



## Optimizing vermicompost rates to enhance soil fertility, nutrient uptake, yield, and fruit quality of organic blackberry under greenhouse conditions

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### ABSTRACT

Organic agriculture plays a vital role in sustainable food production by improving soil health and enhancing the nutritional quality of horticultural crops. This study aimed to determine the optimal dose of vermicompost for the organic cultivation of blackberries in greenhouses. The experiment was conducted during the winters of 2024 and 2025 at the National Center for Organic Agriculture in Qassim, Saudi Arabia, using the blackberry cultivar Prime Ark 45. A randomized complete block design (RCBD) was used to evaluate five vermicompost doses, ranging from 0 to 2 kg per plant. Vermicompost application improved soil fertility by increasing organic matter and available N, P, and K, while reducing salinity and pH. The 1.5 kg/plant rate produced the highest soil and leaf nutrient levels (28–45% above the control), the greatest yield (4.54 kg/plant), and improved fruit physical and chemical qualities, including sugars, total soluble solids, anthocyanins, phenols, and vitamin C; acidity decreased. Increasing the rate from 1.5 to 2 kg/plant led to a decrease in yield and quality. In conclusion, the study suggests that 1.5 kg of vermicompost per plant is the optimal dose to maximize soil fertility, yield, and fruit quality in organic greenhouse blackberry production.

**Contribution/Originality:** This study contributes to the existing literature by determining the optimal rate of vermicompost for organic blackberry production. It uses a precise estimation methodology. The study is among the few that have investigated the effects associated with the application rate. The main contribution of the research is that the use of 1.5 kg improves yield and quality results.

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## 1. INTRODUCTION

Blackberries (*Rubus fruticosus* L.) are a high-value fruit crop, noted for their rich nutritional composition and unusual sensory features. Soil fertility and nutrient management techniques have a significant impact on these traits. It is well known that worm castings, a stable organic by-product of earthworm-mediated biodegradation, are a multipurpose organic amendment that can enhance soil structure, nutrient availability, microbial activity, and plant growth regulator concentration (Calderon & Mortley, 2021; Gutiérrez-Miceli et al., 2007). Unlike synthetic fertilizers, vermicompost delivers slowly released macro- and micronutrients, combined with beneficial microbes that boost nutrient uptake, resulting in higher plant growth, increased yield, and fruit quality (Sharma et al., 2024; Wang et al., 2010).

Recent studies have highlighted the physiological responses of blackberries and other small fruits, demonstrating their significant influence on soil fertility and nutrient dynamics. Vegetative growth, flowering, and fruit quality appear to be closely linked to healthy soil-plant interactions and balanced nutrient uptake. Research indicates that incorporating organic amendments and adopting sustainable management practices can significantly boost plant metabolism, promote fruit development, and improve overall crop quality (Finn & Clark, 2019; Strik, Clark, Finn, & Thompson, 2017). More recent data indicate that organic inputs promote nitrogen uptake and enable improved fruiting in berry crops (Pereira, Silva, & Santos, 2021; Weber, 2022).

These findings highlight the importance of further investigating vermicompost as an organic input with strong potential to improve soil fertility and enhance crop productivity. They also reinforce the scientific justification for evaluating its use in protected blackberry production systems as a sustainable practice to improve soil performance, yield, and overall production efficiency.

Numerous studies have confirmed the positive effects of worm composting on horticultural crops. Arancon, Edwards, Bierman, Welch, and Metzger (2004) reported that applying worm compost to strawberries increased leaf area by 37% and yield by 35%, even under conditions of macronutrient availability (Abu-Zahra, 2016). Similar results have shown that worm composting improves the biochemical properties of fruit, such as vitamin C, soluble solids, and phenolic compounds, while reducing acidity and enhancing flavor and color (Wang et al., 2010).

Scientific research indicates that vermicompost, produced by the biological decomposition of organic matter by worms, is an important source for improving soil fertility and enhancing crop production. Many studies have demonstrated its ability to enhance soil physical structure, increase organic matter content, and improve the availability of essential nutrients, while stimulating beneficial microbial communities that contribute to increased uptake efficiency and shoot and root growth.

This leads to improved crop yield and fruit quality (Abafita, Shimbir, & Kebede, 2014; Arancon et al., 2004; Ghadimi, Sirousmehr, Ansari, & Ghanbari, 2021; Jindo et al., 2016; Mahmud, Abdullah, & Yaacob, 2020; Mulatu & Bayata, 2024; Ndour et al., 2025; Tejada, Gonzalez, Hernandez, & Garcia, 2008; Wu, Chen, Liu, Zhang, & Yang, 2023). As evidenced by recent research, determining the optimal addition rate is a key factor in maximizing the benefits of this fertilizer, as over-fertilization can lead to element imbalance or slow growth, while moderate rates, especially in vegetables and horticultural crops, lead to significantly improved growth and biochemical indicators, as demonstrated by pot experiments that studied the effect of different application depths and rates on plant response to vermicompost (Ho et al., 2022).

While the use of vermicompost in blackberry production has been explored in other crops, limited research has investigated its effects on blackberry growth, soil fertility, and fruit quality under organic farming and greenhouse conditions. Therefore, this study aimed to evaluate the impact of different vermicompost application rates on soil chemical properties, leaf nutrient content, yield, and fruit quality of organically grown blackberries in a controlled greenhouse environment. The goal was to determine the optimal vermicompost dose that maximizes productivity and fruit quality.

## 2. MATERIALS AND METHODS

### 2.1. Experimental Site and Plant Material

The experiment was conducted during the 2024 and 2025 growing seasons at the National Center for Organic Agriculture, Qassim, Saudi Arabia (25°48'23" N, 42°52'24" E), to evaluate the effect of vermicompost on soil properties and the performance of organically grown blackberry plants under air-conditioned greenhouse conditions. The region is characterized by an arid climate, with hot summers and mild winters.

Two-year-old blackberry plants (*Rubus fruticosus* L., cv. Prime-Ark 45 Primocane) were used in this study. Plants were cultivated in air-conditioned greenhouses at a spacing of 1.5 m between plants and 2.0 m between rows. The greenhouse environment was maintained at daytime temperatures of 20–25 °C, nighttime temperatures of 15–18 °C, relative humidity of 50–65%, and a photoperiod of 10–15 hours per day.

All standard organic horticultural practices were followed, including irrigation management and the use of organic fertilizer adjusted to the plant growth stages. A uniform NPK organic fertilizer regime was applied to all treatments.

**Table 1.** The physical and chemical properties of the experimental soil.

Particle size distribution (%)			Soil texture	EC (ds/m <sup>-1</sup> )	pH	Available (Na) ppm	Available (K) %	Available N %	Available (P) %	O.M %
Sand	Silt	Clay								
90	5	5	Sandy	3.23	7.25	118	0.10	0.09	0.04	1.13

Table 1 presents the physical and chemical properties of the experimental soil. The soil is classified as sandy in texture, with a high sand content (90%) and low proportions of silt (5%) and clay (5%). The electrical conductivity (EC) value of 3.23 dS m<sup>-1</sup> indicates moderate salinity, while the soil pH of 7.25 reflects a slightly neutral to mildly alkaline reaction.

The soil contains moderate available sodium (118 ppm) but relatively low levels of available potassium (0.10%), nitrogen (0.09%), and phosphorus (0.04%), indicating limited native fertility. In addition, the organic matter content is low (1.13%), which is typical of sandy soils and highlights the need for organic amendments to improve soil fertility and nutrient availability.

## 2.2. Experimental Design and Treatments

The study was arranged in a randomized complete block design (RCBD) with four replications. Five vermicompost application rates were tested: 0.0 kg bush<sup>-1</sup> (control), 0.5 kg bush<sup>-1</sup>, 1.0 kg bush<sup>-1</sup>, 1.5 kg bush<sup>-1</sup>, and 2.0 kg bush<sup>-1</sup>. Vermicompost was incorporated around the plant base in the first week of February, following pruning in both seasons.

Vermicompost was prepared in the vermicompost unit at the National Center for Organic Agriculture. The physical and chemical properties of the vermicompost are shown in Table 2.

**Table 2.** Physical and chemical properties of vermicompost.

Properties	Unit	Vermicompost
pH		7.90
EC (dS m <sup>-1</sup> )	(dS m <sup>-1</sup> )	2.79
Organic mater	%	37.27
N	%	0.51
P	%	0.17
K	%	0.62
Ca	%	0.34
Mg	%	0.07
Fe	mg	510
Mn	mg	100
Cu	mg	23
Zn	mg	36

## 2.3. Measurements

### 2.3.1. Soil Chemical Analysis

Soil samples were collected from a depth of 0–30 cm before vermicompost application and after harvest for each treatment. Samples were air-dried, passed through a 2 mm sieve, and analyzed for pH, electrical conductivity (EC), organic matter (OM%), and available nitrogen (N), phosphorus (P), and potassium (K) using standard analytical procedures described by Jackson (1967) and Page, Miller, and Keeney (1982).

### 2.3.2. Leaf NPK Content

Mature leaves were collected midway through the fruiting period, dried in an oven at 70°C, and ground for nutrient analysis. Total nitrogen was determined using the Kjeldahl method. Phosphorus concentration was measured spectrophotometrically using the ascorbic acid-ammonium molybdate method, while potassium content was measured using flame photometry, following the procedures outlined by Page et al. (1982).

### 2.3.3. Yield and Fruit Physical Characteristics

Fruit yield per bush (kg/bush) was recorded from the first harvest (the first week of May) to the last harvest (the last week of September). To measure the fruit weight, length, and width, 25 ripe fruits for each replicate were randomly selected (100 fruits total) for every treatment. Fruit weight (g) was measured using a Mettler (Toledo, Switzerland) balance ( $\pm 0.01$  g accuracy). Fruit length and width (cm) were measured with a hand-held caliper.

### 2.3.4. Fruit Physical Characteristics

To assess the physical fruit characteristics, 25 fully ripe fruits were randomly selected from each replicate (100 fruits per treatment). Fruit weight (g) was determined using a Mettler–Toledo balance (Switzerland) with an accuracy of  $\pm 0.01$  g, while fruit length and width (cm) were measured using a hand-held caliper.

### 2.3.5. Fruit Chemical Characteristics

Total soluble solids (TSS) were measured using a digital refractometer and expressed as Brix (AOAC, 2000). Acidity was estimated in grams of citric acid (100 g<sup>-1</sup> FW) using sodium hydroxide solution according to (AOAC, 2000). Vitamin C (100 mL<sup>-1</sup> juice) was measured by a liquid chromatographic methods (Scherer et al., 2012).

### 3. RESULTS

#### 3.1. Soil Chemical Properties

The use of vermicompost had a significant effect on improving the chemical characteristics of the soil, as shown in Tables 3 and 4. A negative correlation was recorded between increased vermicompost rates and soil salinity (EC) and pH, while a positive correlation was observed with organic matter content and N, P, and K nutrients, reflecting its effective role in increasing soil fertility.

Organic matter % (OM%) increased significantly with increasing rates of vermicompost, with the control treatment recording the lowest values (0.31-0.25%). As the addition rate increased to 1.5 and 2.0 kg/tree, the content rose to its highest levels (0.95-1.00%). This increase reflects the ability of vermicompost to add large amounts of organic carbon and improve soil structure, which enhances microbial activity and increases the soil's ability to retain water and nutrients.

Soil pH: The data indicated a gradual (not noticeable) decrease in soil pH with increasing levels of worm compost, from 7.12–7.01 in the control treatment to 6.13–6.02 at a rate of 1.5 kg of vermicompost. This slight decrease is considered positive, as lowering the pH in alkaline soils contributes to increased availability of nutrients such as iron, zinc, and phosphorus, thus improving root uptake of these elements.

Likewise, soil salinity (EC): The data in Table 3 showed that the control treatment recorded the highest EC value (2.98–2.95 dS/m), while the VC gradually decreased to its lowest value at 1.5 and 2.0 kg (1.30–0.89 dS/m). This decrease indicates the ability of vermicompost to improve soil physical properties and increase cation exchange capacity (CEC), thereby reducing the concentration of salts available in the root zone and limiting the impact of salinity on plants. Higher vermicompost levels (1.5 and 2.0 kg) had a greater effect on reducing salinity and were clearly more effective than lower levels.

The data in Table 4 demonstrate that the use of vermicompost significantly improved the nutritional status of blackberry leaves. The control treatment exhibited the lowest values for nitrogen, phosphorus, and potassium, while these elements gradually increased with higher fertilization rates. A rate of 1.5 kg of vermicompost recorded the highest values for both phosphorus and potassium and resulted in a significant increase in nitrogen content, indicating a substantial enhancement in the availability and uptake of these elements by the roots. Although a rate of 2 kg of vermicompost achieved the highest nitrogen concentration, it did not produce additional increases in phosphorus or potassium.

These findings confirm the vital role of vermicompost in improving soil properties, particularly at the optimal rate of 1.5 kg per bush.

**Table 3.** Effect of Vermicompost addition on soil chemical properties (organic matter (OM%), pH, and soil salinity (EC)).

VC level	Organic matter %		Soil PH		EC (dsm-1)	
	2024	2025	2024	2025	2024	2025
Control	0.31 ± 0.01 d	0.25 ± 0.01 c	7.12 ± 0.19 a	7.01±0.19 a	2.98± 0.28 a	2.95 ± 0.28 a
VC at 0.5 kg	0.46 ± 0.09 c	0.44 ± 0.11 c	6.71 ± 0.72 a	6.60±0.72 a	2.60± 0.22 b	2.57± 0.22 b
VC at 1 kg	0.67 ± 0.03 b	0.63 ± 0.06 b	6.62 ± 0.33 a	6.51±0.33 a	1.95± 0.41 c	1.52± 0.41 c
VC at 1.5 kg	0.95 ± 0.07 a	0.94 ± 0.08 a	6.13 ± 0.18 a	6.02±0.18 a	1.30± 0.09 d	0.89± 0.09 d
VC at 2 kg	0.99 ± 0.03 a	1.00 ± 0.02 a	6.52 ± 0.24 a	6.41±0.24 a	1.38± 0.02 d	0.95± 0.02 d

Note: a-d means in the same column carrying different superscripts are significantly different at P<0.05. VC= Vermicompost.

**Table 4.** Effect of Vermicompost addition on soil chemical properties (nitrogen (N%), phosphorus (P%), and potassium (K%).

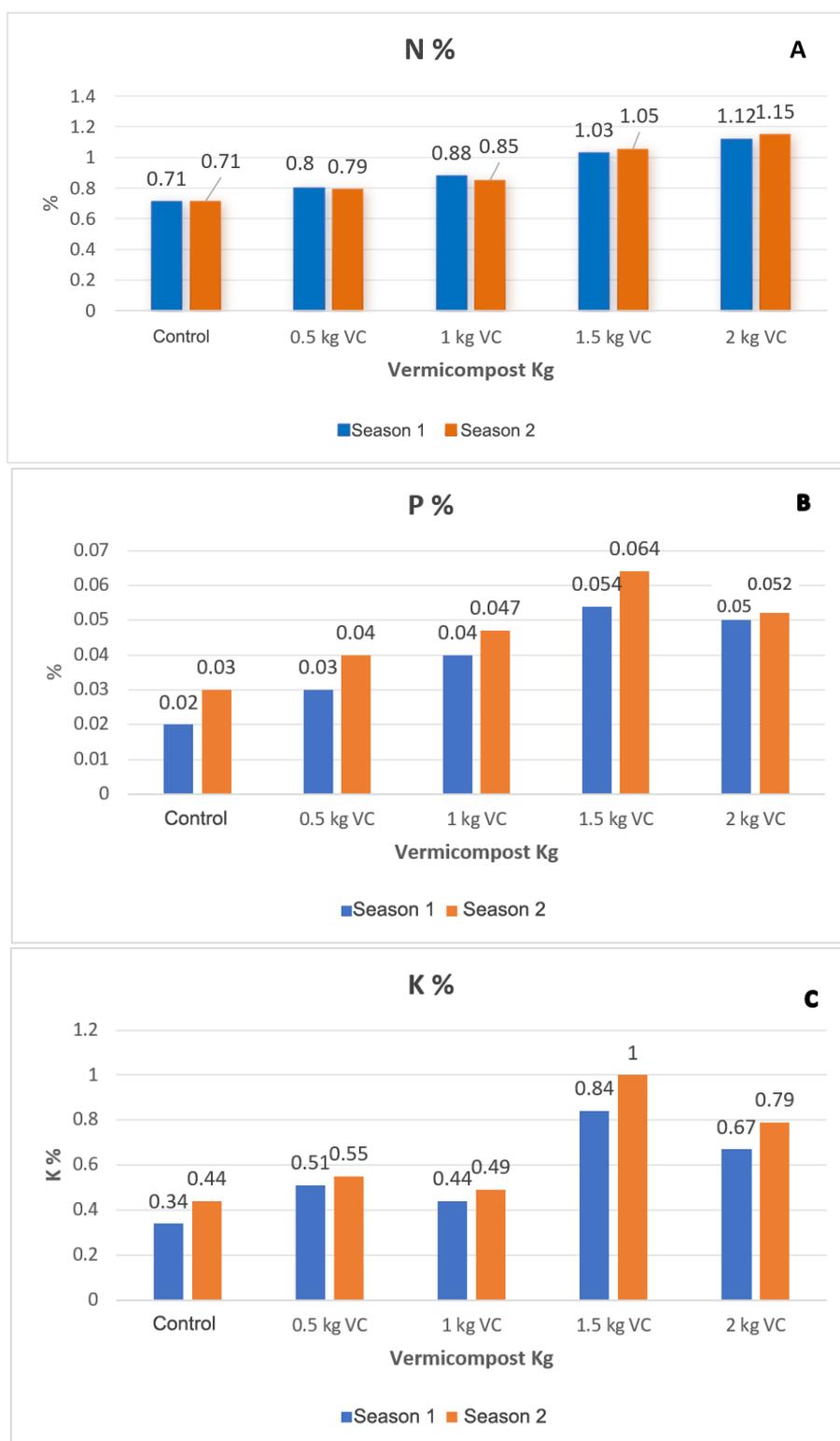
VC level	N %		P (ppm)		K (ppm)	
	2024	2025	2024	2025	2024	2025
Control	0.23 ± 0.01 c	0.24 ± 0.01 c	37.66 ± 0.52 c	40.33±1.52 c	88.67± 10.21 c	89.33 ± 5.33 d
VC at 0.5 kg	0.25 ± 0.01 c	0.27 ± 0.01 c	44.67± 5.51 c	70.67±7.51 b	102.33± 3.51 c	100.67± 2.08 d
VC at 1 kg	0.30 ± 0.02 c	0.31 ± 0.01 c	63.33±2.89 b	83.67±3.21 a	129.30± 19.9 c	140.20± 6.37 c
VC at 1.5 kg	0.49 ± 0.13 b	0.50 ± 0.12 b	80.00±5.00 a	94.00±4.58 a	432.1± 20.10 a	412.9 ± 22.30 a
VC at 2 kg	0.64 ± 0.06 a	0.65 ± 0.05 a	71.33±1.00 ab	88.00±1.00 a	325.2± 21.10 b	326.7± 23.20 b

Note: a-d means in the same column carrying different superscripts are significantly different at P<0.05. VC= Vermicompost.

#### 3.2. Leaf Nutrients (NPK) Content

Figure 1 illustrates the effect of vermicompost application on nitrogen, phosphorus, and potassium (NPK) concentrations in blackberry bush leaves. The figure shows that vermicompost application enhances leaf N, P, and K status, with a clear positive relationship between increasing vermicompost rates and nutrient content in the leaves. This trend indicates improved nutrient availability and uptake as vermicompost levels increase.

Notably, the application of vermicompost at 2 kg/bush resulted in the highest leaf nitrogen content, reaching 1.12% and 1.15%, compared to 0.71% in the control treatment in both seasons. However, the application of vermicompost at 1.5 kg/bush yielded the highest leaf phosphorus (0.054% and 0.064%) and potassium content (0.84% and 1%). Interestingly, at a vermicompost rate of 2 kg per bush, P and K levels declined. Additionally, leaf K content exhibited noticeable fluctuations in response to changes in the vermicompost application rate. The lowest NPK content was observed in the control (0 kg vermicompost).

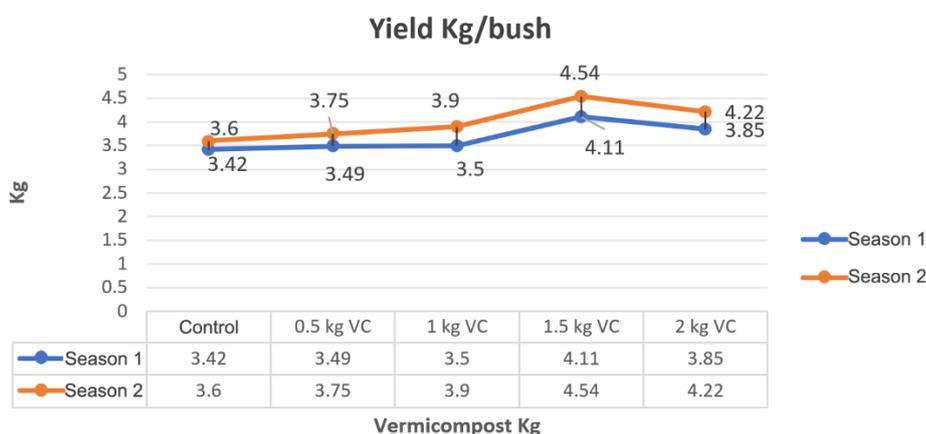


**Figure 1.** Effect of vermicompost addition on blackberry leaf NPK content: (A) nitrogen (N%), (B) phosphorus (P%), and (C) potassium (K%).

### 3.3. Yield (kg/Bush)

The results shown in Figure 2 indicate a significant response in blackberry yield with increasing vermicompost rates to 1.5 kg per bush. Both seasons showed a gradual increase in yield from 0.5 kg to 1.5 kg, achieving the highest yields (4.11 and 4.54 kg in the first and second seasons, respectively). This increase indicates that moderate vermicompost application rates enhance soil fertility and nutrient availability, which in turn positively influence vegetative growth and yield.

It is worth noting that a 2 kg application resulted in a slight decrease in yield, suggesting that excessive application may not provide additional benefits and could even cause nutritional imbalances. Overall, the data indicate that 1.5 kg per bush is the optimal rate for maximizing blackberry yield.



**Figure 2.** Effect of vermicompost addition on blackberry yield.

### 3.4. Fruit Physical Properties

Table 5 exhibits the physical characteristics of blackberry fruit as affected by varying levels of vermicompost. Overall, the application of vermicompost improved fruit weight, length, and width. Significant correlations were found between the level of compost and these parameters for both 2024 and 2025.

The highest fruit weight (19.02–20.84 g), width (2.36–2.40 cm), and length (3.43–4.20 cm) were obtained when 1.5 kg per bush of vermicompost was applied in both seasons. The weight of the fruit increased by 30–35%, the length of the fruit increased by 20–25%, and the width of the fruit increased by 30–34% compared to the control. As observed with the yield, the weight, length, and width of the fruit decreased when 2 kg/bush was used. The lowest fruit weight, length, and width were recorded in the treatment without vermicompost application.

**Table 5.** Effect of vermicompost addition on fruit weight, fruit length, and fruit width of blackberry.

VC level	Fruit weight (g)		Fruit length (cm)		Fruit width (cm)	
	2024	2025	2024	2025	2024	2025
Control	14.50 ± 0.18 d	15.24 ± 1.01 d	2.50 ± 0.10 c	3.36 ± 0.11 d	1.87 ± 0.57 d	2.06 ± 0.05 d
VC at 0.5 kg	15.22 ± 0.31 cd	16.44 ± 0.31 cd	2.80 ± 0.10 b	3.66 ± 0.05 c	2.03 ± 0.60 c	2.20 ± 0.00 c
VC at 1 kg	16.48 ± 0.14 bc	17.51 ± 0.14 bc	3.00 ± 0.10 b	3.80 ± 0.10 bc	2.13 ± 0.5 bc	2.30 ± 0.00 b
VC at 1.5 kg	19.02 ± 0.92 a	20.84 ± 0.77 a	3.43 ± 0.05 a	4.20 ± 0.11 a	2.36 ± 0.57 a	2.40 ± 0.05 a
VC at 2 kg	16.80 ± 0.29 b	18.59 ± 0.29 b	3.23 ± 0.06 a	3.96 ± 0.05 ab	2.27 ± 0.6 b	2.36 ± 0.00 ab

**Note:** a-d means in the same column carrying different superscripts are significantly different at  $P < 0.05$ . VC= Vermicompost.

### 3.5. Fruit Chemical Properties

The addition of vermicompost had a significant effect on the quality of blackberry fruits, as indicated by the levels of ascorbic acid (vitamin C), total anthocyanins, total phenolic compounds, total soluble solids, sugars, and acidity.

Table 6 shows a clear, gradual response in the fruit's chemical content with increasing vermicompost rates. The control treatment recorded the lowest levels of vitamin C (22.8 and 23.4 mg/100 mL), anthocyanins (77 and 80 mg/100 g fresh weight), and total phenols (145 and 150 mg/100 g). In particular, the treatment with 1.5 kg of vermicompost achieved the highest anthocyanin concentration (108 mg/100 g).

The phenolic content continued to increase with increasing vermicompost rates, reaching its highest value at 2.0 kg (167 mg/100 g), a 10–15% increase compared to the control treatment, thus confirming its role in promoting the accumulation of antioxidant compounds. Vitamin C showed a more moderate response but increased in all treatments, reaching its highest value at 2.0 kg (24.7 mg/100 ml), a 5–8% increase over the control treatment.

Overall, 1.5 kg was optimal for increasing anthocyanins, while 2.0 kg achieved the highest phenol and vitamin C content; the control treatment remained the lowest in all quality attributes.

The data in Table 7 clearly show that vermicompost had a positive effect on the quality characteristics of blackberries during the 2024 and 2025 seasons. A gradual improvement was observed in the form of an increase in total soluble solids (TSS) and total sugars, accompanied by a concurrent decrease in acidity. In both seasons, the control treatment recorded the lowest quality levels, achieving the lowest values for TSS (12–13 Brix) and total sugars (9–10%), along with the highest acidity (0.80–0.85%). In contrast, the treatment with 1.5 kg of vermicompost showed the best balance in flavor, achieving the highest sweetness levels (16–17 Brix; approximately 14% of total sugars) while reducing acidity to 0.63–0.68%.

These results indicate a clear advantage in the sugar-to-acid ratio compared to all other treatments, making this ratio the most suitable for improving blackberry fruit quality. Although 2.0 kg of vermicompost improved flavor compared to the control treatment, the reduced sweetness compared to the 1.5 kg treatment suggests a decrease in yield at higher doses. The results indicate that an application rate of 1.5 kg per plant is optimal, consistently producing the greatest improvements in fruit quality.

**Table 6.** Effect of vermicompost addition on ascorbic acid, total anthocyanin, and total phenolic of blackberry.

VC level	Ascorbic acid mg/100 ml		Anthocyanin		Total phenolic	
	2024	2025	2024	2025	2024	2025
Control	22.81 ± 0.01 c	23.37 ± 0.01 b	77.33±2.52 c	79.56±0.23 c	145.67 ± 2.3 c	149.66 ± 0.57 c
VC at 0.5 kg	24.95 ± 0.01 a	23.40 ± 0.01 b	84.66±1.52 bc	82.66±1.55 bc	147.66 ± 0.57 bc	147.33 ± 0.57 c
VC at 1 kg	23.96 ± 0.02 b	23.43 ± 0.02 b	88.33±1.52 b	86.66±1.52 b	147.86 ± 0.23 bc	149.06 ± 1 c
VC at 1.5 kg	23.90 ± 0.04 ab	23.50 ± 0.04 b	108.00±8.96 a	102.10±1.96 a	149.06 ± 1.00 b	158.7 ± 2.00 b
VC at 2 kg	23.84 ± 0.03 bc	24.70 ± 0.14 a	102.33±2.65 a	99.66±1.52 a	158.70 ± 2.00 a	166.70 ± 2.3 a

**Note:** a-c means in the same column carrying different superscripts are significantly different at P<0.05. VC= Vermicompost.

**Table 7.** Effect of vermicompost addition on total soluble solids, total sugar, and total acidity of blackberry.

VC level	Total soluble solids (Brix)		Total sugar (%)		Total acidity (g/100 g fw)	
	2024	2025	2024	2025	2024	2025
Control	12.30 ± 1.00 b	12.73 ± 0.55 c	8.90 ± 0.10 c	10 ± 0.10 d	0.85 ± 0.010 a	0.80 ± 0.02 a
VC at 0.5 kg	12.53 ± 0.70 b	14.33 ± 0.55 b	9.30 ± 0.30 c	11.56 ± 0.68 c	0.80 ± 0.02 ab	0.75 ± 0.02 ab
VC at 1 kg	14.76 ± 0.20 a	15.56 ± 0.20 a	11.40 ± 0.10 b	12.97 ± 0.2 b	0.78 ± 0.02 bc	0.72 ± 0.03 bc
VC at 1.5 kg	15.83 ± 0.15 a	16.63 ± 0.15 a	13.63 ± 0.15 a	13.97 ± 0.28 a	0.68 ± 0.02 d	0.63 ± 0.02 d
VC at 2 kg	13.00 ± 0.20 b	14.33 ± 0.57 b	12.63 ± 0.15 b	10.10 ± 0.10 b	0.72 ± 0.02 cd	0.67 ± 0.02 cd

**Note:** a-d means in the same column carrying different superscripts are significantly different at P<0.05. VC= Vermicompost.

#### 4. DISCUSSION

The findings of this study demonstrate that vermicompost can substantially improve soil quality by reducing soil salinity and pH and by increasing organic matter and nutrient availability. The 55% reduction in soil salinity and pH from 7.32 to 6.02 in our study has been shown in previous studies where the application of organic amendments improves soil structure and salt accumulation (Elmeknassi, Elghali, De Carvalho, Laamrani, & Benzaazoua, 2024). Vermicompost likely encourages microbial activity in the soil, which releases organic acids that lower pH and help maintain optimal nutrient solubility (Jack & Thies, 2006). The increase in soil content of nitrogen, phosphorus, and potassium in this experiment is due to the application of vermicompost for blackberry bushes, aligning with the findings of Jindo et al. (2016), who reported that using compost enhanced macro-nutrients such as NPK compared to conventional fertilizers. The ability of vermicompost to nearly triple nitrogen content suggests enhanced nitrogen mineralization and microbial breakdown of organic matter, which improves nutrient retention and plant uptake (Arancon et al., 2004). Das, Abhishek, Banik, and Swain (2022) found that the use of vermicompost clearly improved the biochemical properties of the soil, including enzyme activity, organic carbon levels, and nutrient availability. This finding is consistent with the results of this study, which indicate its role in enhancing soil fertility and crop productivity. Bithumoniwai, Sharma, Kumar, and Devi (2024) also reported that vermicompost reduces soil salinity and enhances soil fertility, thereby promoting plant growth and increasing yield. Similarly, Ohra, Patel, Singh, and Verma (2024) confirmed that vermicompost contributes to improving soil health, nutrient availability, and crop productivity.

The vermicompost significantly enhanced the NPK content in the leaves of blackberry bushes, with nitrogen content increasing at a rate of 2 kg/bush, while phosphorus and potassium reached their highest levels at 1.5 kg/bush. This increase indicates that vermicompost not only raises the availability of nutrients in the soil but also improves the plant's ability to absorb them. Mahmud et al. (2020) confirmed this trend, finding that vermicompost increases the concentrations of various nutrients, including N, P, K, Mg, Ca, S, Fe, Zn, B, and Al in both soil and plants. However, the decline of P and K at 2 kg/bush indicates nutrient imbalance or competition among root uptake pathways. Ndur et al. (2025) reported that excess compost applications may limit the availability of specific nutrients due to altered soil microbial dynamics.

Our findings showed that vermicompost significantly improved yield and fruit physical characteristics. The highest yield per bush and maximum fruit weight, length, and width were obtained at 1.5 kg per bush compared with the control. Similar findings have been reported in strawberries by Singh, Sharma, Kumar, Gupta, and Patil (2008) and Arancon et al. (2004). This increase in fruit yield and physical characteristics suggests that vermicompost stimulates vegetative growth, photosynthesis, and translocation of assimilates to fruits. In our results, vermicompost enhanced NPK availability, reduced soil salinity and pH, and, as a result, improved the growth and productivity of blackberries. Moreover, vermicompost contains humic acid, fulvic acid, hormones, and nutrients, which increase yield (Tejada & González, 2009; Tejada et al., 2008). Humic acid alone stimulates plant growth by activating cell respiration, photosynthesis, protein synthesis, water and nutrient uptake, and enzyme activities, consequently increasing yield (Chen, De Nobili, & Aviadi, 2004). A decline in fruit yield, weight, length, and width at 2 kg/bush suggests that excessive compost could disrupt soil nutrient availability or alter root-zone conditions, leading to reduced fruit development (Ho et al., 2022). Mousavi, Chalavi, Ghasemi, and Hadadinejad (2023) reported that the combined application of vermicompost and nitroxin significantly improved the growth and yield characteristics of blackberry plants.

The fruit quality was clearly enhanced by the application of vermicompost. The highest levels of anthocyanin, total soluble solids, and total sugars, along with the lowest total acidity, were observed at 1.5 kg per bush. However, the highest total phenols were found at 2 kg per bush, and the maximum ascorbic acid content was recorded at 0.5 kg per bush. Increases in anthocyanin, TSS, and total sugars, coupled with reduced total acidity, indicate that moderate

vermicompost application significantly improves fruit quality. Singh et al. (2008) reported that strawberries receiving vermicompost were firmer, higher in TSS, lower in acidity, and exhibited an attractive color. Anthocyanin pigment biosynthesis and fruit coloration require adequate nutrient availability, particularly nitrogen and phosphorus (Abud-Archila et al., 2018; Zheng et al., 2020). The increase in TSS and TS suggests that vermicompost enhances vegetative growth, photosynthesis, and translocation of photoassimilates to fruits. Wu et al. (2023) found that vermicompost enhanced vegetative growth, the content of NPK in the fruit, and the translocation of carbohydrates to tomato fruits. Meanwhile, the increase in total phenolic content at 2 kg/bush suggests that higher compost levels may enhance antioxidant compounds (Sałata et al., 2022). Remarkably, the highest ascorbic acid content was observed at a rate of 0.5 kg/bush, indicating that a significant increase in organic matter may alter vitamin C synthesis pathways in plants. A similar trend has been observed previously in organic carrot production (Kováčik, Wierzbowska, Smoleń, Polláková, & Jabbarov, 2022) as well as in tomatoes and cabbage (Calderon & Mortley, 2021).

Overall, these results emphasize the importance of carefully controlling vermicompost application rates to promote soil health, increase fruit yield, and improve biochemical properties. The results indicate that exceeding 1.5 kg per bush may cause nutrient imbalances and result in reduced productivity.

## 5. CONCLUSION

The results of this study clearly show that using vermicompost can significantly improve soil health, nutrient availability, and the overall performance of blackberry plants grown under organic greenhouse conditions. Applying vermicompost at 1.5 kg per bush was the most effective rate, resulting in improved soil quality, higher nutrient content in the leaves, increased fruit yield, and notable improvements in fruit size and quality. While higher rates, such as 2 kg per bush, continued to enhance certain parameters, such as phenolic content, they also caused a decline in yield and certain nutrients, likely due to imbalances in nutrient uptake. These results point to the critical role of using vermicompost at the optimal rate for achieving the best results in both productivity and fruit quality, without overloading the soil.

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