

Growth and yield responses of bell pepper to combined chemical and organic fertilizer applications

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Abstract

This study investigated various combinations of chemical fertilizer, organomineral fertilizer, and vermicompost in pepper (*Capsicum annuum* L.) cultivation to mitigate soil degradation and quality decline associated with the sole use of chemical fertilizers. Conducted at Van Yüzüncü Yıl University, the research evaluated plant growth, fruit characteristics, and yield parameters under ten different fertilization treatments. The results showed that organomineral + vermicompost combinations achieved the highest values in plant growth, as well as early, marketable, and total yield. The highest total yield was obtained from the T8 treatment, reaching 939.50 kg da⁻¹, while the highest fruit number per plant was recorded in T2 (12.81 fruits plant⁻¹). Chemical fertilizers promoted rapid early growth; however, integrating them with vermicompost provided superior performance, particularly in terms of sustainability. These combined treatments also resulted in greater fruit length, diameter, and average fruit weight. Overall, the study demonstrated that organic and organomineral fertilizer combinations can significantly enhance yield and fruit quality in pepper production while reducing chemical fertilizer use and supporting an environmentally friendly production approach.

Keywords: Bell pepper, growth parameters, organic fertilizer, vermicompost, yield

INTRODUCTION

Long term reliance on chemical fertilizers contributes to soil degradation, lowers nutrient concentrations in fruits, and ultimately reduces overall fruit quality (Kochakinezhad et al., 2012). In sustainable production systems, part of the required nutrient supply can be replaced with organic inputs to protect human health, preserve the environment, and improve soil structure (Mengistu et al., 2017). Chemical fertilizers are widely used due to their rapid nutrient availability and immediate effects on plant growth and yield. However, their long-term and excessive use may lead to soil degradation, reduced organic matter content, nutrient imbalance, and environmental pollution. In contrast, organic fertilizers such as vermicompost improve soil structure, microbial activity, and nutrient retention, although their nutrient release is generally slower and less predictable. Therefore, integrating chemical and organic fertilizers has been suggested as a practical approach to combine the advantages of both systems while minimizing their individual limitations.

Pepper (*Capsicum annuum* L.), an important member of the Solanaceae family, originated in the Americas and has a wide global distribution. It was introduced to Europe by Spanish explorers in the late 15th century and subsequently spread to Africa and Asia through trade routes. Today, pepper is widely consumed worldwide as both a fresh vegetable and a spice. In addition to its contribution to flavor and color, pepper fruits are an important source of vitamins and minerals for human nutrition (Sahin et al., 2022). According to the Food and Agriculture Organization (Gürbüz et al., 2024), global pepper cultivation covered approximately 2.05 million hectares, with a total production of 36.29 million tons in 2021. Asia accounted for the largest share of production (67.9%), followed by America, Europe, and Africa. China was the leading pepper producer worldwide, followed by Türkiye, Indonesia, and Mexico. According to 2023 data, annual bell pepper production was recorded at 395,441 tons (Çolak & Yazar 2024). Achieving high yield and quality in pepper production requires balanced nutrition supported by appropriate fertilization strategies and suitable environmental conditions. Due to its suitable climate, Türkiye is among the leading countries in pepper production (Bayram et al., 2019; Çolak & Yazar, 2024). In addition to being consumed as a food product, pepper is also used in the production of dyes and pharmaceutical products due to the antioxidant compound capsaicin, which imparts a pungent taste. Pepper is a nutritionally important

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vegetable containing considerable amounts of protein, carbohydrates, minerals, and vitamins. Moreover, hot pepper contains the alkaloid capsaicin, which is responsible for its pungent and burning flavor (Kartal & Şahin, 2025).

As the world population rapidly increases, agricultural lands are gradually decreasing. To produce enough food in parallel with this population growth, the unconscious and excessive use of chemical fertilizers, hormones, and pesticides has caused pollution of water and air, decreased soil fertility, and adverse effects on human health (Öztemiz, 2008). Integrated pest management strategies are widely used in sustainable agriculture. Good Agricultural Practices represent an alternative production system aimed at restoring the natural balance disrupted by improper agricultural practices, maintaining sustainability, protecting soil fertility, ensuring environmentally friendly production, controlling diseases and pests through biological methods, and enhancing not only yield but also product quality (Taşbaşı & Zeytin, 2003; Kurtar & Ayan, 2004).

This study aimed to identify agricultural inputs that support sustainable farming conditions by forming combinations of chemical fertilizers, solid vermicompost, and organomineral fertilizers for pepper cultivation, thereby minimizing ecological damage. The findings obtained from this study, which evaluated not only plant and fruit quality parameters but also yield characteristics, revealed important and meaningful results.

MATERIALS AND METHODS

Experimental Site and Design

The Sumo F1 bell pepper seedlings used in this study were obtained from a private agricultural company. The trial was conducted in open-field experimental plots at Van Yüzüncü Yıl University, located at 38° 34' 25" N latitude and 43° 17' 40" E longitude. Seedlings were transplanted on 11 June 2021 at a spacing of 100 cm between rows and 50 cm within rows. To reduce edge effects, fruit samples were collected from six central plants during the third and fourth harvests. Soil analysis conducted before planting revealed no salinity issues, low organic matter content, high lime content, and a slightly alkaline pH (Table 1). Throughout the growing season, a drip irrigation system was used to maintain consistent soil moisture. Under open-field conditions, irrigation was applied every two days, depending on prevailing climatic conditions, and the same irrigation regime was uniformly applied to all treatments. Climatic data for the 2021 growing period are provided in Table 2.

Fertilization Program

A comprehensive fertilization program consisting of ten different treatments was applied. Three types of fertilizers were used: chemical fertilizer (Gübretaş), earthworm vermicompost (Yaşa Tarım), and organomineral fertilizer (Hektaş). These fertilizers were applied either individually or in various combinations, including a control group without fertilization. The contents of the chemical, vermicompost, and organomineral fertilizers are shown in Table 3, and the treatment combinations were prepared at five different ratios: 0%, 25%, 50%, 75%, and 100% (Table 4). The fertilizers were applied to the plots on June 3, 2021, one week before seedling transplantation. To compensate for nitrogen deficiency in plots where chemical fertilizer was applied alone or in combination, urea fertilizer was additionally applied twice at approximately four-week intervals during the growing season. Disease and pest management was conducted uniformly across all treatments. Cultural practices were adopted as the primary control strategy, and chemical interventions were applied only when necessary according to standard agricultural recommendations. All plots were managed using the same approach to prevent any confounding effects on plant growth and yield.

Table 1 Soil analysis data of the experimental field

Parameter	Value
P (mg kg ⁻¹)	5.50
K (mg kg ⁻¹)	11.04
Organic matter (%)	0.93
Lime (%)	10.84
pH (%)	7.83
Electrical conductivity/ Salt (%)	0.01
Structure (%)	sand: 37, clay: 24.3, silt: 38.6
N (%)	0.17
Mn (mg kg ⁻¹)	0.98
Na (mg kg ⁻¹)	86.35
Fe (mg kg ⁻¹)	1.12
Cu (mg kg ⁻¹)	0.53
Zn (mg kg ⁻¹)	0.46
Ca (mg kg ⁻¹)	1025
Mg (mg kg ⁻¹)	134

Table 2 Some climatic parameters of the experimental area in 2021 (14th Regional Directorate of Meteorology)

Parameter	May	June	July	August	September
Average temperature (°C)	19.2	21.1	24.5	26.4	22.8
Minimum temperature (°C)	10.5	14.3	17.1	19.6	16.5
Maximum temperature (°C)	27.8	27.9	31.8	33.2	29.1
Sunshine duration	11.9	12.7	12.5	12.6	11.8
Precipitation (mm)	8.1	14.7	12.7	15.5	1.1
Wind (m s ⁻¹)	3.1	2.7	2.1	2.3	2.1
Relative humidity (%)	41.8	48.3	34.2	30.9	35.8
Evaporation (mm)	65.2	188.5	199.4	213.4	25.0

Table 3 Ingredients of fertilizers used in the plant growing process

Chemical fertilizer (CF) (20:20:20) (%)	Triple superphosphate (TSP)	%46 nitrogen fertilizer	Organomineral fertilizer (OMF) 11:11:11 (%)	Vermicompost (VC) (%)
● Total nitrogen:20 ● Ammonium nitrogen:3.9 ● Nitrate nitrogen: 5.9 ● Urea (N-NH₂):10.2 ● Water soluble phosphorus pentoxide:20 ● Water-soluble potassium oxide: 20 ● Water soluble iron:0.05 ● Water soluble copper:0.02 ● Water soluble zinc:0.02 ● Water soluble manganese:0.02	● Water soluble phosphorus pentoxide:39 ● Phosphorus pentoxide soluble in neutral ammonium citrate (P₂O₅): 42	● Urea:46	● Organic matter:18.00 ● Total nitrogen:11.00 ● Ammonium nitrogen:5.00 ● Urea nitrogen:6.00 ● Water soluble potassium oxide:11.00 ● Total phosphorus pentoxide:11.00 ● Water soluble phosphorus pentoxide:9.00 ● Water soluble sulfur trioxide:7.00 ● Total sulfur trioxide:11.00 ● Total zinc:0.10 ● Total humic acid + fulvic acid:5.00	● Organic matter:35.00 ● Total nitrogen:2.00 ● Organic nitrogen:1.00 ● Water soluble potassium oxide:2.00 ● Total phosphorus pentoxide:0.40 ● Total humic acid + fulvic acid:20.00 ● C/N:10.04 ● Max. EC (dS/m):2.00 ● Max moisture:35.00 ● pH:6-8

Table 4 Doses of fertilizers used in the plant growing process

Treatment	Fertilizer combinations	Fertilizer doses
T1	Control	-
T2	CF _(100%)	19.8 kg da ⁻¹ N:P:K (20:20:20) + 14.21 kg da ⁻¹ TSP + 23.63 kg da ⁻¹ %46 urea
T3	VC _(100%)	741.5 kg da ⁻¹
T4	OMF _(100%)	134.82 kg da ⁻¹
T5	CF _(25%) + VC _(75%)	4.75 kg da ⁻¹ N:P:K (20:20:20) + 3.55 kg da ⁻¹ TSP + 5.91 kg da ⁻¹ %46 urea + 556.13 kg da ⁻¹ VC
T6	CF _(50%) + VC _(50%)	9.9 kg da ⁻¹ N:P:K (20:20:20) + 7.11 kg da ⁻¹ TSP + 11.82 kg da ⁻¹ %46 urea + 370.75 kg da ⁻¹ VC
T7	CF _(75%) +VC _(25%)	14.85 kg da ⁻¹ N:P:K (20:20:20) + 10.66 kg da ⁻¹ TSP + 17.73 kg da ⁻¹ %46 urea + 185.38 kg da ⁻¹ VC
T8	OMF _(25%) +VC _(75%)	33.71 kgda ⁻¹ OMF + 556.13 kg da ⁻¹ VC
T9	OMF _(50%) + VC _(50%)	67.41 kg da ⁻¹ OMF + 370.75 kg da ⁻¹ VC
T10	OMF _(75%) + VC _(25%)	101.12 kg da ⁻¹ OMF + 185.38 kg da ⁻¹ VC

CF: Chemical fertilizer; VC: Vermicompost; OMF: Organomineral fertilizer

Plant–Fruit Quality and Yield Parameters

Plant Growth: Plant height (cm) and stem diameter (mm) were measured at three times, 20 days intervals, on centrally located plants free from edge effects.

Plant height: The vertical length of the plant was measured from the soil surface to the tip of the apical shoot using a ruler and expressed in centimeters (cm).

Stem diameter: The stem diameter was measured just above the soil surface using a digital caliper and expressed in millimeters (mm).

Fruit Characteristics: Fruits harvested from the same plants were evaluated using the following parameters

Fruit length (mm): Measured from the peduncle cavity to the blossom end using a digital caliper.

Fruit diameter (mm): Measured at the widest equatorial point perpendicular to the peduncle using a digital caliper.

Fruit shape index: Calculated as the ratio of fruit length to diameter.

Number of fruits per plant (fruits/plant): Determined by counting the total number of fruits on each plant.

Average fruit weight (g): Calculated by dividing the total fruit weight by the total number of fruits.

Yield Components: Fruits from each plot were weighed separately throughout the harvest period.

Harvesting started on July 31, 2021 and ended on September 14, 2021. A total of six harvests were conducted on July 31, August 7, August 14, August 24, September 1, and September 14, 2021.

Total yield (kg da⁻¹): The total harvested fruit weight from all harvests.

Early yield (kg da⁻¹): Fruit weight collected during the first of harvest.

Marketable yield (kg da⁻¹): Obtained by subtracting the weight of small, deformed, or physiologically defective fruits from the total yield.

Statistical Analysis

The data obtained in the study were evaluated using one-way analysis of variance (ANOVA) in the SPSS statistical software at a significance level of $p \leq 0.05$. Differences among treatment means, when statistically significant, were grouped using Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Plant-Fruit Quality and Yield Parameters

In the study, plant height and stem diameter were recorded at three growth stages at 20-day intervals. In the first measurement, plant height was higher in all fertilizer combinations compared to the control plants, with the highest value obtained from the T10 treatment (19.44 cm) and the lowest from the T1 (control) group (14.86 cm). In the second and third measurements, the highest plant heights were recorded in plants treated with 100% chemical fertilizer (T2), with values of 31.22 cm and 36.22 cm, respectively, while the lowest values were obtained from the T5 combination (24.97 and 29.97 cm) (Table 5). Across all three periods, the highest stem diameter values were generally observed in the treatments where chemical fertilizer was combined with organomineral fertilizer or vermicompost (Table 5).

Joshi and Vig (2010) reported that cattle-based vermicompost significantly increased tomato plant height compared to the control, with plants receiving 15%, 30%, and 45% vermicompost reaching heights of 63, 63.4, and 63.5 cm, respectively. Daneshvar et al. (2022) in celery, Jigme et al. (2015) in broccoli, and Gale et al. (2006) in spinach stated that plants supplied with chemical fertilizers were taller than those receiving organic fertilizers, attributing this to increased N availability and rapid N release. However, excessive nitrogen may reduce soil organic matter and contribute to environmental pollution (White & Brown 2010). Therefore, in accordance with good agricultural practices, fertilizer combinations containing vermicompost that produced values close to those of 100% chemical fertilizer in this study are considered more beneficial.

Mengistu et al. (2017) reported that combining mineral fertilizer with vermicompost enhanced crop growth and that integrating chemical fertilizer with vermicompost increased tomato plant height by 23–52% in the first and second branches. Bhunia et al. (2021) found that in bell pepper, low doses of BBRDM (bovine-blood-rumen-digesta mixture) produced the highest plant height, stem diameter, number of fruits, and fruit weight among chemical fertilizer, vermicompost, and BBRDM treatments. Malik et al. (2011) reported that among various organic and inorganic fertilizer combinations applied to two hybrid pepper cultivars, the highest plant height, fruit length, fruit diameter, and fruit number per plant were obtained from treatments with high organic fertilizer content. Vermicompost application also increased shoot length (17.06%), root length (43.74%), number of leaves per plant (39.93%), and leaf area (54.95%) in tomato (Eswaran & Mariselvi, 2016). Mengistu et al. (2017) further reported that applying 75% inorganic fertilizer (105 N and 40 P kg ha⁻¹) combined with excreta-based vermicompost (11.5 t ha⁻¹) increased the total number of fruits per plant by 89.94%. According to Wang et al. (2017), vermicompost and chicken manure compost promoted plant growth more effectively than traditional urea fertilizer or unfertilized control, increasing growth parameters including stem diameter and plant height. Thuy et al. (2017) found that the highest vermicompost dose (30 t ha⁻¹) improved fruit characteristics such as fruit pattern index, fruit flesh thickness, and dry matter content. Al-Harbi et al. (2020) reported that organic fertilizer applications caused slight changes in fruit length, while BC 2% + compost 2% and compost 4% significantly increased

fruit width in sweet pepper. In Biquinho pepper, mineral and biofertilizer applications did not cause significant block-based variation in fruit length or fruit diameter (Pereira et al., 2021).

In this study, the combination of chemical fertilizer and vermicompost produced the greatest fruit width and length, whereas T4, T7, and T10 exhibited the highest shape index values. The highest fruit number per plant was recorded in T2 (12.81 fruits) and T8 (10.78 fruits). Average fruit weight was highest in T2 and T4 (Table 6).

In this study, early yield, marketable yield, and total yield—three different yield components—showed statistically significant differences among all fertilizer combinations. The highest early yield was obtained from the T9 treatment (403.50 kg da⁻¹), whereas the lowest was recorded in the T1 (control) group (65.33 kg da⁻¹). For marketable yield, T8, T9, and T10 produced the highest values with 779.50, 773.50, and 775.00 kg da⁻¹ respectively, while T1 (control) had the lowest value at 441.67 kg da⁻¹ (Table 7). The high performance of T8, T9, and T10 treatments is considered to be related to improved soil–plant interactions resulting from the combined application of organomineral fertilizer and vermicompost. This interaction is thought to enhance soil properties and nutrient availability, which may have contributed to improved plant growth and yield performance. Similar results have been reported in recent studies. Vermicompost application significantly increased plant height, fruit number, and yield in *Capsicum annuum* compared to unfertilized control treatments. Alam et al. (2023) reported that the highest fruit yield (11.26 t ha⁻¹) and fruit number (9.51 fruits plant⁻¹) were obtained under 20 t ha⁻¹ vermicompost application. Moreover, Güneş et al. (2023) demonstrated that organic and chemical fertilizer applications caused significant differences in yield and yield components among pepper varieties, supporting the effectiveness of integrated fertilization strategies. In line with these findings, Ekincialp (2024) reported that combined chemical and organic fertilizer applications improved nutrient availability and bioactive compound accumulation in bell pepper, while also supporting yield performance and reducing dependence on sole chemical fertilization.

Vaidyanathan and Vijayalakshmi (2017) and Tesfay et al. (2018) reported that optimum vermicompost applications increased yield in tomato. Mengistu et al. (2017) found that combining inorganic fertilizer (75% of both 105 N and 40 P kg ha⁻¹) with excreta-based vermicompost (11.5 t ha⁻¹) produced 104.23% higher marketable yield and 89.94% higher total yield compared to the unfertilized control. In sweet pepper, the highest early yield (13.760 t ha⁻¹) and marketable yield (38.381 t ha⁻¹) were obtained from the BC 2% + compost 2% application, while the lowest values (8.441 t ha⁻¹ and 22.092 t ha⁻¹) were recorded in the control group. The same treatment provided a 56.6% increase in total yield compared to the control (Al-Harbi et al., 2020). Zayed et al. (2013) reported that organic fertilizer applications significantly increased early yield (4.984 kg/plot), total yield (58.179 kg/plot), and total number of fruits per plot (444.375) in pepper. In the present study, the highest total yield was obtained from the T8 combination (939.50 kg da⁻¹), while the lowest value was recorded in T1 (control) with 493.67 kg da⁻¹ (Table 7).

Table 5. Effect of different fertilizer treatments on plant height (cm) and on stem diameter (mm) measured at three times (1st, 2nd, and 3rd measurements) for 20-day intervals

Plant height				Stem diameter		
Treatment	1 st	2 nd t	3 rd	1 st	2 nd	3 rd
T1	14.86±2.46	27.85±0.89	32.85±0.89	5.78±0.61	8.05±1.06	10.55±1.06
T2	19.19±1.80	31.22±4.03	36.22±4.03	7.26±0.90	10.45±2.15	12.95±2.15
T3	15.03±1.24	27.70±2.44	32.70±2.44	6.65±1.21	9.82±1.31	12.32±1.31
T4	16.72±5.92	25.78±6.01	30.78±6.01	6.54±1.90	8.35±2.36	10.86±2.34
T5	15.35±3.60	24.97±4.73	29.97±4.73	6.17±1.74	8.01±1.83	10.51±1.83
T6	16.20±4.23	29.63±3.30	34.63±3.30	6.90±1.86	9.82±1.44	12.32±1.44
T7	17.67±2.17	27.17±2.80	32.17±2.80	6.53±1.15	8.11±0.88	10.61±0.88
T8	19.29±2.12	29.79±4.12	34.79±4.12	7.27±1.08	9.68±1.03	12.18±1.03
T9	16.99±3.32	27.57±5.29	32.57±5.29	7.08±1.26	9.03±2.00	11.53±2.00
T10	19.44±4.42	29.33±4.69	34.33±4.69	6.89±1.29	9.29±1.08	11.79±1.08

Table 6. Effects of different fertilizer treatments on fruit width (mm), fruit length (mm), shape index, fruit weight (g), and number of fruits per plant

Treatment	Fruit width	Fruit length	Fruit weight	Fruit count/plant	Shape index
T1	49.72±3.47	69.00±4.60	37.50±7.45	6.78±1.55	1.40±0.06
T2	53.92±0.88	78.46±2.99	41.57±1.50	12.81±4.38	1.47±0.07
T3	51.90±4.60	73.27±3.94	34.63±4.48	8.64±0.89	1.44±0.20
T4	48.54±1.20	72.74±4.64	41.97±6.79	6.50±2.59	1.52±0.13
T5	50.92±3.77	72.35±1.71	36.67±1.69	8.03±1.50	1.46±0.09
T6	54.03±3.18	74.34±3.35	35.70±2.96	9.68±1.34	1.39±0.12
T7	52.68±1.16	78.88±5.89	37.07±2.22	8.56±3.37	1.51±0.09
T8	53.19±2.62	72.67±8.14	37.00±5.66	10.78±1.96	1.40±0.21
T9	52.52±5.15	73.92±0.70	35.92±10.57	9.37±3.09	1.44±0.15
T10	53.96±5.34	72.62±4.62	37.88±6.95	9.06±1.51	1.51±0.08

Table 7. Effects of different fertilizer treatments on early yield, marketable yield, and total yield (kg da⁻¹) in bell pepper.

Treatment	Early yield	Marketable yield	Total yield
T1	65.33±17.04c	441.67±96.57b	493.67±48.43c
T2	224.33±128.15a-c	712.50±143.54ab	853.50±126.57ab
T3	140.67±30.29bc	523.00±102.72ab	603.00±128.97a-c
T4	386.00±134.35a	569.00±289.91ab	601.00±311.13a-c
T5	189.00±88.83a-c	491.00±110.81b	553.00±86.00bc
T6	288.67±160.03ab	591.00±29.31ab	688.33±82.59a-c
T7	276.00±43.84a-c	713.00±195.16ab	774.50±259.51a-c
T8	202.33±88.30a-c	779.50±24.75a	939.50±187.38a
T9	403.50±88.39a	773.50±30.41a	882.00±183.85ab
T10	347.00±135.76ab	775.00±5.66a	831.00±35.36ab

Different letters indicate significant differences among the means in the column at $p \leq 0.05$ (according to Duncan's multiple comparison test)

CONCLUSION

This study demonstrated that the combined use of chemical and organic fertilizers, including vermicompost and organomineral fertilizers, significantly improved the growth, fruit quality, and yield of bell pepper (*Capsicum annuum* L.) compared to sole chemical fertilizer or the unfertilized control. While chemical fertilizers promoted rapid initial growth, the integration of organic amendments offered a more sustainable fertilization strategy by supporting soil health and long-term productivity.

Among the tested treatments, the organomineral + vermicompost combination T8 produced the highest total yield (939.50 kg da⁻¹), indicating its superior performance in terms of productivity. In addition, treatments combining organomineral fertilizers with vermicompost (particularly T8 and T9) resulted in higher early and marketable yields, as well as improved fruit length, diameter, and average fruit weight.

Overall, these results emphasize the sustainable advantages of integrating organomineral fertilizers with vermicompost, as this approach not only enhances yield and fruit quality but also reduces reliance on chemical fertilizers, contributing to environmentally friendly and sustainable bell pepper production systems.

Conflict of Interest

The author declares that there is no conflict of interest.

Author Contribution

The author contributed to all stages of the study, including experimental design, data collection, analysis, interpretation, and manuscript preparation.

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