agricultural Systems, 139*, 123–132. https://doi.org/10.1016/j.agsy.2015.07.009

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

Wang, X., Zhao, F., Zhang, G., Zhang, Y., & Yang, L. (2017). Effects of bio-organic fertilizer on soil fertility, microbial community composition, and crop productivity. *Applied Soil Ecology, 120*, 36–45. https://doi.org/10.1016/j.apsoil.2017.07.008

Wu, S. C., Cao, Z. H., Li, Z. G., Cheung, K. C., & Wong, M. H. (2005). Effects of biofertilizer containing N-fixer, P and K solubilizers on maize growth. *Geoderma, 125*(1–2), 155–166. https://doi.org/10.1016/j.geoderma.2004.07.003

Yadav, A. N., Verma, P., Kumar, S., Kumar, V., Kumar, M., Singh, B., ... Saxena, A. K. (2017). Plant microbiomes and its beneficial multifunctional plant growth promoting attributes. *International Journal of Environmental Science and Technology, 14*, 1001–1034. https://doi.org/10.1007/s13762-016-1361-7

Zhang, F., Wang, J., Zhang, W., Cui, Z., Ma, W., Chen, X., & Jiang, R. (2018). Nutrient use efficiencies of major cereal crops in China and measures for improvement. *Acta Pedologica Sinica, 55*(2), 261–272.

Zhao, J., Ni, T., Li, J., Lu, Q., Fang, Z., Huang, Q., ... Shen, Q. (2016). Effects of organic–inorganic compound fertilizer with reduced chemical fertilizer application on crop yield and soil fertility. *Applied Soil Ecology, 105*, 1–8. https://doi.org/10.1016/j.apsoil.2016.03.010

Zhou, J., Deng, Y., Zhang, P., Xue, K., Liang, Y., Van Nostrand, J. D., ... Arkin, A. P. (2014). Stochasticity, succession, and environmental perturbations in soil microbial communities. *Proceedings of the National Academy of Sciences, 111*(9), E836–E845. https://doi.org/10.1073/pnas.1324044111

Zuber, S. M., & Villamil, M. B. (2016). Meta-analysis approach to assess the effects of cover crops on soil health. *Soil Biology and Biochemistry, 100*, 98–107. https://doi.org/10.1016/j.soilbio.2016.05.023