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Enhanced tomato (*Solanum lycopersicum* L.) yield and soil biological properties through integrated use of soil, compost, and foliar fertilization under greenhouse conditions

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Abstract

This study investigates the combined effects of standard soil fertilization, composted animal manure, and foliar fertilization on tomato yield, soil nutrient content, and soil biological properties under greenhouse conditions. The experiment was conducted from March to October 2023 using a completely randomized block design with four replications. The treatments included: 1) Control (no fertilization), 2) Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da), 3) Standard soil fertilization + composted animal manure (2 t/da), 4) Standard soil fertilization + foliar fertilization (1 kg 17-17-17/100 liters of water every 20 days), and 5) Standard soil fertilization + compost + foliar fertilization. Tomato seedlings (*Solanum lycopersicum* L. cv. Roma) were transplanted into pots filled with clay soil. Throughout the experiment, soil moisture content was maintained at field capacity. Plants were harvested on October 30, 2023, and data on fruit yield, soil nutrient content (NPK), and soil biological properties (microbial biomass C, CO_2 production, and dehydrogenase enzyme activity) were recorded. The highest yield (4.5 kg/plant) was observed in the treatment combining standard soil fertilization, composted animal manure, and foliar fertilization, representing a 275% increase compared to the control (1.2 kg/plant). The standard soil fertilization treatment alone yielded 2.8 kg/plant (133.3% increase), while the combination with composted animal manure yielded 3.5 kg/plant (191.7% increase), and with foliar fertilization, 3.9 kg/plant (225% increase). Soil analyses showed significant increases in available nitrogen, phosphorus, and potassium in the combined treatments. The highest biological properties were also recorded in the combined treatment.

Keywords: Tomato yield, soil fertilization, compost, foliar fertilization, soil biological properties.

Introduction

Intensive agricultural practices have led to significant soil degradation and reduced productivity worldwide (Kopittke et al., 2019). The continuous use of chemical fertilizers has contributed to the decline in soil organic matter, nutrient imbalance, and disruption of soil microbial communities. To address these issues, sustainable fertilization techniques that enhance soil health and improve crop yield are essential (Ning et al., 2017; Krasilnikov et al., 2022; Dincă et al., 2022).

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Tomato (*Solanum lycopersicum* L.) is one of the most widely cultivated and economically important vegetable crops globally (Padmanabhan et al., 2016). Tomatoes require a balanced supply of nutrients for optimal growth, development, and fruit production. Nitrogen (N), phosphorus (P), and potassium (K) are the primary macronutrients essential for tomato growth (Tereda et al., 2023). However, conventional fertilization practices often fail to provide a balanced nutrient supply, leading to suboptimal yields and soil health (Montgomery and Biklé, 2021).

Compost, a well-known organic amendment, has been shown to improve soil structure, increase microbial activity, and enhance nutrient availability (Wright et al., 2022). Compost adds organic matter to the soil, which is crucial for water retention, nutrient cycling, and overall soil fertility (Gülser et al., 2015). Moreover, foliar fertilization, the application of nutrients directly to plant leaves, offers a rapid and efficient method of nutrient delivery. Foliar fertilizers can quickly correct nutrient deficiencies and support plant growth during critical developmental stages (Gülser et al., 2019).

Integrating organic amendments like compost with conventional soil and foliar fertilization practices can provide a holistic approach to nutrient management. This integrated strategy aims to improve both soil health and crop productivity by ensuring a continuous and balanced supply of nutrients (Chang et al., 2007; Gentile et al., 2008; Liu et al., 2010; Ai et al., 2012; Bowles et al., 2014; Zhang et al., 2016; Wang et al., 2023; Tang et al., 2023).

The objective of this study is to evaluate the effects of combining standard soil fertilization, composted animal manure, and foliar fertilization on tomato yield, soil nutrient content, and soil biological properties under greenhouse conditions. By comparing these treatments, we aim to identify the most effective nutrient management strategy for enhancing tomato productivity and soil health.

Material and Methods

Soil, Compost, and Tomato Plant

The experiment was conducted using soil, compost, and tomato plants (F1 tomato). The soil samples were processed and analyzed to determine their physical and chemical properties. The compost used was analyzed for its organic matter content and nutrient composition. The tomato plants were cultivated under controlled greenhouse conditions.

The soil used in the experiment was characterized by several analyses. The texture was determined using the hydrometer method (Bouyoucos, 1962). The pH and electrical conductivity (EC) were measured in a 1:1 soil-water suspension using a pH meter (Peech, 1965) and an EC meter (Bower and Wilcox, 1965), respectively. Calcium carbonate ($CaCO_3$) content was determined volumetrically using the Scheibler calsimeter (Rowell, 2010). Organic matter content was analyzed by the wet oxidation with $K_2Cr_2O_7$ (Walkley and Black, 1934). Total nitrogen (N) content was determined using the Kjeldahl method (Bremner, 1965). Available phosphorus (P) was measured in a 0.5M $NaHCO_3$ extract using a spectrophotometer (Olsen and Dean, 1965). Exchangeable potassium (K) was determined in a 1 N NH_4OAc extract using a flame photometer (Pratt, 1965).

The compost used in the experiment was analyzed for its organic matter content and nutrient composition. Organic matter was determined by loss on ignition at 550°C. Total nitrogen (N) content was analyzed using the Kjeldahl method. Total phosphorus (P) was measured in the extract obtained from dry ashing using a spectrophotometer. Total potassium (K) was determined in the extract obtained from dry ashing using a flame photometer (Jones, 2001).

Experimental Design

The experimental treatments are as follows:

1. Control (no fertilization)
2. Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da)
3. Standard soil fertilization + composted animal manure (2 t/da)
4. Standard soil fertilization + foliar fertilization (1 kg 17-17-17/100 liters of water every 20 days)
5. Standard soil fertilization + composted animal manure (2 t/da) + foliar fertilization (1 kg 17-17-17/100 liters of water every 20 days)

The experiment was established in a randomized complete block design with four replications. Soil samples were air-dried in the shade, crushed with a wooden mallet, and passed through a 4 mm sieve. Five kilograms of the processed soil were placed into each pot. The fertilizers used were ammonium sulfate (21% N) as the nitrogen source, monoammonium phosphate (12% N, 61% P_2O_5) as the phosphorus source, and potassium sulfate (50% K_2O) as the potassium source. The standard soil fertilization application included 30 kg N/da, 8 kg P_2O_5/da, and 40 kg K_2O/da. The compost application was 2 t/da of composted animal manure. Tomato seedlings were transplanted to the greenhouse on March 15, 2023, with one seedling planted per pot. Foliar fertilization was applied every 20 days using 1 kg 17-17-17+me fertilizer per 100 liters of water to the relevant pots.

Throughout the experiment, soil moisture content was maintained at field capacity by daily weighing of the pots and adjusting the water levels accordingly. During the experiment, ripe tomatoes were harvested and their weights recorded. At the end of the experiment on October 30, 2023, soil and plant samples were collected. Soil samples were analyzed for available nitrogen (NH_4+NO_3) using 1 N KCl extraction followed by Kjeldahl distillation (Bremner, 1965), available phosphorus in a 0.5 M $NaHCO_3$ extract using a spectrophotometer (Olsen and Dean, 1965), and exchangeable potassium in a 1 N NH_4OAc extract using a flame photometer (Pratt, 1965). Biological properties of the soil, including microbial biomass carbon, CO_2 production, and dehydrogenase enzyme activity, were also measured. Microbial biomass carbon was determined using the method of Anderson and Domsch (1978), CO_2 production was measured as described by Anderson (1982), and dehydrogenase activity was determined following Pepper (1995). Leaf samples from each pot were analyzed for N, P, and K contents (Jones, 2001).

Results and Discussion

Soil and Compost Characteristics

The physical and chemical properties of the soil and compost used in the experiment are presented in Tables 1 and 2, respectively.

Table 1. Physical and chemical properties of the soil used in the experiment

Property	Value
Texture	Clay (48% clay, 23% silt, 29% sand)
pH	7.58
Electrical Conductivity (EC)	0.79 dSm^{-1}
Lime (CaCO3)	18%
Organic Matter	1.36%
Total Nitrogen (N)	0.198%
Available Phosphorus (P)	8 mg kg^{-1}
Exchangeable Potassium (K)	0.986 cmol/kg

Table 2. Chemical properties of the compost used in the experiment

Property	Value
Organic Matter	43%
Total Nitrogen (N)	2.52%
Total Phosphorus (P)	1.68%
Total Potassium (K)	4.47%
pH	7.19
Electrical Conductivity (EC)	3.69 dSm^{-1}

The soil texture, comprising 48% clay, 23% silt, and 29% sand, indicates a clay soil, which can present challenges for tomato cultivation due to its poor drainage and tendency to become compacted. However, clay soils also have a high nutrient-holding capacity and can retain moisture well, which can be beneficial in maintaining soil moisture levels. The soil pH of 7.58 is slightly alkaline but still within the acceptable range for tomato growth. The EC value of 0.79 dSm^{-1} suggests low salinity, which is favorable for plant growth. The $CaCO_3$ content of 18% is relatively high, which can help in buffering soil pH. The organic matter content of 1.36% is low, suggesting the need for organic amendments to improve soil fertility. The total nitrogen content of 0.198%, available phosphorus of 8 mg kg^{-1}, and exchangeable potassium of 0.986 cmol/kg reflect the basic nutrient status of the soil, which needs enhancement for optimal tomato growth.

The compost used in the experiment had a high organic matter content of 43%, which is beneficial for improving soil structure and water-holding capacity. The total nitrogen content of 2.52% is substantial, providing a good source of nitrogen for plant growth. The total phosphorus content of 1.68% and total potassium content of 4.47% indicate that the compost is rich in essential nutrients, which can supplement the soil nutrient status effectively. The pH of 7.19 is slightly alkaline, and the EC value of 3.69 dSm^{-1} suggests moderate salinity, which is typical for compost but should be monitored to avoid potential salt stress in plants.

The combination of these soil and compost characteristics provides a comprehensive understanding of the initial conditions of the experiment. The low organic matter and nutrient content in the soil highlight the importance of compost and fertilization treatments in enhancing soil fertility and supporting plant growth. The subsequent sections will discuss the effects of these treatments on tomato yield, soil properties, and plant nutrient content.

Tomato Yield

The tomato yield results for the different treatments are presented in Table 3. The highest yield was observed in the treatment with standard soil fertilization, composted animal manure, and foliar fertilization, while the lowest yield was recorded in the control treatment with no fertilization. The percentage increase in yield compared to the control and the standard soil fertilization treatment is also calculated.

Table 3. Tomato yield for different fertilization treatments

Treatment	Tomato Yield (kg/plant) ± S.D.*	Yield Increase (%) Compared to Control	Yield Increase (%) Compared to Standard Soil Fertilization
Control (no fertilization)	1.2 ± 0.2	-	-
Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da)	2.8 ± 0.3	133.3	-
Standard soil fertilization + composted animal manure (2 t/da)	3.5 ± 0.4	191.7	25.0
Standard soil fertilization + foliar fertilization (1 kg 17-17-17+me/100 L)	3.9 ± 0.4	225.0	39.3
Standard soil fertilization + compost + foliar fertilization	4.5 ± 0.5	275.0	60.7

*Standard Deviation

The tomato yield results indicate significant differences among the treatments. The control treatment, which did not receive any fertilization, had the lowest yield of 1.2 kg per plant, indicating the limited nutrient availability in the soil. The standard soil fertilization treatment increased the yield to 2.8 kg per plant, representing a 133.3% increase compared to the control. This highlights the importance of essential nutrients such as nitrogen, phosphorus, and potassium in promoting plant growth and fruit production.

The addition of composted animal manure to the standard soil fertilization further increased the yield to 3.5 kg per plant, a 191.7% increase compared to the control and a 25.0% increase compared to standard soil fertilization alone. This increase can be attributed to the improved soil structure, enhanced microbial activity, and additional nutrients provided by the compost. Compost improves soil organic matter content, which is crucial for water retention, nutrient availability, and overall soil fertility.

The treatment with standard soil fertilization and foliar fertilization resulted in a yield of 3.9 kg per plant, a 225.0% increase compared to the control and a 39.3% increase compared to standard soil fertilization alone. Foliar fertilization allows for the direct absorption of nutrients through the leaves, providing a rapid and efficient method of nutrient delivery. This treatment was effective in supplying additional nutrients during critical growth stages, leading to improved plant health and fruit production.

The highest yield of 4.5 kg per plant was observed in the treatment combining standard soil fertilization, composted animal manure, and foliar fertilization. This yield represents a 275.0% increase compared to the control and a 60.7% increase compared to standard soil fertilization alone. This combination provided the most comprehensive nutrient management strategy, ensuring both soil and foliar nutrient supply. The synergy between soil-applied and foliar-applied nutrients, along with the benefits of compost, resulted in the optimal growth conditions for the tomato plants. The increased yield in this treatment highlights the importance of integrating multiple fertilization strategies to maximize crop productivity.

Numerous studies have shown that both soil and foliar fertilization, as well as the addition of organic matter to soils (Ouédraogo et al., 2001; Gao et al., 2015; Maltas et al., 2018; Kızılkaya et al., 2022; Zhou et al., 2022; İslamzade et al., 2023), can enhance crop yields. Furthermore, several studies have indicated that the combined application of compost with both soil and foliar fertilization results in the greatest increase in crop yields (Gentile et al., 2008; Zhang et al., 2016). Similarly, in this research, results demonstrate that the integration of compost and foliar fertilization with standard soil fertilization can significantly enhance tomato yield. The combined application provides a balanced nutrient supply, improves soil health, and ensures efficient nutrient uptake, leading to higher fruit production.

NPK Content in Tomato Leaves

The nitrogen (N), phosphorus (P), and potassium (K) content in tomato leaves for different treatments are presented in Table 4. The sufficiency levels for tomato leaves are: N: 3.20 - 4.50%, P: 0.50 - 1.20%, and K: 5 - 10%.

Table 4. NPK content in tomato leaves for different fertilization treatments

Treatment	N (%) ± S.D.*	P (%) ± S.D.*	K (%) ± S.D.*
Control (no fertilization)	2.0 ± 0.2	0.3 ± 0.1	3.0 ± 0.3
Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da)	3.5 ± 0.3	0.7 ± 0.2	4.5 ± 0.4
Standard soil fertilization + composted animal manure (2 t/da)	4.0 ± 0.3	0.9 ± 0.2	5.5 ± 0.5
Standard soil fertilization + foliar fertilization (1 kg 17-17-17+/100 L)	4.2 ± 0.3	1.0 ± 0.2	5.8 ± 0.5
Standard soil fertilization + compost + foliar fertilization	4.5 ± 0.3	1.2 ± 0.2	6.5 ± 0.6

*Standard Deviation

The NPK content in tomato leaves varied significantly among the treatments. In the control treatment, the levels of N (2.0%), P (0.3%), and K (3.0%) were all below the sufficiency range, indicating a deficiency in essential nutrients due to the absence of fertilization.

In the standard soil fertilization treatment, the nitrogen content increased to 3.5%, phosphorus to 0.7%, and potassium to 4.5%. Although N and P were within the sufficiency range, K remained slightly below the recommended level. This indicates that while soil fertilization improved the nutrient status, additional potassium supplementation might be needed.

The addition of composted animal manure to the standard soil fertilization further improved the nutrient levels, with N at 4.0%, P at 0.9%, and K at 5.5%. All values were within or above the sufficiency range, highlighting the positive impact of compost on nutrient availability.

The treatment with standard soil fertilization and foliar fertilization resulted in N, P, and K contents of 4.2%, 1.0%, and 5.8% respectively. These values were all within the sufficiency range, demonstrating the effectiveness of foliar fertilization in providing additional nutrients directly to the leaves.

The highest NPK levels were observed in the treatment combining standard soil fertilization, compost, and foliar fertilization, with N at 4.5%, P at 1.2%, and K at 6.5%. This treatment provided the most balanced and sufficient nutrient supply, ensuring optimal plant growth and development.

It is noteworthy that there were no significant differences in NPK content between the treatments of standard soil fertilization + composted animal manure and standard soil fertilization + foliar fertilization. This may be due to nutrient translocation from leaves to fruits as yield increases, resulting in nutrient dilution in the leaves. The highest yielding treatment (standard soil fertilization + compost + foliar fertilization) had the best nutrient content in the leaves, indicating that this combination most effectively meets the plant's nutritional needs. Similarly, studies by Yin et al. (2018); Gülser et al. (2019); Uçgun and Altindal (2021); Liu et al (2021) and Zhang et al. (2023) have shown that soil and foliar fertilization applications increase both crop yield and the nutrient content (NPK) of plants. Additionally, compost applications to the soil have been found to enhance crop yield and improve plant nutrient content (Ouédraogo et al., 2001; Wright et al., 2022). Furthermore, it has been determined by Gentile et al. (2008) and Zhang et al. (2022) that combining organic fertilizers with inorganic fertilizers significantly increases the nutrient content of plants. In this research, results emphasize the importance of integrating compost and foliar fertilization with standard soil fertilization to achieve optimal nutrient levels in tomato leaves. The combined application not only enhances yield but also ensures a sufficient supply of essential nutrients, thereby improving overall plant health and productivity.

Changes in Soil NPK Content

The available nitrogen (NH_4+NO_3), phosphorus (P), and potassium (K) content in the soil for different treatments are presented in Table 5. The control treatment showed the lowest levels of available NPK, while the treatments with standard soil fertilization, compost, and foliar fertilization resulted in increased soil nutrient contents.

The soil nutrient content varied significantly among the treatments. The control treatment, which did not receive any fertilization, had the lowest levels of available nitrogen (15 mg kg^{-1}), phosphorus (5 mg kg^{-1}), and potassium (0.873 cmol/kg). These low values indicate a deficiency in essential nutrients due to the absence of fertilization.

Table 5. Available NPK content in soil for different fertilization treatments

Treatment	Available N (NH_4+NO_3) (mg kg^{-1}) ± S.D.	Available P (mg kg^{-1}) ± S.D.	Available K (cmol/kg) ± S.D.
Control (no fertilization)	15 ± 2	5 ± 1	0.873 ± 0.05
Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da)	45 ± 5	15 ± 2	1.200 ± 0.10
Standard soil fertilization + composted animal manure (2 t/da)	60 ± 6	18 ± 2	1.450 ± 0.12
Standard soil fertilization + foliar fertilization (1 kg 17-17-17/100 L)	50 ± 5	16 ± 2	1.300 ± 0.10
Standard soil fertilization + compost + foliar fertilization	65 ± 6	20 ± 2	1.600 ± 0.15

*Standard Deviation

In the standard soil fertilization treatment, the available nitrogen content increased to 45 mg/kg, phosphorus to 15 mg/kg, and potassium to 1.200 cmol/kg. This significant increase highlights the importance of providing essential nutrients such as nitrogen, phosphorus, and potassium through soil fertilization to improve soil fertility and plant nutrient availability.

The addition of composted animal manure to the standard soil fertilization further increased the available nitrogen content to 60 mg kg^{-1}, phosphorus to 18 mg kg^{-1}, and potassium to 1.450 cmol/kg. These values indicate the positive impact of compost on nutrient availability in the soil. Compost not only adds organic matter but also provides a slow-release source of nutrients, enhancing soil fertility over time.

The treatment with standard soil fertilization and foliar fertilization resulted in available nitrogen, phosphorus, and potassium contents of 50 mg kg^{-1}, 16 mg kg^{-1}, and 1.300 cmol/kg, respectively. While foliar fertilization primarily targets nutrient delivery to the leaves, it also contributes to soil nutrient content, although to a lesser extent compared to soil-applied fertilizers and compost.

The highest available NPK levels were observed in the treatment combining standard soil fertilization, compost, and foliar fertilization, with available nitrogen at 65 mg kg^{-1}, phosphorus at 20 mg kg^{-1}, and potassium at 1.600 cmol/kg. This treatment provided the most comprehensive nutrient management strategy, ensuring a balanced supply of nutrients to the soil.

It is noteworthy that while the addition of compost significantly increased soil nutrient content, the treatments involving foliar fertilization did not result in as large an increase. This can be attributed to the fact that foliar fertilization primarily enhances nutrient uptake by the leaves, with less impact on soil nutrient levels. However, the combination of soil fertilization, compost, and foliar fertilization provided the most effective approach to improving both soil and plant nutrient status. Similarly, it has been determined that the application of chemical fertilizers and compost to soils significantly increases the available NPK levels (Gentile et al., 2008; Diacono and Montemurro, 2010; Demelash et al., 2014; Güler et al., 2015; Manolikaki and Diamadopoulos, 2019), and the highest increases were observed when chemical fertilizers were applied together with organic materials (Wan et al., 2021). In this research, results demonstrate that integrating compost and foliar fertilization with standard soil fertilization can significantly enhance soil nutrient content. The combined application not only improves plant growth and yield but also enhances soil health and fertility, ensuring sustainable agricultural practices.

Biological Properties of Soil

The biological properties of the soil, including microbial biomass carbon, CO2 production, and dehydrogenase enzyme activity, are presented in Table 6. The treatments with compost and foliar fertilization showed improved biological activity compared to the control.

The biological properties of soil varied significantly among the treatments, reflecting the impact of different fertilization strategies on soil microbial activity and health.

The control treatment, which did not receive any fertilization, had the lowest levels of microbial biomass carbon (95 mg CO_2–C 100 g^{-1}), CO2 production (35 µg CO_2 g^{-1} $24h^{-1}$), and dehydrogenase activity (9 µg TPF g^{-1} $24h^{-1}$). These low values indicate limited microbial activity and soil health in the absence of nutrient inputs.

The standard soil fertilization treatment improved the biological properties of the soil, with microbial biomass carbon increasing to 152 mg CO_2-C 100 g^{-1}, CO_2 production to 52 µg CO_2 g^{-1} $24h^{-1}$, and dehydrogenase activity to 19 µg TPF g^{-1} $24h^{-1}$. This indicates that the addition of essential nutrients through soil fertilization enhances microbial activity and overall soil health.

Table 6. Biological properties of soil for different fertilization treatments

Treatment	Microbial Biomass C, mg CO_2–C 100 g^{-1} ± S.D.*	CO_2 Production, µg CO_2 g^{-1} $24h^{-1}$ ± S.D.*	Dehydrogenase Activity, µg TPF g^{-1} $24h^{-1}$ ± S.D.*
Control (no fertilization)	95 ± 9	35 ± 5	9 ± 1
Standard soil fertilization (30 kg N/da, 8 kg P_2O_5/da, 40 kg K_2O/da)	152 ± 14	52 ± 7	19 ± 2
Standard soil fertilization + composted animal manure (2 t/da)	245 ± 23	78 ± 9	31 ± 3
Standard soil fertilization + foliar fertilization (1 kg 17-17-17/100 L)	198 ± 19	69 ± 8	27 ± 2
Standard soil fertilization + compost + foliar fertilization	297 ± 28	103 ± 11	34 ± 3

*Standard Deviation

The addition of composted animal manure to the standard soil fertilization further enhanced the biological properties, with microbial biomass carbon reaching 245 mg CO_2–C 100 g^{-1}, CO2 production at 78 mg CO2/kg soil/day, and dehydrogenase activity at 31 µg TPF g^{-1} $24h^{-1}$. Compost provides organic matter and nutrients that support microbial growth and activity, improving soil structure and fertility.

The treatment with standard soil fertilization and foliar fertilization resulted in microbial biomass carbon of 198 mg CO_2–C 100 g^{-1}, CO2 production of 69 µg CO_2 g^{-1} $24h^{-1}$, and dehydrogenase activity of 27 µg TPF g^{-1} $24h^{-1}$. The relatively high biological activity in this treatment can be attributed to the improved plant growth resulting from foliar fertilization. Better plant growth leads to greater root biomass, which in turn releases more root exudates. These exudates serve as a food source for soil microbes, thus enhancing microbial activity and soil health.

The highest biological activity was observed in the treatment combining standard soil fertilization, compost, and foliar fertilization. This treatment resulted in microbial biomass carbon of 297 mg CO_2–C 100 g^{-1}, CO2 production of 103 µg CO_2 g^{-1} $24h^{-1}$, and dehydrogenase activity of 34 µg TPF g^{-1} $24h^{-1}$. The combination of soil and foliar fertilization with compost provides a comprehensive nutrient management strategy that enhances soil microbial activity and overall soil health. Similarly, numerous studies have shown that the application of organic materials and chemical fertilizers to soils increases the number and activity of soil microorganisms, thereby improving soil biological properties (Chang et al., 2007; Kızılkaya, 2008; Liu et al., 2010; Ai et al., 2012; Bowles et al., 2014; Wang et al., 2023; Tang et al., 2023). In this research, results highlight the importance of integrating compost and foliar fertilization with standard soil fertilization to improve soil biological properties. Enhanced microbial activity and enzyme function contribute to better nutrient cycling, soil structure, and plant health, promoting sustainable agricultural practices.

Conclusion

This study investigated the combined effects of standard soil fertilization, compost, and foliar fertilization on tomato yield, soil nutrient content, and soil biological properties under greenhouse conditions. The results demonstrated that integrating compost and foliar fertilization with standard soil fertilization significantly enhances tomato yield and improves soil health. The highest tomato yield was observed in the treatment combining standard soil fertilization, composted animal manure, and foliar fertilization, resulting in a 275% increase compared to the control. This combination provided a comprehensive nutrient management strategy, ensuring an optimal supply of essential nutrients and promoting better plant growth and fruit production. Soil analyses revealed that the integration of compost and foliar fertilization significantly increased the available nitrogen, phosphorus, and potassium levels in the soil. The highest nutrient content was recorded in the treatment with standard soil fertilization, compost, and foliar fertilization, indicating the effectiveness of this integrated approach in enhancing soil fertility. The biological properties of the soil, including microbial biomass carbon, CO_2 production, and dehydrogenase enzyme activity, were also significantly improved by the combined application of compost and foliar fertilization. The highest microbial activity was observed in the treatment combining standard soil fertilization, compost, and foliar fertilization. This improvement is attributed to the enhanced plant growth and root exudates, which serve as a food source for soil microbes.

In conclusion, the integration of compost and foliar fertilization with standard soil fertilization offers a sustainable and effective strategy for enhancing tomato yield and soil health. This approach not only provides a balanced nutrient supply but also improves soil structure and microbial activity, contributing to better nutrient cycling and overall soil fertility. Future research should focus on optimizing the application rates and timing of these treatments to further enhance their effectiveness and economic feasibility. The results of this study highlight the importance of adopting comprehensive nutrient management practices to achieve sustainable agricultural productivity.

For future research, it is recommended to explore the effects of integrating compost and foliar fertilization with standard soil fertilization under different climatic conditions and with different crop species. This could provide valuable insights into the versatility and robustness of this nutrient management strategy across various agricultural settings. Additionally, investigating the long-term impacts of these fertilization practices on soil health and productivity would further contribute to the understanding of sustainable agricultural practices. By examining these factors, researchers can better understand how to optimize fertilization strategies to maximize crop yield and soil health in diverse environments.

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