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Research Article

Effect of Organic Amendments on Micronutrients (Fe, Zn and Cu) Uptake by Tomato (*Lycopersicon Esculentum Miller*) Plant

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Abstract

This study explores the effectiveness of organic amendments animal manure, compost, and vermicompost in reducing the accumulation of trace heavy metals (Fe, Zn, and Cu) in tomatoes grown in contaminated soil collected from the Akaki River area. The experiment was conducted over two consecutive growing seasons (2019/2020 and 2020/2021), with organic materials applied at concentrations of 3%, 6%, and 9%. The results demonstrated that all three organic amendments significantly reduced heavy metal concentrations in both the soil and tomato fruits compared to the untreated control. Among the amendments, vermicompost proved to be the most effective in lowering the uptake of heavy metals, followed by compost and then animal manure. Specifically, the application of 9% vermicompost decreased iron concentrations in tomato fruits from 461.67 mg/kg to 196.82 mg/kg, zinc from 5.75 mg/kg to 3.30 mg/kg, and copper from 12.17 mg/kg to 4.27 mg/kg in the 2019 season. Similar trends were observed in the 2020 season, confirming the consistency of the treatment effects. These reductions brought metal levels closer to or within the permissible limits established by FAO/WHO guidelines for safe food consumption. The study highlights the potential of organic amendments particularly vermicompost as an effective and sustainable strategy for mitigating heavy metal contamination in agricultural soils. By enhancing soil quality and reducing metal bioavailability, these organic treatments contribute to improved crop safety and promote environmentally sound agricultural practices, especially in areas affected by industrial pollution and wastewater irrigation.

Keywords

Heavy Metals, Organic Amendments, Soil Remediation, Vermicompost, Tomato Plants

1. Introduction

In developing countries, unplanned industrial growth and improper disposal of waste contribute to soil and water contamination, including with heavy metals, which severely impact public health and the environment [1]. Heavy metals, like lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn), accumulate in soils, affecting plant growth and entering the food chain, thus posing health risks [2]. This contamination threatens agricultural productivity and food security, especially in rapidly urbanizing areas. Organic amendments, such as compost, manure, and agricultural residues, are commonly used to remediate contaminated soils, reducing metal bioavailability and improving soil properties [3]. These amend-

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ments can bind metals, making them less available to plants, and provide an environmentally friendly, low-cost method for soil remediation [4].

Soil pH, organic material composition, and microbial activity play significant roles in the efficiency of organic amendments in immobilizing heavy metals. Research shows that organic materials like cow manure and compost can effectively reduce metal concentrations in soils, thus preventing metals from entering the food chain [5]. The effectiveness of these materials can be quantified by calculating heavy metal removal efficiency, as demonstrated by Emenike et al [6]. In Ethiopia, studies show that crops grown in contaminated soils often exceed international food safety standards for heavy metals, highlighting the need for remediation [7].

This study focuses on assessing the efficiency of organic amendments, such as manure, compost, and vermicompost, in remediating heavy metal contamination in Akaki soil, Ethiopia. The objectives are to evaluate the effectiveness of organic amendments in reducing trace metals in soil, determine their impact on tomato plants, and measure metal levels before and after treatment. Findings will contribute to sustainable agricultural practices in contaminated regions and improve food safety and environmental health.

2. Materials and Methods

1. Study Area

This study was conducted using soil samples collected from the Akaki River catchment area, located at the western border of the main Ethiopian Rift Valley and the eastern part of Addis Ababa (8° 46′–9° 14′N, 38° 34′–39° 04′E). The area surrounding the Akaki River is characterized by intense small-scale horticultural irrigation farming, rapid population growth, abandoned development projects, industrialization, poor sanitation, and untreated waste disposal. These anthropogenic activities have resulted in severe deterioration of both surface and groundwater quality. According to Alemayehu [8], large quantities of untreated solid, liquid, and gaseous waste are generated and released into the environment, particularly from industrial effluents, sewage, sludge, runoff, and urban waste. The contaminated Akaki River is extensively used for irrigation of horticultural crops, including tomatoes, potatoes, lettuce, Swiss chard, and cabbage, by local farmers in the river's catchment area.

2. Soil Sample Collection and Preparation

A total of 45 composite soil samples were collected from the Akaki irrigation farms at a depth of 0–20 cm using an auger. The samples were transported to the Soil, Water, and Plant Analysis Laboratory at Debre Zeit Agricultural Research Center for subsequent laboratory analysis and pot experiments. Upon arrival, the samples were air-dried at room temperature for seven days, and large soil particles, debris, and other materials were removed. The dried samples were then divided into two portions: one for pot experiments and the other for laboratory analysis. A sub-sample for laboratory analysis was ground using a mortar and pestle and passed through a 2 mm sieve. The homogenized samples were stored in polyethylene bags until further analysis.

3. Pot Experiment

The pot experiment was conducted to evaluate the effectiveness of three organic materials animal manure, compost, and vermicompost—at three application rates (3%, 6%, and 9% on a dry weight basis), with an untreated control soil. The treatments were as follows:

1) Untreated soil (control)
2) Soil + 3% animal manure
3) Soil + 6% animal manure
4) Soil + 9% animal manure
5) Soil + 3% compost
6) Soil + 6% compost
7) Soil + 9% compost
8) Soil + 3% vermicompost
9) Soil + 6% vermicompost
10) Soil + 9% vermicompost

The organic materials were thoroughly mixed into the soil by hand, and each pot was filled with 4 kg of the amended soil. Each treatment, including the control, was replicated three times for accuracy.

The pots were then watered and stored in a greenhouse, allowing the soil to settle for a minimum of two weeks at room temperature before planting. Tomato seeds were disinfected by immersing them in a 3% (v/v) formaldehyde solution for 5 minutes to avoid fungal contamination. After washing the seeds with distilled water, they were sown into the prepared soil.

Tomato plants were regularly watered, and the pots were rotated randomly to ensure uniform plant growth. Once the plants reached maturity, they were harvested. The plants were cleaned under running water to remove any remaining soil and other materials. After cleaning, the plants were dried, milled, sieved, and stored in polyethylene bags for laboratory analysis.

Tomato Sample Digestion

A 0.5 g portion of the prepared tomato samples was digested by adding 10 mL of a concentrated nitric acid (HNO_3), hydrochloric acid (HCl), and hydrogen peroxide (H_2O_2) mixture (8:1:1, v/v/v) in a borosilicate digestion flask. The mixture was heated at 120 ℃ for 3 hours on a block digester. After digestion, the resulting clear and colorless solution was filtered into a 50 mL volumetric flask and diluted to the mark with distilled water. The digested samples were preserved for trace metal analysis. A blank solution was also prepared and digested following the same procedure [9, 10].

4. Soil and Organic Materials Sample Digestion

Soil samples collected before the pot experiment, after tomato harvesting, as well as the organic materials (vermicompost, compost, and animal manure), were digested for metal analysis. A 0.5 g portion of each sample was transferred into a digestion tube, and 5 mL of deionized water was added. The mixture was then treated with 30 mL of a concentrated acid mixture (HNO_3: HCl; 69%:37%, volume ratio 5:1). The samples were digested in a digestion hood at 200 ℃ for 1 hour and allowed to cool. Following cooling, 2 mL of H_2O_2 was added to the digestion mixture and the samples were further heated for an additional 30 minutes. After digestion, the samples were filtered into a 100 mL volumetric flask and diluted to the mark with distilled water [11]. A blank sample was also digested under similar conditions. The metal content in the digested samples was determined using atomic absorption spectroscopy (AAS) at the Holeta Agricultural Research Center Soil, Plant, and Water Analysis Laboratory.

5. Chemical Analysis of Soil and Organic Materials

The chemical properties of the Akaki soil samples before and after the pot experiment, as well as the organic materials used, were determined according to standard procedures. Soil and organic material pH were measured potentiometrically using a 1:2.5 soil-to-water ratio (pH-H_2O) [12]. Electrical conductivity (EC) was determined from the supernatant using a conductivity meter (Richards, 1969). Organic matter content was analyzed using the Walkley-Black wet oxidation method [13]. Total nitrogen was determined by the Kjeldahl method [14]. Phosphorus content in both soil and organic materials was quantified using the Olsen method [15]. Cation exchange capacity (CEC) was determined for both the soil and organic materials following the method described by Jackson [16].

6. Statistical Analyses

Statistical analyses were conducted using SAS version 9.2. Pearson's linear correlations were used to assess the relationships among various chemical properties and the available concentrations of Fe, Zn, and Cu in the soil. The significance of differences among treatment means was evaluated using the Least Significant Difference (LSD) test at a significance level of $p<0.05$ [17].

3. Results and Discussion

1. Impact of Organic Material Amendments on Soil Chemical Properties

Chemical properties of the Akaki soil were analyzed both before and after the pot experiment to evaluate the impact of organic material amendments. The initial chemical properties of the contaminated Akaki soil are presented below: pH (8.81 and 8.62), electrical conductivity (EC) (0.20 and 0.21 dS/m), total nitrogen (TN) (0.09 and 0.10%), organic matter (OM) (0.16 and 0.14%), phosphorus (P) (15 and 16 mg/kg), and cation exchange capacity (CEC) (38 and 37 cmol/kg) for the first and second experimental years, respectively. These values suggest that the Akaki soil is slightly alkaline, with low levels of organic matter and total nitrogen, but moderate phosphorus content and cation exchange capacity.

The chemical properties of the organic materials animal manure, compost, and vermicompostwere also analyzed for both experimental years and are summarized in Table 1.

Table 1. *Organic materials (animal animal manure, compost and vermicompost) used for pot experiment analyzed chemical properties.*

Year 2019						Year 2020				
Parameter	**%TN**	**%OM**	**P mg/kg**	**pH (1:5)**	**EC ds/m**	**%TN**	**%OM**	**P mg/kg**	**pH (1:2.5)**	**EC ds/m**
Vermicompost	0.70	11.03	85.95	7.22	2.05	0.81	12.01	70.89	7.08	2.01
Animal manure	1.04	26.25	74.10	7.56	3.6	1.07	25.45	71.12	7.34	3.45
Compost	0.56	9.38	91.10	7.02	3.15	0.61	10.01	95.34	7.12	3.33

The study assessed the effects of organic amendments (animal manure, compost, and vermicompost) on the chemical properties of trace metal-contaminated soil during the 2018/2019 and 2019/2020 growing seasons. Results indicated that organic amendments influenced soil pH, electrical conductivity (EC), total nitrogen (TN), phosphorus (P), organic matter (OM), and cation exchange capacity (CEC). Across both years, soil pH, EC, and CEC slightly decreased with the application of organic materials, particularly with vermicompost, which caused the most significant reduction in pH. By the second year, the impact on pH was less pronounced, with no significant differences except in the 3% animal manure treatment. Total nitrogen content increased with higher application rates, with vermicompost showing the most notable boost, supporting findings by [4] and Clemente et al. [3], which showed that organic amendments enhance nitrogen content in soils. Available phosphorus also rose significantly, especially at higher application rates, with vermicompost and compost proving the most effective, consistent with the work of Zhang et al. [18] and Abate & Hailu [19], who highlighted the role of organic materials in enhancing phosphorus availability. CEC decreased slightly at higher organic material rates, likely due to soil structural changes, a phenomenon also reported by Walker et al. [20] and Emenike et al. [6]. Overall, the study suggests that organic amendments, especially vermicompost, enhance soil fertility and help immobilize metals, though the long-term effects depend on the type and rate of application, aligning with previous research on soil remediation and metal immobilization [2, 7].

Table 2. *Soil chemical properties after pot experimentation of tomato.*

Year 2019							Year 2020					
Parameters	**PH**	**EC dS/m**	**%TN**	**P ppm**	**CEC**	**%OM**	**PH**	**EC dS/m**	**%TN**	**P ppm**	**CEC**	**%OM**
Untreated soil	8.74a	0.17ab	0.11e	19.62f	30.79ab	2.0e	7.81b	0.19a	0.10e	11.62f	31.34a	1.79h
Soil + 3%animal manure	8.71a	0.18a	0.15cd	25.87e	35.65a	2.18f	7.13d	0.16bc	0.12d	15.16e	27.78b	2.20f
Soil + 6% animal manure	8.60b	0.18a	0.20b	28.80cde	30.56ab	2.36ef	7.51c	0.14de	0.12d	17.75cd	24.64c	2.53de
Soil + 9% animal manure	8.67ab	0.16ab	0.25a	30.93c	29.07b	2.34ef	7.03d	0.12e	0.13d	20.85b	21.69d	2.76c
Soil + 3% compost	8.67ab	0.15ab	0.12e	30.01c	31.26ab	2.50e	8.07a	0.17b	0.15c	17.17cd	28.24b	1.93gh
Soil + 6%compost	8.65ab	0.18a	0.16c	26.47de	33.56ab	2.84d	7.56c	0.15cd	0.15c	20.54b	25.58c	2.41e
Soil +9%compost	8.60b	0.12b	0.21b	30.83c	31.36ab	3.36c	7.11d	0.12c	0.17bc	24.24a	21.23de	2.92b
Soil+3%vermicom post	8.45c	0.18a	0.14d	37.34b	27.29b	4.63b	8.15a	0.19a	0.17bc	16.39de	28.24b	2.00g
Soil +6% vermicompost	8.33d	0.17ab	0.20b	44.49a	33.47ab	4.65b	7.44c	0.16bc	0.19b	18.34e	25.83c	2.64cd
Soil +9% vermicompost	8.14e	0.12b	0.24a	47.89a	27.33b	5.23a	7.04d	0.12e	0.22a	21.43	20.25e	3.08a
CV	0.75	18.18	7.73	7.26	11.89	4.37	1.59	6.55	5.48	4.97	2.86	3.48
LSD (0.05)	0.11	0.08	0.02	4.01	6.35	0.24	0.2	0.02	0.02	1.56	1.25	0.15

Values were given as means of triplicate analysis. The mean in the same column having different superscript letters are significantly differ from each other at 5% confident interval.

2. Accumulation of trace heavy metals in soil samples before and after pot experiment

The Fe, Cu and Zn content of animal animal manure, compost, and vermicompost were analysed for both experimental years and are summarized in Table 1. The effect of animal animal manure, compost, and vermicompost applied at 3%, 6%, and 9% concentrations to heavy metal-contaminated Akaki River irrigated soil was studied in a pot experiment aimed at heavy metal remediation. The concentrations of Fe, Zn, and Cu were measured in the tomato-growing soils treated with organic materials after the pot trials. The results indicated that as the amount of organic material applied increased, the concentrations of these trace metals in the soil decreased. Among the organic materials tested, vermicompost caused the most significant reduction in trace heavy metal concentrations Table 4. Organic materials such as vermicompost, animal animal manure, and compost help immobilize metals by transforming them from their available forms into organic-metallic complexes, making them less available to plants [21].

Table 3. *Accumulation of metals in organic material before pot experiment.*

	Year 2019			Year 2020		
Parameter	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**	**Cu**
Vermicompost	4102.78	78.12	34.12	3175.45	64.59	45.57
Animal manure	4807.01	81.04	37.64	4521.17	60.49	42.64

	Year 2019			Year 2020		
Parameter	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**	**Cu**
Compost	4267.23	64.57	20.15	4520.12	59.12	48.32
Akaki soil	20041.02	219.02	298.49	19546.00	256.02	231.65

Table 4. Soil chemical properties after pot experiment of tomato.

	Year 2019			Year 2020		
Parameters	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**	**Cu**
Untreated soil	18466.70a	203.73a	242.45a	18786.70a	241.33a	214.17a
Soil + 3% animal manure	16066.70c	172.33b	181.34b	17010.00b	203.67b	175.32b
Soil + 6% animal manure	13033.30f	155.33d	163.91c	12893.30e	183.00c	151.10c
Soil + 9% animal manure	12116.70g	130.33f	121.01e	12196.70f	157.00e	110.22f
Soil + 3% compost	17333.30b	155.00d	161.09c	17100.00b	186..33c	140.27d
Soil + 6%compost	14913.30d	144.33e	145.63d	14833.30c	165.33de	128.54e
Soil +9%compost	12000.00g	113.00g	122.62e	11973.30f	144.67	100.62f
Soil+3%vermicompost	14200.0e	164.67c	142.13d	14360.00d	196.00c	138.12de
Soil +6% vermicompost	11000.00h	140.67e	105.30f	10883.30g	170.67d	87.57g
Soil +9% vermicompost	7800.00i	141.33e	99.33f	8933.30h	163.00de	76.40h
CV	2.56	2.64	3.20	1.76	2.80	4.68
LSD (0.05)	600.56	6.88	8.52	419.93	8.69	10.63

The results from the soil metal concentrations in the 2019 and 2020 experimental years in Table 4. show significant trends in the effects of organic material amendments (animal manure, compost, and vermicompost) on trace heavy metals (Fe, Zn, Cu) in the contaminated Akaki River soil. The observed reductions in trace heavy metal concentrations with the increasing application of organic materials indicate that organic amendments play a key role in the remediation of heavy metal-contaminated soils. This reduction is likely due to the immobilization of metals from their available, plant-uptake forms into less bioavailable organic-metallic complexes, a mechanism that is especially effective in vermicompost. Vermicompost contains not only high levels of organic matter but also beneficial microorganisms, which may enhance the transformation and stabilization of metals in the soil [22, 23].

The observed decreases in the concentrations of iron (Fe), zinc (Zn), and copper (Cu) in soils treated with organic amendments reflect the capacity of these materials to reduce the bioavailability of heavy metals. This, in turn, limits the uptake of these metals by plants, which is crucial for maintaining soil health and improving agricultural productivity. This is particularly important in regions where heavy metal contamination poses significant risks to both plant growth and food safety. Vermicompost was found to be the most effective organic amendment for reducing trace metal concentrations, followed by compost and animal animal manure. This suggests that the composition and form of the organic material significantly influence the effectiveness of metal remediation [22, 24].

These findings are consistent with broader research indicating that organic amendments, especially those rich in organic matter like vermicompost, can enhance soil structure, increase metal retention, and reduce the bioavailability of toxic metals. As a result, they are vital tools for sustainable agriculture and soil remediation efforts, offering an environmentally friendly approach to mitigating soil contamination and improving long-term soil fertility [25, 22, 24].

Iron (Fe)

In both years, the highest concentration of iron was found in the untreated contaminated soil (18466.7 mg/kg in 2019 and 18786.7 mg/kg in 2020). Organic material amendments significantly reduced the iron content in the soil, with the greatest reduction observed in the 9% vermicompost treatment (7800 mg/kg in 2019 and 8933.3 mg/kg in 2020). The reduction in iron concentration is likely due to the ability of organic materials, especially vermicompost, to bind with iron, transforming it into less bioavailable forms, thereby reducing its concentration in the soil. The decrease in Fe with increasing organic material application indicates the immobilization of metals through organic-metallic complex formation, which makes them less accessible for plant uptake [21].

Zinc (Zn)

Zinc concentrations followed a similar trend, with the untreated contaminated soil having the highest concentrations (203.73 mg/kg in 2019 and 241.33 mg/kg in 2020). The application of organic amendments significantly lowered the zinc levels. The 9% vermicompost treatment led to the lowest zinc concentrations (141.33 mg/kg in 2019 and 163 mg/kg in 2020), demonstrating that vermicompost has a strong capacity to reduce available zinc in the soil. Similar to iron, zinc is immobilized by the organic material amendments, which bind it in forms that are unavailable for plant uptake. Vermicompost, in particular, appears to be more effective in reducing zinc concentrations compared to animal animal manure and compost [26].

Copper (Cu)

Copper concentrations also showed a decreasing trend with increasing organic material application. The untreated soil had the highest copper levels (242.45 mg/kg in 2019 and 214.17 mg/kg in 2020). As with iron and zinc, the application of organic materials decreased copper levels in the soil, with the 9% vermicompost treatment resulting in the lowest copper concentrations (99.33 mg/kg in 2019 and 76.4 mg/kg in 2020). The ability of organic amendments to reduce copper levels is consistent with their role in forming stable organic-metallic complexes that limit copper availability in the soil. This suggests that vermicompost, with its higher organic matter content, is particularly effective in reducing soil copper concentrations [25].

3. Heavy metal removal efficiency

Table 5. *Trace metals removal efficiency of animal manure, compost and vermicompost.*

	Year 2019			Year 2020		
Trace elements	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**	**Cu**
Contaminated soil+3% animal manure	0.13	0.15	0.25	0.09	0.16	0.18
Contaminated soil +6% animal manure	0.29	0.24	0.32	0.31	0.24	0.29
Contaminated soil+9% animal manure	0.34	0.36	0.50	0.35	0.35	0.49
Contaminated soil+ 3% compost	0.06	0.24	0.34	0.09	0.23	0.35
Contaminated soil +6% compost	0.19	0.29	0.40	0.21	0.31	0.40
Contaminated soil + 9% compost	0.35	0.45	0.49	0.36	0.40	0.53
Contaminated soil +3% vermicompost	0.23	0.19	0.41	0.24	0.19	0.36
Contaminated soil+ 6% vermicompost	0.40	0.31	0.57	0.42	0.29	0.59
Contaminated soil+ 9% vermicompost	0.58	0.31	0.59	0.52	0.32	0.64

The heavy metal removal efficiencies for different organic amendments (animal manure, compost, and vermicompost) in contaminated soil were assessed over two years. The results show that higher application rates (6% and 9%) of all organic materials led to higher removal efficiencies for trace metals (Fe, Zn, and Cu). Vermicompost consistently demonstrated the highest removal efficiency, particularly at the 9% application rate, where it achieved the greatest reduction in metal concentrations. Compost also showed a significant effect, especially at the 9% rate, while cattle animal manure was less effective overall, with lower removal efficiencies for all metals.

These findings indicate that vermicompost is the most effective organic amendment for heavy metal remediation, followed by compost and animal manure. he observed trend of increasing heavy metal removal efficiencies with higher application rates of organic materials, particularly vermicompost, aligns with recent studies highlighting the effectiveness of organic amendments in mitigating soil contamination by trace metals. Several recent studies have demonstrated that organic materials such as compost, animal manure, and vermicompost can significantly reduce the bioavailability of heavy metals in contaminated soils through mechanisms like adsorption, complexation, and the enhancement of soil microbial activity [27, 28]. Among these, vermicompost has been noted for its superior metal retention capacity, which can be attributed to its high organic matter content and the presence of beneficial microorganisms that promote the transformation of metals into less bioavailable forms [26, 29].

Additionally, studies have shown that compost and animal manure also contribute to reducing heavy metal concentrations, although to a lesser extent compared to vermicompost. This is consistent with findings by Zhang et al. [30], who noted that compost can improve soil structure and reduce metal mobility, while animal manure is effective in enhancing the soil's cation exchange capacity (CEC), thus contributing to metal immobilization.

The effectiveness of organic amendments in heavy metal remediation reflects their potential role in sustainable agriculture, as they not only improve soil health but also reduce the risks associated with metal contamination in agricultural systems [25, 27].

4. Accumulation of heavy metals in tomato grown in contaminated Akaki soil treated with organic materials

The results presented in Table 6 indicate the accumulation of heavy metals (Fe, Zn, and Cu) in tomatoes grown in contaminated Akaki soil and treated with various organic materials (animal manure, compost, and vermicompost). The data from both years (2019 and 2020) show that the application of organic amendments significantly reduced the concentrations of these trace metals in tomato fruits compared to the control (untreated soil). This suggests that organic materials have a positive impact on the remediation of heavy metal contamination in soils and reduce the uptake of these metals by crops.

Overall, the results from this study demonstrate that organic amendments, especially vermicompost, can significantly reduce the concentrations of Fe, Zn, and Cu in tomatoes grown in contaminated Akaki soil. Vermicompost was found to be the most effective in reducing these metal concentrations, followed by compost and animal manure. These findings align with previous research, which highlights the role of organic amendments in improving soil health, enhancing metal retention, and reducing the bioavailability of toxic metals, thus preventing their uptake by crops [21, 26].

Table 6. *Accumulation of heavy metals in tomato grown in contaminated Akaki soil treated with organic materials.*

	Year 2019			**Year 2020**		
Parameters	**Fe**	**Zn**	**Cu**	**Fe**	**Zn**	**Cu**
Untreated soil	461.67a	5.75a	12.17a	407.67a	8.04a	13.08a
Soil + 3% animal manure	402.67c	4.53b	9.07b	350.17c	5.92b	9.64b
Soil + 6% animal manure	325.83f	4.58b	8.20c	286.00e	5.60c	8.87c
Soil + 9% animal manure	315.42fg	3.43cd	5.78e	260.00f	4.48e	6.43e
Soil + 3% compost	431.67b	4.64b	7.82c	375.33b	5.82b	8.49c
Soil + 6%compost	372.83d	3.80c	7.31d	318.50d	4.89d	7.88d
Soil +9%compost	300.00g	2.97e	5.20f	245.17fg	3.90f	5.77f
Soil+3%vermicompost	355.00e	4.33b	7.11d	325.67d	5.86b	7.68d
Soil +6% vermicompost	275.00h	3.70c	5.27f	234.00g	4.71d	5.84f
Soil +9% vermicompost	196.82i	3.30de	4.27g	152.67h	4.32e	4.84g
CV	2.87	5.66	3.46	3.10	2.27	3.00
LSD (0.05)	16.91	0.40	0.43	15.72	0.21	0.40

1) Iron (Fe) in Tomato

Fe is an essential nutrient for both humans and plants, playing a crucial role in various biological processes such as electron transport and oxygen regulation. However, excessive iron can be toxic, leading to health issues such as oxidative stress and tissue damage [31]. In the control soil, the concentration of iron in tomatoes was 461.67 mg/kg in 2019 and 407.67 mg/kg in 2020, which may exceed the recommended limits for safe consumption, according to FAO/WHO guidelines. However, the application of organic materials, including animal manure, compost, and vermicompost, significantly reduced iron concentrations in the tomato fruits. The concentration of iron in tomatoes decreased with increasing animal manure application. At 9% animal manure, the concentration dropped to 315.42 mg/kg in 2019 and 260.00 mg/kg in 2020, suggesting that animal manure helped immobilize iron in the soil, thereby reducing its bioavailability and preventing its uptake by tomato plants. Similarly, compost also reduced iron concentrations in tomatoes. At 9% compost, the concentration decreased to 300.00 mg/kg in 2019 and 245.17 mg/kg in 2020. Vermicompost was the most effective, reducing iron levels to 196.82 mg/kg in 2019 and 152.67 mg/kg in 2020 at 9% application. Vermicompost likely proved most effective due to its high organic matter content and the presence of beneficial microorganisms that facilitate the immobilization of heavy metals [21, 26].

2) Zinc (Zn) in Tomato

Zn is another essential micronutrient involved in numerous physiological functions, including immune system support, enzyme activity, and cell signaling [32]. However, excessive zinc intake can result in toxicity, leading to health issues such as kidney and liver damage [33]. The initial concentrations of zinc in tomatoes from the control soil were 5.75 mg/kg in 2019 and 8.04 mg/kg in 2020, which exceeded the recommended safe limits for consumption. The application of organic materials significantly reduced zinc levels in tomatoes. At 9% animal manure, the zinc concentration decreased to 3.43 mg/kg in 2019 and 4.48 mg/kg in 2020, reflecting the ability of animal manure to lower zinc bioavailability in the soil. Compost also effectively reduced zinc concentrations. At 9% compost, zinc levels decreased to 2.97 mg/kg in 2019 and 3.90 mg/kg in 2020, showing that compost was effective, though less so than vermicompost. Vermicompost consistently reduced zinc concentrations in tomatoes, with the lowest levels observed at 9% vermicompost (3.30 mg/kg in 2019 and 4.32 mg/kg in 2020). This highlights the superior efficacy of vermicompost in immobilizing zinc in the soil, making it less available for plant uptake [26, 21, 34].

3) Copper (Cu) in Tomato

Copper (Cu) is vital for many biological functions in both plants and animals. However, excessive copper in food crops poses a significant health risk. The copper concentration in tomatoes grown in control soil was 12.17 mg/kg in 2019 and 13.08 mg/kg in 2020, which exceeds safe limits for consumption. The application of organic materials led to a reduction in copper concentrations in tomatoes. At 9% animal manure, copper concentrations dropped to 5.78 mg/kg in 2019 and 6.43 mg/kg in 2020, showing that animal manure effectively reduced copper uptake. Compost also led to a reduction in copper concentrations in tomatoes, with levels dropping to 5.20 mg/kg in 2019 and 5.77 mg/kg in 2020 at 9% compost. Vermicompost showed the most significant reduction in copper concentrations, with levels dropping to 4.27 mg/kg in 2019 and 4.84 mg/kg in 2020 at 9%. This supports the hypothesis that vermicompost, due to its high organic matter and microbial content, is particularly effective in mitigating copper contamination in the soil [34, 21, 26].

4. Conclusion

In conclusion, the application of organic amendments, particularly vermicompost, proved to be an effective strategy for reducing the accumulation of trace heavy metals (Fe, Zn, Cu) in tomatoes grown in heavy metal-contaminated soil from the Akaki River area. The results demonstrated that all organic materials—animal manure, compost, and vermicompost significantly reduced the concentrations of these metals in both the contaminated soil and the tomato plants, with vermicompost showing the greatest efficiency. The reduction in metal concentrations was achieved by immobilizing the metals in the soil, thus limiting their bioavailability and uptake by plants. The concentrations of Fe, Zn, and Cu in tomatoes grown with 9% vermicompost application were reduced to levels much closer to the recommended safe limits set by the FAO and WHO, thereby enhancing food safety. This study highlights the critical role of organic amendments in mitigating the risks of heavy metal contamination in agricultural soils, contributing to safer and more sustainable farming practices. The findings support the use of vermicompost and other organic materials as viable solutions for remediating contaminated soils and improving the safety of food crops for human consumption.

Abbreviations

DZARC	Debre Zeit Agricultural Research Center
EIAR	Ethiopian Institute of Agricultural Research Center
HARC	Holeta Agricultural Research Center
LSD	Least Significant Difference

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Conflicts of Interest

The authors declare no conflicts of interest.

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