Asian J Agric & Biol. xxxx(x).
DOI: 10.35495/ajab.2024.073

AJAB

Original Article

Evaluation of copper stress on maize and its remediation by application of compost and vermicompost

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Received:
April 20, 2024

Accepted:
June 25, 2024

Published Online:
September 3, 2024

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Abstract

Recently, conversion of organic waste into useful products (organic fertilizers) is an emergent option for soil health restoration and sustainable ecosystem. In developing countries, excessive use of untreated wastewater and agrochemicals caused serious impact on food security and soil health. In this regard, the incorporation of recycled organic byproducts like compost (CP) and vermicompost (VC) have significant contribution in soil restoration by providing carbon and nutrients in polluted soil. A pot study was carried out to investigate the influence of CP and VC on maize growth and yield under copper stress. Maize was sown as a test plant in pots with 7 different treatments along with three repeats, such as T1: Control (CK); T2: 1% compost (CP 1%); T3: 2% Compost (CP 2%); T4: 5% Compost (CP 5%); T5: 1% vermicompost (VC 1%); T6: 2% Vermicompost (VC 2%) and T7: 5% Vermicompost (VC 5%). The current findings exhibited that incorporation of CP and VC prominently enhanced maize growth, biomass, plant height, chlorophyll contents, NPK status in soil and plant tissues. In addition, the results revealed that soil pH was prominently reduced by 0.54 and 0.59 units when CP and VC were mixed in Cu polluted soil. The addition of CP and VC at 5% rate presented the profound reduction in soil Cu by 24.41% and 43.02% respectively over control. Whereas Cu uptake by maize tissues was also reduced by 45% and 47% when CP and VC were incorporated at 5% rate. Overall, among all the treatments and application rates VC at 5% exhibited prominent results over control as well as other soil additives.

Keywords: Copper, Compost, Vermicompost, Immobilization, Maize

How to cite this:

Jabar A, Athar M, Mehmood K, Ishfaq T, Bashir S, Iqbal Z, Hussain M, Zahra A, Sherani J, Khan S, El- Sheikh MA and Ahmed T. Evaluation of copper stress on maize and its remediation by application of compost and vermicompost. Asian J. Agric. Biol. xxxx(x): 2024073. DOI: https://doi.org/10.35495/ajab.2024.073

Introduction

In current era, overpopulation needs the expansion of industrial activities and agricultural production to meet the food demand which could led to increase the significant introduction of contaminants in widespread areas of this planet (Shivaraj et al., 2020). Owing to the continuous shifting of environmental dynamics, the exposure of heavy metal (HM) within the plant-soil environment has led to an extensive reduction in the growth and development of major crop plants globally (Sharma et al., 2020). Moreover, pollution stemming from HMs and inadequate fertilization practices presents a significant risk to the sustainability of the environment and the production of healthy food. In addition, the accumulation of heavy metals in ecosystem and their connection with human health has become an emerging global concern for food security.

According to the World Health Organization (WHO) report presented in 2020, confirmed that 0.42 million peoples have been died because of 200 various diseases caused through the introduction of heavy metals in the soils (WHO, 2020). However, most of the metal elements are considered as micronutrients at minor concentration levels, in which copper (Cu) plays a key role as the major component of metalloproteins and other macromolecules that can serve for metabolic processes (Nazir et al., 2019). While sometimes presence of Cu in excessive amount imposes serious disorder in soil health and plants growth which ultimately damage food web. Thus, restoration of polluted soil health is a very important target for the scientific experts (Palansooriya et al., 2019).

In this regard, several approaches have recently been adopted to curtail the hazards linked with PTEs and to promote crop development, including phytostabilization and chemical immobilization (Wang et al., 2018). Chemical immobilization of heavy metals through soil passivators is an emerging solution worldwide due to their easy availability and low cost. Soil passivators includes organic materials (biochar, crop straws, compost, vermicompost and manures) and inorganic materials (industrial byproducts, clay minerals and chemical fertilizers) could be used for polluted soil restoration (Bashir et al., 2019, 2020, 2021).

Vermicompost (VC) is described as an important environmentally friendly soil conditioner induced after the decomposition of organic residues through non-thermophilic microbes and earth worms' activity (Ding et al., 2021). It has potential to enrich soil with essential macro and micronutrients after degradation of residues (Nurhidayati et al., 2018), and can improve soil physico-chemical and biological characteristics (Wu et al., 2019). It has the capacity to retain moisture in soils, improve porosity and nutrients status in degraded soils. Additionally, its incorporation can remediate Cd polluted soil and other PTEs associated with human health. The recent study explained by Alam et al. (2020) confirmed the usefulness of vermicompost to decrease PTEs (Cd, Cr, Pb, and Mn) accumulation in radish tissues and thereby improve food quality and minimize the risk that are connected to public health. Several previous studies confirmed the utilization of vermicompost as soil passivator for the immobilization of trace metals ions, which ultimately reduce their toxicity and solubility in soil (Khan et al., 2019; Shen et al., 2022).

Compost is also considered an organic soil fertilizer and conditioner that can have potential to passivate soil health and remove toxic elements from soils. Its addition can decrease the soluble fraction of PTEs in soil because it has greater surface area, cation exchange capacity (CEC) and has the strong affinity to metallic substance for complexation (Chen et al., 2020). Several studies confirmed the addition of compost induced from various wastes have potential to stabilize metals mobility in soil, improves plant growth and alters soil pH as well as enhance soil nutrients and organic matter status (Jones et al., 2016; Bashir et al., 2021).

Based on the above information, we hypothesized that addition of compost and vermicompost at different application rates might have great contribution to immobilize Cu in calcareous nature Cu contaminated soil Thus, a more detailed understanding is required to govern the Cu cycle in alkaline soil after applying soil additives which might be useful for choosing a more suitable product and its application rate for maize growth and soil health restoration.

This research is expected to evaluate: (a) how compost and vermicompost and their different levels can contribute to reduce Cu availability in soil (b) how the existence of high Cu content in soil influences maize growth and nutrients availability. These features are crucial to raise the efficiency of soil conditioners for the provision of useful information to choose the most suitable soil amendment.

Material and Methods

Soil and amendment collection

Soil was collected from the upper horizon of the farmland of Dera Ghazi Khan, Pakistan in 2022 where wastewater and fungicides were applied for crop cultivation. The obtained soil was then transferred to the University greenhouse for air drying. Dried samples were ground and passed through a 2-mm sieve for pot study. A portion of the prepared soil sample was further ground and passed through 25-mm sieve for basic physicochemical analysis of the studied soil are as follows: pH (7.80), organic matter (0.57%), available phosphorus (8.19 $mg \cdot kg^{-1}$), available potassium (85 $mg \cdot kg^{-1}$), electrical conductivity (1.39 $mS \cdot cm^{-1}$). Compost and vermicompost were purchased from Barrani agriculture research institute (BARI), Chakwal, Pakistan which was induced after the decomposition of vegetable waste, manure, and fruits peeling waste materials. The chemical properties of compost and vermicompost are as follows: pH (7.35 and 7.29); N (1.19 and 1.35 %); P (0.95 and 1.12 %); K (1.26 and 1.52%) and carbon contents (27 and 32%) respectively.

Pot experiment

A pot study was performed under the natural environment in the Department of Botany, Ghazi University, Dera Ghazi Khan. There were seven treatments with three replicates applied for maize growth under Cu polluted soil. Soil was amended with the following treatments: T1: (CK); T2: CP 1%; T3: CP 2%; T4: CP 5%; T5: 1VC 1%; T6: VC 2% and T7: VC 5%. All the dose levels of studied soil additives were mixed homogeneously in all experimental units and irrigated with distilled water to maintain the moisture level at 60% for two weeks. After two weeks, when soil reached its field capacity, 5 maize seeds were sown in each pot. Each pot was fertigate with NPK (1.49g:0.375g:0.679) using urea, SOP and DAP for N, K and P, respectively.

Soil chemical analysis

After maize harvesting, soil samples were taken from each experimental unit and analyzed for soil pH and EC as briefly described by (Bashir et al., 2018). The Walkley-Black method was used for the estimation of SOM. Cu contents were estimated using $CaCl_2$ extractable method as described by Bashir et al. (2020), analyzed by using atomic absorption spectrophotometer (AA-240FS Varian, USA). Soil available-P was calculated by calorimetric method using spectrophotometer UV-1500 and K was determined as described in our previous studies (Lu, 2000).

Plant analysis

The chlorophyll contents in maize leaves were observed using SPAD meter from each experimental pot. Afterward, the dried plant tissues were finely ground and digested using a combined mixture of HNO_3 and $HClO_4$ with (9:4 v/v) ratio to measure the Cu contents, as detailed in the previous study (Bashir et al., 2022). The agronomic parameters were also estimated using manual methods. Bioaccumulation and translocation factor was calculated as described in the previous study Bashir et al. (2019) using the following formula: BCF= Cu in root/Cu in soil.

Statistical analysis

The Statistical analysis of the current study data was proceeded and performed the analysis using the software (Statistics 8.1). One-way ANOVA was observed for analysis and the Duncan's multiple range with ($p = 0.05$) was adopted.

Results

Effect of compost and vermicompost on soil pH

In a current study, it was observed that the incorporation of compost (CP) and vermicompost (VC) as soil amendments showed the significant alteration in copper degraded farmland (Figure 1). The prominent ($p<0.05$) reduction in soil pH was detected by 0.54 and 0.59 when VC and VC along with BC and Fe were applied in combination relative to control.

Effect of compost and vermicompost on soil organic matter

In a current study, it was observed that the incorporation of compost (CP) and vermicompost (VC) as soil amendments showed a significant alteration in organic matter (OM) contents in copper degraded farmland (Figure 2). The substantial increment in soil organic matter was estimated at 13.63%, 30% and 40.6% after the mixing of studied soil with CP at 2%, 3% and 5% respectively over control. In a similar manner, VC was applied at 2%, 3% and 5% showed the profound increment in soil OM by 34.5%, 39.7% and 44% respectively relative to control.

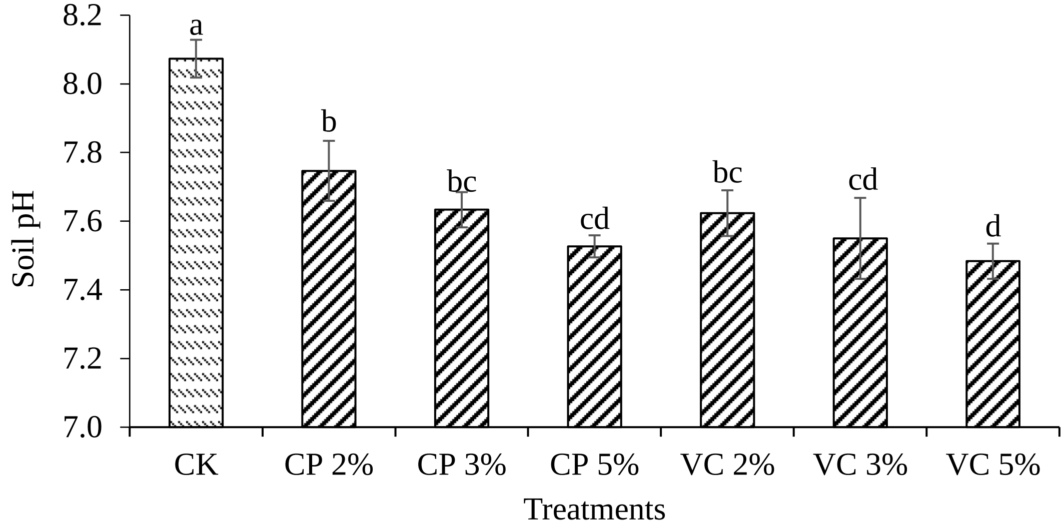

Figure-1. Effect of compost and vermicompost on soil pH. Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC). Error bars are the SD of the means (n = 3) and different letters indicated that values are significantly different at p < 0.05.

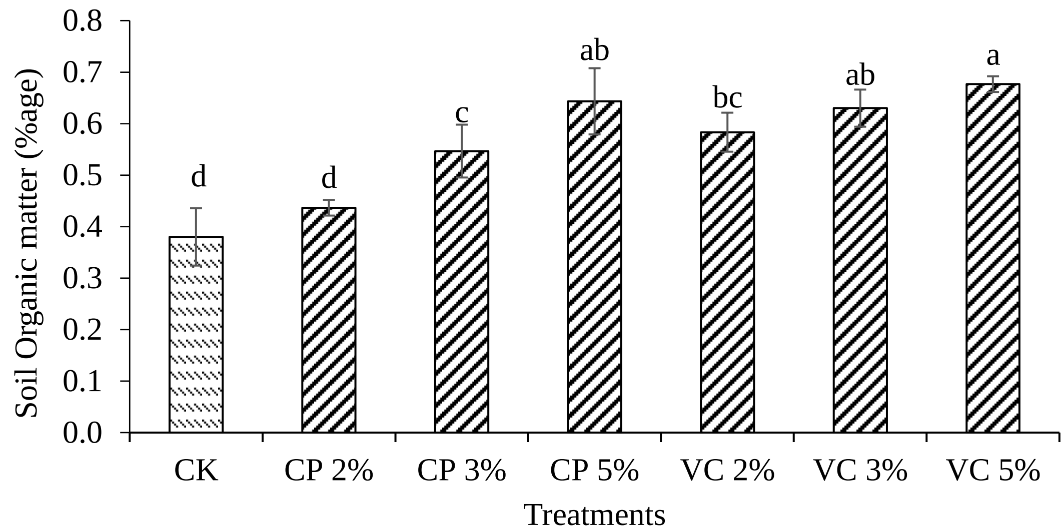

Figure-2. Effect of compost and vermicompost on soil organic matter (SOM). Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC). Error bars are the SD of the means (n = 3) and different letters indicated that values are significantly different at p < 0.05.

Effect of compost and vermicompost on the soil copper

In a current study, it was observed that the incorporation of compost and vermicompost as soil amendments showed the significant alteration in copper degraded farmland (Figure 3). The substantial (p<0.05) decrease in soil copper was noticed by 11.6, 17.44 and 24.41% when compost was mixed into the soil at 2%, 3% and 5% respectively. Similarly, the momentous decrease in soil copper was examined by 22.9, 29.06 and 43.02% when vermicompost was mixed into the soil at 2%, 3% and 5% respectively.

Effect of compost and vermicompost on the copper contents in maize shoot

In a current study, it was observed that the incorporation of CP and VC as soil amendments showed the significant alteration in copper degraded farmland (Figure 4). The substantial (p<0.05) decrease in soil copper content of maize shoot was noticed by 45% and in root by 40.75% when CP was mixed into the soil at 5% respectively. Similarly, the momentous decrease in soil copper content in maize shoot was studied by 47.03% and in root by 61.6% when VC was mixed into the soil at 2%, 3% and 5% respectively.

The substantial (p<0.05) decrease in bioaccumulation factor was noticed by 0.87% and 0.75% unit when VC and CP were introduced at 5% respectively against control. While the reduction in TF was noticed by 35% and 41% when CP and VC were applied at 5% rate over control (Figure 5).

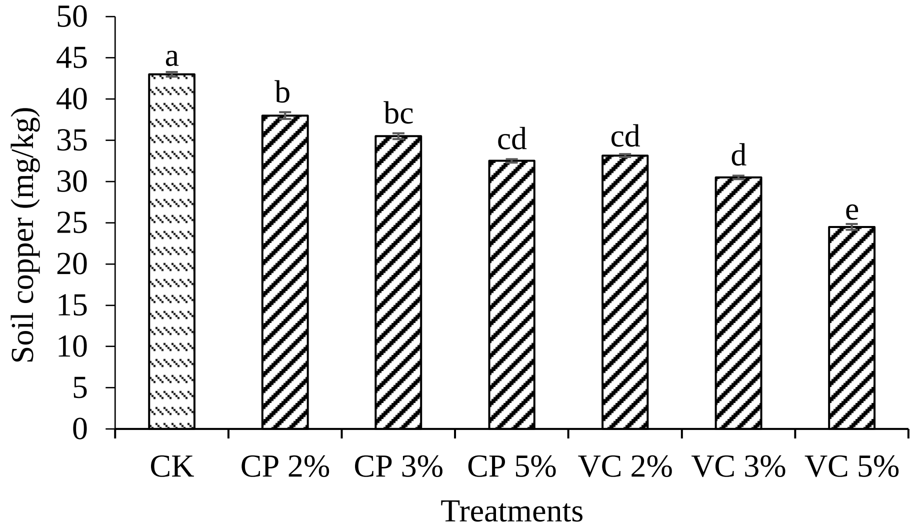

Figure-3. Effect of compost and vermicompost on the soil copper. Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC). Error bars are the SD of the means (n = 3) and different letters indicated that values are significantly different at p < 0.05.

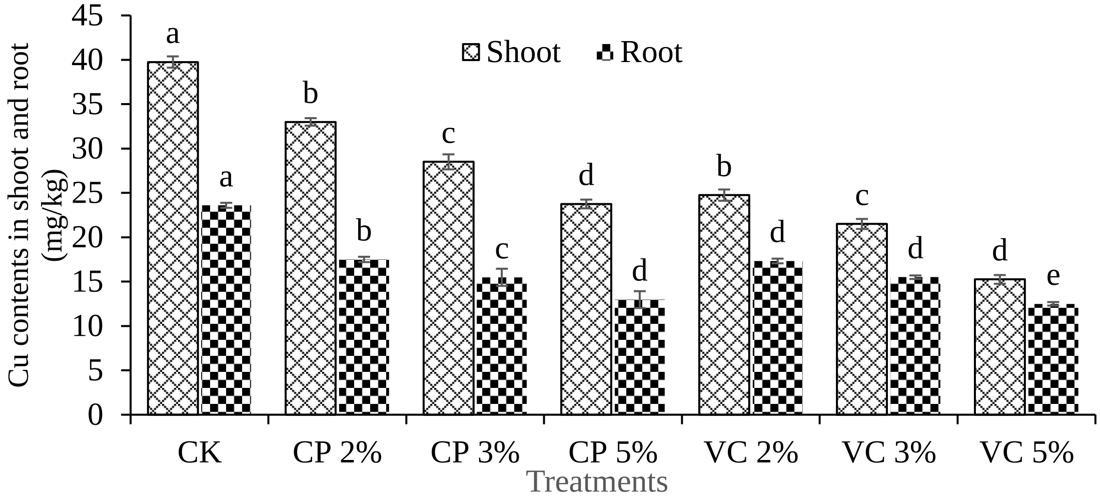

Figure-4. Effect of compost and vermicompost on the copper contents in maize shoot. Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC). Error bars are the SD of the means (n = 3) and different letters indicated that values are significantly different at p < 0.05.

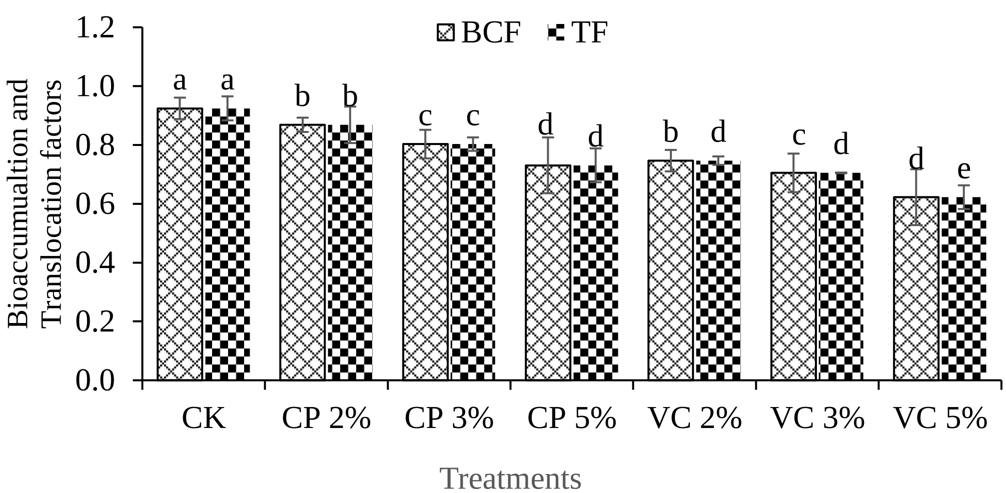

Figure-5. Effect of compost and vermicompost on bioaccumulation and translocation factor in maize shoot. Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC). Error bars are the SD of the means (n = 3) and different letters indicated that values are significantly different at p < 0.05.

Effect of compost and vermicompost on plant height

In current study, it was observed that the incorporation of CP and VC exhibited the significant alteration in copper degraded farmland (Tab.1). The profound (p<0.05) increment in plant height was noticed by 19.76% and 21.34% when CP and VC were mixed into the soil at 5% respectively. Similarly, the highest improvement in plant dry shoot biomass was observed by 17.4 g and 16.5 g at 5% rate of VC and CP. The chlorophyll contents were also enhanced by 23.9 for CP and 24.8 for VC. A similar trend was recorded in all growth parameters (Table 1).

Effect of compost and vermicompost on soil and plant nutrients uptake and availability

According to the findings of present study exhibited that addition of organic soil additives effectively boosts the nutrients mobility in soil and improved their status in plant shoot. All the concern parameters values are presented in Table 2.

Table-1. Effect of compost and vermicompost on plant growth characters. The abbreviations are as follows: Plant height (PH); fresh shoot weight (FSW); Dry shoot weight (DSW); Fresh root weight (FRW); Chlorophyll (Chl); Leaf Area (LF); Relative water content (RWC). Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC).

Treatment	PH (cm)	FSW (g)	DSW (g)	FRW (g)	DRW (g)	CHl	RWC (%age)	LA
CK	66.3bc	25.4d	11.2d	11.0d	5.2c	17.5d	51.7d	215.7e
CP 2%	82.7a	28.0c	13.3c	14.9c	5.7bc	21.2c	54.7cd	227.7de
CP3%	81.3ab	29.6bc	14.6bc	15.3bc	6.3abc	23.9bc	57.0c	239.8cd
CP 5%	72.0abc	32.0ab	16.7a	16.5ab	6.8ab	25.5b	65.3a	257.0ab
VC 2%	59.3c	28.8bc	15.4ab	15.2bc	5.3c	26.4b	57.7bc	233.2cd
VC 3%	82.7aa	30.5ab	16.7a	16.7ab	6.2abc	24.8b	61.3b	246.0bc
VC 5%	79.7ab	32.6a	17.4a	17.0a	7.2a	29.3a	68.3a	261.0a
LSD	15.43	2.81	1.97	2.18	1.37	2.71	3.97	14.79

Table-2. Effect of compost and vermicompost on soil and plant nutrient status. These abbreviations are as follows: Soil Nitrogen (SN); Soil Phosphorus (SP); Soil potassium (SK); Plant nitrogen (PN); Plat Phosphorus (PP); Plant Potassium (PK). Treatments are as follows: Control (CK); Compost (CP); Vermicompost (VC).

Treatment	SN (%)	SP (mg. Kg^{-1})	SK (mg. Kg^{-1})	PN (g. Kg^{-1})	PP (g. Kg^{-1})	PK (g. Kg^{-1})
CK	0.02d	7.33d	89.00e	10.73d	1.57d	2.13d
CP 2%	0.02d	8.62cd	95.67d	13.30c	2.20d	3.17bc
CP3%	0.03c	9.91bc	102.00bc	14.50bc	4.10c	3.77b
CP 5%	0.03ab	10.88ab	107.67ab	15.40ab	4.49bc	4.80a
VC 2%	0.03bc	9.45c	101.00cd	14.37bc	4.33c	2.77cd
VC 3%	0.03ab	10.92ab	109.00a	15.20ab	5.40ab	4.93a
VC 5 %	0.03a	11.29a	111.33a	16.19a	6.07a	5.51a
LSD	NS	1.35	6.13	1.59	1.01	0.88

Discussion

The intensive increase of Cu in cultivated lands, resulting from excessive spray of Cu-based agrochemicals to protect plants from pathogenic attack and chemical fertilizers for plants growth and development, pose a substantial hazard to the crop production and food security. Therefore, it is an urgent need to seek substitute or strategies to eliminate Cu involvement in cultivated land. In this regard, use of organic waste byproducts having ability to cope PTEs stress and provide resistance against pest attack. The current findings revealed that the transformation of various organic waste into valuable organic fertilizers can be considered an emerging solution for soil health restoration and sustainable crop production under polluted ecosystems (Bashir et al., 2022).

It has been demonstrated that organic amendments compost and vermicompost with their different dose levels having excellent effects on maize yield and soil improvement (Wang et al., 2021; Wang et al., 2019). The current findings suggested that amelioration of soil using compost and vermicompost exhibited the profound results to modify soil pH and organic matter as well as improved the nutrients status (N, P and K) which are in line with (Wang et al., 2018). The substantial decline in soil pH among all the experimental units is due to the inside mechanism after the VC containing organic material decomposition which could lead to release organic acids (Sabijon and Sudaria, 2018). It can be described that release of acids (humic and fulvic acids) have potential to react with carbonates and bicarbonates of alkaline soils which might have great contribution to promote neutralization and subsequently reduced soil pH (López et al., 2021). While, the profound increase in soil nutrients and carbon status in cu polluted soil were noticed which might be due to the decomposition of organic residues in soil which could contribute to retain moisture in the soil, develop soil structure and enhance the nutrients availability in the soil solution which make them available to plants for their development (Ghobadi et al., 2021). It can be suggested that addition of organic soil additives have potential to improve microbial activity which could modify the nutrients status in polluted soil through mineralization and fixation process in the degraded soils (Medyńska-Juraszek et al., 2020)

According to the findings of the present study, it has been attributed that CP and VC have potential to remediate Cu polluted soil through several inside mechanisms. Firstly, the presence of organic substance contains functional groups including amide, carboxyl, amino acids, and hydroxyl groups could provide the space to Cu for complexation and bindings which could led immobilization of Cu in polluted environment (Bashir et al., 2022; Jones et al., 2016). Secondly, these materials can modify soil pH and cations exchange capacity of studied soil which might have great share to immobilize Cu in polluted soil (Chen et al., 2020). Thirdly, these substances can provide substrate to microbes which could easily transform highly toxic fraction of Cu into less mobile residual form via the processes which can directly and indirectly facilitate and promote adsorption, complexation, precipitation, and redox reactions (Soja et al., 2018).

These results were in line with the recent study examined by Wang et al. (2023) confirmed the efficiency of vermicompost along with shell powder for cadmium removal from wastewater. Moreover, they confirmed that their addition in field also showed the profound reduction in Cd contents by 42.18% to 68.75% in green garlic as well as augmented microbial activity and ameliorate soil properties. Additionally, another investigation suggested by Pan et al. (2022) confirmed that incorporation of vermicompost along with zero valent iron concurrently reduced the mobile portion of As and Cd in soil by 30.6% and 21.7% in laterite which could led to reduce As- and Cd-accumulation in water spinach shoot by 72.0% in paddy soil and 47.6% in laterite. The combined mixing of vermicompost and Iron as soil passivators showed the profound improvement in the soil chemical properties as well as plant growth (biomass, height, SPAD values) characteristics.

Zhang et al. (2019) conducted a study to evaluate the effectiveness of vermicompost in column study for Pb, Cd and Cr immobilize in the leachate by 93, 97 and 75.5%, with the accumulated adsorbed amount of 11.80, 4.81 and 5.62 mg g^{-1}, respectively over control. over control. Our results suggested that addition of organic soil additives (CP and VC) effectively enhance maize growth by improving chlorophyll contents, fresh and dry biomass as well as leaf area which might be due to availability of nutrients in polluted soil after the decomposition of soil additives and release of essential elements in soil solution. Similar results were obtained in the previous study described by Ibrahim et al. (2022) reported that the application of vermicompost along with ascorbic acid prominently improved tomato growth by increasing plant height by 40.4 cm and dry matter by 52.4 g over control. Several previous studies confirmed that organic based soil additives have the ability to improve soil physical structure like soil aggregation which could enhance water retention ability and nutrients mobility in the degraded soils. In addition, use of compost and vermicompost as soil additives could release and exchange essential elements in the soils which could contribute to promote photosynthesis process, root elongation and cell division, as well as metabolic activities (Yassen et al., 2020; Piya et al., 2018; Mahmud et al., 2018).

Previous studies described that the amount of chlorophyll was enhanced when plants were treated with organic amendments. This may be due to the addition of amino acids, alkaloids, enzymes, hormones, and vitamins, which could increase the amount of chlorophyll. The other reason is that high availability of nutrients like nitrogen (N) in the organic waste byproducts, which is an important part of chlorophyll, may enhance the content of chlorophyll (Mounissamy et al., 2021; Mensah and Frimpong, 2018).

Conclusion

The present study revealed that the addition of compost and vermicompost gradually decreased the available forms of copper (Cu) in soil by 43%; consequently, the amounts of copper uptake by maize shoot was decreased by 61.1%. In addition, the findings confirmed that the application of soil organic amendments has a significant impact on all agronomic parameters, such as root length, shoot length, plant height, root and shoot dry weight, leaf area, as well as chemical parameters N, P, K, pH, and organic matter in soil. In comparison to compost, vermicompost is recognized as an effective soil ameliorator to increase the soil nutrients status N (45.16%); P (35.07%); and K (20.05%). Similarly, plant growth parameters were also influenced after the introduction of vermicompost in copper polluted alkaline soil.

Acknowledgment

The authors would like to extend their sincere appreciation to the Researchers Supporting Project Number (RSP2024R182) King Saud University, Riyadh, Saudi Arabia.

Disclaimer: None.
Conflict of Interest: None.
Source of Funding: This research project was funded by the Researchers Supporting Project Number (RSP2024R182) King Saud University, Riyadh, Saudi Arabia.

Contribution of Authors

Jabar A: Conceived idea, conducted the experiment, collected & analyzed data and prepared the final draft for submission
Athar M & Zahra A: Contributed to draft preparation and data analysis
Mehmood K, Ishfaq T & Sherani J: Draft preparation, final editing and proofreading
Bashir S: Conceptualization, analyzed the collected data and revised the first draft
Iqbal Z & Ahmed T: Literature review, editing and proof reading
Hussain M: Data analysis and result interpretation
Khan S: Final formatting, reviewing, proof reading and submission as corresponding author
El- Sheikh MA: Conceptualization and funding

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