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RESEARCH PAPER

Impact of increasing vermicompost applications on the growth performance of radish (*Raphanus sativus*) in cadmium-contaminated soil

Fırat Uzun[1], Mahmoud Nazzal[1]*, Ömer Faruk Öztürk[1], Omar Amjed Hasan Chalabee[1], İrem Güler[1], Sude Uluğ[1], Ummahan Çetin Karaca[1]

[1] Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Selcuk University, Konya 42150, Türkiye

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***Corresponding Author**
Tel.: +90 332 223 28 38
E-mail: mahmutnazzal@gmail.com

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Abstract

Soil contamination by heavy metals, including cadmium (Cd), adversely impacts plant growth and affects agricultural productivity. Organic improvements, especially vermicompost (VC), may reduce metal toxicity. This study investigated the impact of increasing VC dosages on the growth of radish (*Raphanus sativus*) under Cd stress. A greenhouse experiment was performed using a randomized plot design with four replications. In this experiment, four different vermicompost (VC) rates (0%, 1%, 2%, and 4%) and three Cd concentrations (0, 5, and 10 mg kg^{-1}) were applied. The Cherry Belle cultivar was cultivated and harvested 45 days post-sowing. The shoot's length and weight (fresh and dry), the tuber's diameter, and the tuber's weight (fresh and dry) were all measured. The vermicompost treatment significantly ($p \leq 0.01$) enhanced all parameters. The lowest values have been determined without vermicompost at 10 mg Cd kg^{-1}. The maximum shoot length and tuber diameter were achieved with 4% vermicompost and no cadmium, whereas the highest shoot and tuber weights were obtained with 4% vermicompost at 10 mg Cd kg^{-1}. In summary, vermicompost reduced Cd toxicity and improved radish growth and yield, suggesting its potential as a sustainable solution for soils contaminated with heavy metals.

Introduction

Heavy metal contamination in soil has become a global concern due to the increasing use of chemical fertilizers, soil conditioners, pesticides, sewage sludge, and wastewater in agricultural practices (Khan et al., 2007). These metals accumulate in soils through agricultural activities, mining, industrial processes, vehicular emissions, and natural events such as volcanic eruptions (Rodríguez-Hernández et al., 2022; Yang et al., 2022). Among these metals, Cd is considered one of the most hazardous due to its high toxicity, mobility, and persistence in the environment. Cd has no known biological function in plants, animals, or humans, and poses serious risks to both plant growth and human health (Marschner, 2008). It enters agricultural soils through natural sources, such as parent materials rich in heavy metals, as well as anthropogenic inputs, including atmospheric deposition, phosphate fertilizers, and sewage sludge application. Cd contamination reduces plant productivity by disrupting key physiological and

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biochemical processes such as photosynthesis, water balance, and nutrient uptake (Rizwan et al., 2016). In agricultural soils, Cd concentrations typically range from 0.01 to 2.7 mg kg^{-1} under uncontaminated conditions (Kubier et al., 2019; Huang et al., 2022), while contaminated soils may contain more than 3 mg kg^{-1}, depending on soil type and pollution source (Kubier et al., 2019). Cd toxicity symptoms in plants generally occur when Cd concentrations in plant tissues exceed 3-30 mg kg^{-1} (Ismael et al., 2018; Haider et al., 2021). It also competes with essential nutrients such as zinc (Zn), iron (Fe), and magnesium (Mg), thereby reducing their uptake and translocation within the plant (Khaliq et al., 2019). Moreover, Cd can move through soil, water, and air, eventually entering the food chain and accumulating in edible plant parts such as grains (Robson et al., 2014). To counter these effects, several studies have shown that applying mineral fertilizers containing micronutrients such as Zn, Fe, Mn, silicon, and selenium can reduce Cd uptake by plants through competitive absorption mechanisms (Hussain et al., 2021). In recent years, increasing attention has been directed toward organic fertilizers due to their environmental advantages over chemical alternatives. Organic fertilizers support soil health, reduce pollution, and enhance plant growth (Khaitov et al., 2019; Alam et al., 2020). Among these, VC, a stabilized organic amendment produced through the decomposition of organic waste by earthworms particularly valued in organic farming. It improves soil structure by increasing porosity and aeration, enhancing water retention, and fostering high levels of microbial activity (Garg and Gupta, 2009; Demir et al., 2010; Boran, 2015). In arid and semi-arid regions, such as Türkiye, the scarcity of soil organic matter poses a major challenge to sustainable agriculture. As emphasized by Yıldız (2012), increasing organic matter levels in such soils is critical for long-term productivity.

VC has been shown in numerous studies to improve crop growth and quality. For example, Adiloğlu et al. (2015) reported that higher VC doses significantly increased lettuce yield, plant diameter, leaf size, and fresh weight, while nutrient content remained largely unchanged, except for increases in Fe and Mn. Similarly, Büyükfiliz and Adiloğlu (2016) found that VC reduced Fe, Zn, and B concentrations in sunflower but enhanced the uptake of N, P, K, Mg, Ca, Cu, and Mn. In another study, Adiloğlu et al. (2017) observed that increasing VC doses significantly decreased the concentrations of heavy metals such as Cr, Co, Cd, Ni, and Pb in cucumber plants. These findings collectively suggest that VC not only enhances plant quality but also mitigates heavy metal toxicity. Other organic amendments, such as biochar, have also been shown to significantly influence plant responses under heavy metal stress. For instance, under Cd stress conditions, Demirbaş and Coşkan (2019) reported that biochar application increased maize yield. Likewise, Özkan et al. (2016) demonstrated that VC improved several soil properties, including pH and available phosphorus. The mobility and bioavailability of heavy metals in soil can be influenced by various factors associated with organic fertilizers, such as their solubility, salt content, pH, and the redox potential of the soil (Walker et al., 2004; Angelova et al., 2010). Considering these findings, the present study aims to investigate the effects of increasing VC dosages on the growth and developmental parameters of radish (*Raphanus sativus*) cultivated in soil artificially contaminated with Cd.

Materials and Methods

The experiment was conducted in the greenhouse facilities of the Department of Soil Science and Plant Nutrition, Faculty of Agriculture, Selçuk University, using 3-kg capacity plastic pots arranged in a completely randomized design (CRD) with four replications. The physical and chemical properties of the soil are provided in Table 1, while the chemical characteristics of the VC are presented in Table 2. A total of 48 pots were used in a factorial design consisting of three Cd levels (0, 5, and 10 mg kg^{-1}) and four VC application rates (0%, 1%, 2%, and 4%). The factorial arrangement and allocation of treatments are illustrated in Figure 1. The VC application rates were expressed as percentages of the dry weight of the potting soil (w/w). For a pot containing 3,000 g of dry soil, the corresponding amounts of vermicompost added were 0 g (0%), 30 g (1%), 60 g (2%), and 120 g (4%). Vermicompost was thoroughly mixed with the soil before filling the pots to ensure uniform distribution. These application rates were selected based on previous greenhouse experiments and agronomic recommendations, which reported beneficial effects of vermicompost at 1-5% (w/w) on soil physicochemical properties and plant growth (Arancon et al., 2019; Juleel et al., 2023; Demir and Kiran, 2019; Kiran, 2019). The common nutrient content in vermicompost is organic carbon 27.20%, N 1.83%, K 0.8%, Ca 5.70%, and other micronutrients in small amounts. Cadmium was applied in dry form as $CdCl_2$ and thoroughly mixed into the soil. The radish cultivar 'Cherry Belle' was used as the test plant. To meet the plants' nutritional requirements, a uniform application of base fertilizers was incorporated into the soil before sowing. Nitrogen was added as urea (46% N) at a rate of 100 mg kg^{-1} (300 mg pot^{-1}); phosphorus was supplied using triple superphosphate (43% P_2O_5) at 50 mg kg^{-1} (150 mg pot^{-1}); potassium was added as potassium sulfate (51% K_2O) at 100 mg kg^{-1} (300 mg pot^{-1}); and magnesium was provided as magnesium sulfate (16% MgO) at the same rate. Micronutrients were also added as follows: boron at 2 mg kg^{-1} (6 mg pot^{-1}) from Etidot-67 (20.8% B), zinc at 2 mg kg^{-1} (6 mg pot^{-1}) from zinc sulfate (23% Zn), and iron at 5 mg kg^{-1} (15 mg pot^{-1}) from iron sulfate (19% Fe).

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Table 1. Some physical and chemical analysis results of the soil sample were used in the experiment

Parameters		Results	Method
Texture		Clay loam	Bouyoucos 1951
pH [1:2.5 soil: distilled water]		7.75	Richards 1954
EC [1:5 soil: distilled water, µS cm^{-1}]		130	U.S. Salinity Lab. Staff 1954
Lime (CaC	%	30	Hızalan and Ünal 1966
Organic matter		1.45	Smith and Weldon, 1941
N (NH_4-N+NO_3-N	mg kg^{-1}	17	Bremner 1965
P (Available)		9.6	Olsen et al. 1954
K (Exchangeable)		236	FAO, 1990
Ca (Exchangeable)		7400	
Mg (Exchangeable)		168	
Fe (Available)		1.78	Lindsay and Norvell 1978
Cu (Available)		0.38	
Mn (Available)		6.6	
Zn (Available)		0.16	
Cd (Available)		0.03	
B (Available)		1.3	Richards 1954

Table 2. Some chemical properties of the vermicompost used in the experiment

Characteristics		Value	Characteristics		Value
K (Exchangeable)	%	0.8	pH		7.92
Ca (Exchangeable)		5.7	EC (1:5) dS/m		2.95
Mg (Exchangeable)		0.7	Organic Matter	%	44.62
Fe (Total)	mg kg^{-1}	0.84	C (Total organic carbon)		27.2
Zn (Total)		84	C/N		14.86
Mn (Total)		430	N (Total)		1.83

Radish plants were harvested 45 days after sowing, or upon reaching full maturity, and key growth parameters were measured immediately after harvest. These parameters included shoot length, shoot fresh and dry weights, tuber diameter, and tuber fresh and dry weights. During hand harvesting, each plant was carefully uprooted to minimize damage to the shoots and tubers. Following harvest, plants were gently washed with distilled water to remove adhering soil particles. Shoot length was measured using a standard ruler for morphological evaluation. Fresh weights of shoots and tubers were determined using a precision digital scale. To assess dry biomass, the samples were oven-dried at 65 °C until a constant weight was achieved. Tuber diameter was measured using a digital caliper for accuracy.

Statistical analyses were conducted using Minitab 19 software. Analysis of variance (ANOVA) was performed to evaluate the effects of treatments, and

Control	Control	Control	Control
Cd-0+VC-1	Cd-0+VC-1	Cd-0+VC-1	Cd-0+VC-1
Cd-5+VC-1	Cd-5+VC-1	Cd-5+VC-1	Cd-5+VC-1
Cd-10+VC-1	Cd-10+VC-1	Cd-10+VC-1	Cd-10+VC-1
Cd-0+VC-2	Cd-0+VC-2	Cd-0+VC-2	Cd-0+VC-2
Cd-5+VC-2	Cd-5+VC-2	Cd-5+VC-2	Cd-5+VC-2
Cd-10+VC-2	Cd-10+VC-2	Cd-10+VC-2	Cd-10+VC-2
Cd-0+VC-4	Cd-0+VC-4	Cd-0+VC-4	Cd-0+VC-4
Cd-5+VC-4	Cd-5+VC-4	Cd-5+VC-4	Cd-5+VC-4
Cd-10+VC-4	Cd-10+VC-4	Cd-10+VC-4	Cd-10+VC-4
Cd-5+VC-0	Cd-5+VC-0	Cd-5+VC-0	Cd-5+VC-0
Cd-10+VC-0	Cd-10+VC-0	Cd-10+VC-0	Cd-10+VC-0

Figure 1. Layout of the experimental design, showing the factorial arrangement of three Cd levels (Cd-0, Cd-5, and Cd-10 mg kg^{-1}) and four vermicompost (VC) application rates (VC-0%, VC-1%, VC-2%, and VC-4%) across 48 pots. The control treatment is Cd-0 + VC-0%.

mean comparisons were carried out using Tukey's test at a significance level of $p \leq 0.01$ when significant differences were detected.

Results and Discussion

The results demonstrated that increasing VC doses had a statistically significant effect ($p \leq 0.01$) on specific growth parameters of radish plants cultivated in Cd-contaminated soil. Notably, the interaction between VC and Cd treatments was significant for shoot length. The greatest shoot length (25.50 cm) was observed in plants treated with 2% and 4% VC without Cd contamination (Figure 2), whereas the shortest shoot length (19.25 cm) occurred in plants exposed to 10 mg Cd kg^{-1} without any VC application. These findings are consistent with previous research. For instance, Abdoosi (2019) reported that the VC application mitigated the negative impact of Cd on spinach growth, particularly plant height. Similarly, Syed et al. (2022) observed that VC significantly enhanced plant height when applied in combination with NPK fertilizers and heavy metals. In their study, the tallest spinach plants (23.10 cm) were recorded under the treatment of 5 t ha^{-1} vermicompost + N25P8K10 + Pb4, while the shortest (4.10 cm) was observed under Cd treatment alone. Both Cd and Pb independently suppressed plant growth to comparable extents. Furthermore, Chen and Lai (2025) showed that soil amendments such as sulfur-enriched VC improved organic matter content and reduced the bioavailability of Cd. The application of such amendments shifted Cd from highly mobile forms (acid-soluble and exchangeable fractions) to less mobile, oxidizable fractions, thereby limiting its mobility and accumulation. This transformation supported enhanced plant growth, as demonstrated in lettuce. The application of 4% VC combined with 10 mg Cd kg^{-1} soil resulted in the highest shoot fresh weight (33.03 g), indicating it as the most effective treatment. Similarly, 4% VC with 5 mg Cd kg^{-1} also significantly increased shoot fresh weight (Figure 3). Organic amendments like VC reduced Cd mobility within the cytoplasm and organelles, while enhancing its sequestration in the cell wall and vacuoles. This effect was particularly noted by Chen and Lai (2025), who reported that VC combined with organic fertilizers from chicken manure increased sulfur and thiol compound concentrations in lettuce.

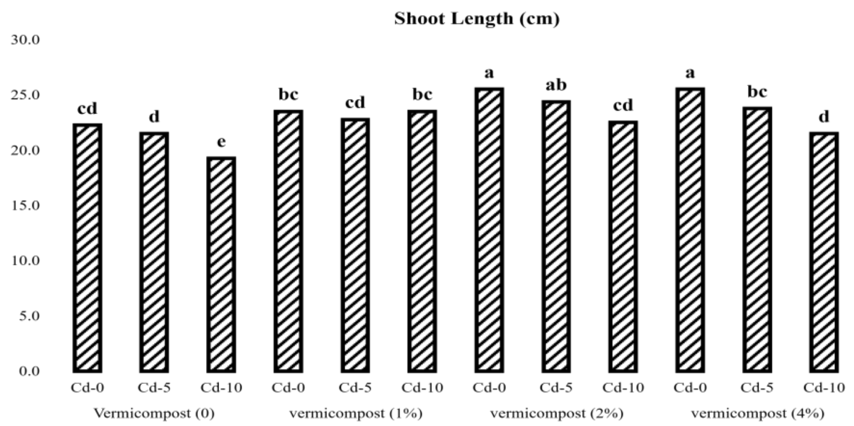

Figure 2. Effects of increasing doses of VC on the shoot length of radish plants grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at $p \leq 0.01$. Values sharing the same letter are not significantly different

The lowest shoot fresh weight (19.83 g) was observed in radish plants grown in soils treated with 5 and 10 mg Cd kg^{-1} without any VC application (Figure 3), indicating that the absence of VC under Cd stress negatively impacted plant growth. Conversely, increasing doses of VC had a statistically significant positive effect ($p \leq 0.01$) on shoot biomass in radish plants cultivated in Cd-contaminated soil. Mojdehi et al. (2022) reported that elevated heavy metal concentrations in the growth medium increased superoxide dismutase (SOD) activity by 30–50% in ornamental sunflowers, indicating oxidative stress. However, the application of VC effectively reduced metal accumulation in soil, tubers, and stems, thereby mitigating stress-related effects. These findings suggest that VC can alleviate heavy metal toxicity, and ornamental sunflowers may also serve as potential phytoremediators in Pb- and Cd-contaminated soils.

Regarding shoot dry weight, the highest values were recorded in plants treated with 4% VC + 5 mg Cd kg^{-1} (2.31 g), 2% VC without Cd (2.41 g), and 4% VC + 10 mg Cd kg^{-1} (2.42 g). The lowest shoot dry weight (1.82 g) was observed in plants grown without any VC application (Figure 4). Similarly, increasing doses of VC significantly influenced radish tuber diameter in Cd-contaminated soils. The largest average tuber diameter (26.64 mm) was obtained from plants treated with the highest VC dose (4%) across different Cd levels. In

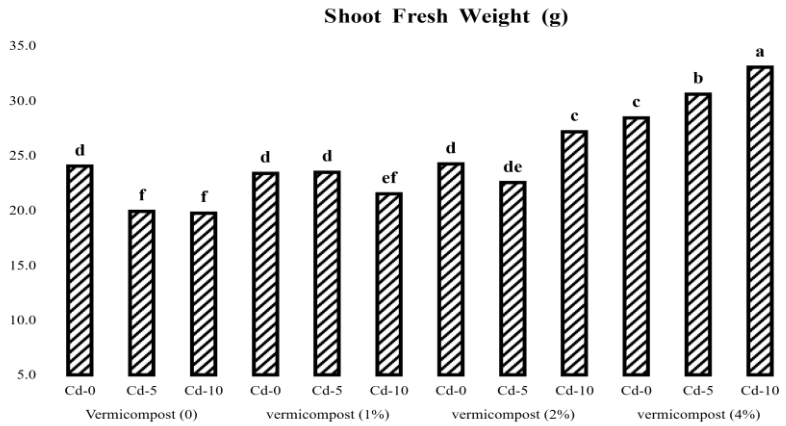

Figure 3. Effects of increasing doses of VC applications on shoot fresh weight of radish plants grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at *p*≤0.01. Values sharing the same letter are not significantly different

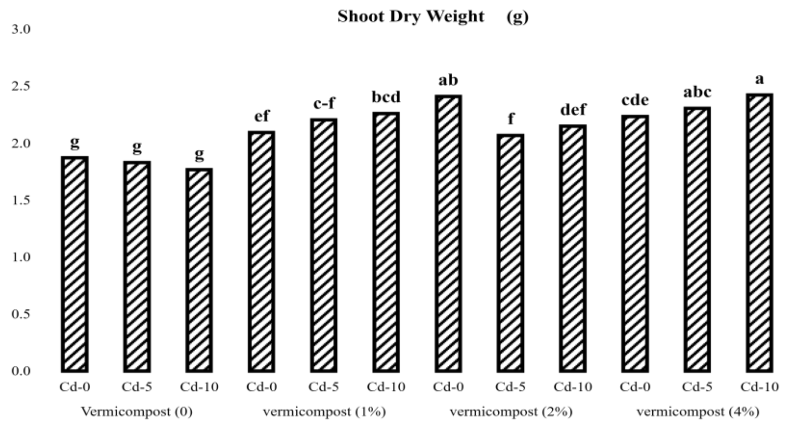

Figure 4. Effects of increasing VC doses on shoot dry weight of radish plants grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at *p*≤0.01. Values sharing the same letter are not significantly different

contrast, the smallest diameter (16.40 mm) was recorded in plants exposed to 10 mg Cd kg^{-1} without VC supplementation (Figure 5). Supporting these findings, Al Mamun et al. (2021) conducted pot experiments on Cd-contaminated soil (0.8 mg kg^{-1} Cd) using varying doses of VC and biochar. Their study showed that the combined application of 5 t ha^{-1} VC and biochar reduced Cd concentration in red amaranth (*Amaranthus cruentus*) by 72% and significantly enhanced biomass production.

Similarly, Yen et al. (2021) reported significant increases in the fresh weight of lettuce and pak choi (ranging from 3.9 to 14.4 g per plant) following VC application, compared to controls (0.4-2.5 g per plant). This improvement was attributed to enhanced organic matter content and increased availability of phosphorus, as well as exchangeable magnesium and potassium. Moreover, VC treatment reduced Cd accumulation in plant tissues by 60-75%. In another study, Abdoosi (2019) observed that Cd exposure significantly decreased the dry weight of spinach, whereas VC application notably improved it, with a 49.4% increase recorded upon the incorporation of 10% VC into the soil relative to the control.

In the current study, increasing VC doses significantly influenced the tuber fresh weight of radish plants grown in Cd-contaminated soils. The highest tuber fresh weights-29.35 g and 30.03 g-were recorded in plants treated with 4% VC combined with 5 and 10 mg Cd kg^{-1}, respectively. In contrast, the lowest tuber fresh weight (16.90 g) was observed in control plants that received neither VC nor Cd treatment (Figure 6). These findings suggest that VC applications can enhance tuber biomass even under heavy metal stress, likely due to improved soil structure and nutrient availability. The increased availability of essential minerals-particularly phosphorus, which supports root development and nutrient uptake-is considered a key factor in the observed root weight improvement (Ebrahimi et al., 2021; Khosropour et al., 2022).

The results of the study indicate that increasing VC doses significantly affected the tuber dry weight of radish plants cultivated in Cd-contaminated soils. The highest average tuber dry weight (1.99 g) was recorded in plants treated with 4% VC, followed closely by those grown in soil without VC but exposed to 10 mg Cd kg^{-1}

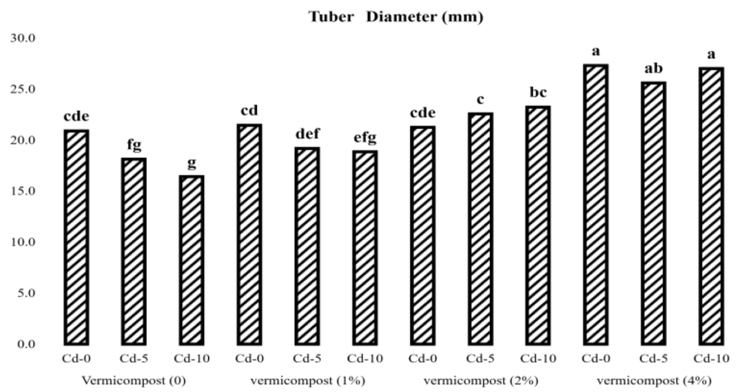

Figure 5. Effects of increasing doses of VC applications on the tuber diameter of radish plants grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at $p \leq 0.01$. Values sharing the same letter are not significantly different

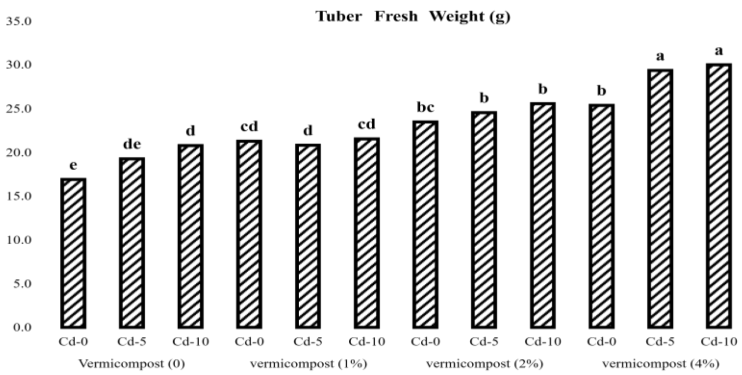

Figure 6. Effects of increasing doses of VC applications on the tuber fresh weight of radish plants grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at $p \leq 0.01$. Values sharing the same letter are not significantly different

(1.91 g). In contrast, the lowest tuber dry weight (1.26 g) was observed in plants receiving 1% VC in combination with 5 mg Cd kg^{-1}, with similarly low values detected in treatments lacking both VC and Cd. These findings highlight the importance of sufficient VC application in enhancing tuber development and mitigating the adverse effects of Cd stress (Figure 7).

Based on Table 3 and the analysis of production components, the results revealed several positive correlations among the measured parameters. Plant height was positively correlated with shoot dry weight and tuber diameter. Fresh plant weight showed a strong positive relationship with shoot dry weight, tuber diameter, and tuber fresh weight. Additionally, shoot dry weight was positively associated with both tuber diameter and tuber fresh weight. Tuber diameter also correlated positively with tuber fresh and dry weights, and a similar positive correlation was observed between tuber fresh and dry weights.

The application of VC to Cd-contaminated soils mitigates the adverse effects of Cd by reducing its toxicity and enhancing soil health. This positive impact is largely due to the chemical and biological composition of VC, which improves soil structure, fertility, and microbial activity. Numerous studies have confirmed that VC enhances the biological, chemical, and physical properties of soil, thereby supporting the growth of healthy, high-yielding plants (Arancon et al., 2003; Jat and Ahlawat, 2006; Alam et al., 2007; Ali et al., 2007; Singh et al., 2008; Rangarajan et al., 2008). For instance, Ethur et al. (2021) observed that VC application improved shoot development and fruit yield in Cd-contaminated pepper plants, with optimal results at a 50% VC rate. Similarly, Wang et al. (2021) reported increased lettuce biomass and reduced Cd accumulation following the use of a VC-based composite amendment (95% VC + 5% modified shell powder). Iqbal et al. (2024) found that VC application enhanced the grain yield of fragrant rice under Cd stress, improved soil fertility, and enriched fungal diversity, while also reducing Cd uptake in grains, shoots, and tubers. In another study, Wu et al. (2025) demonstrated that VC improved celery biomass in Cd-contaminated field conditions by lowering soil Cd availability and promoting bacterial communities capable of immobilizing Cd. Overall, VC contributes to sustainable agriculture by enhancing soil fertility, retaining moisture, supplying essential nutrients, and

Table 3. Correlation matrix of growth parameters in radish

	Shoot Length	Shoot Weight	Fresh Shoot Weight	Dry Tuber Diameter	Tuber fresh weight
Shoot Fresh Weight	0.23				
Shoot Dry Weight	0.58**	0.66**			
Tuber Diameter	0.46**	0.89**	0.61**		
Tuber fresh weight	0.24	0.80**	0.67**	0.77**	
Tuber dry weight	-0.08	0.34*	0.10	0.38**	0.48**

	Shoot Length	Shoot Weight	Fresh Shoot Weight	Dry Tuber Diameter	Tuber fresh weight
Shoot Fresh Weight	0.23				
Shoot Dry Weight	0.58**	0.66**			
Tuber Diameter	0.46**	0.89**	0.61**		
Tuber fresh weight	0.24	0.80**	0.67**	0.77**	
Tuber dry weight	-0.08	0.34*	0.10	0.38**	0.48**

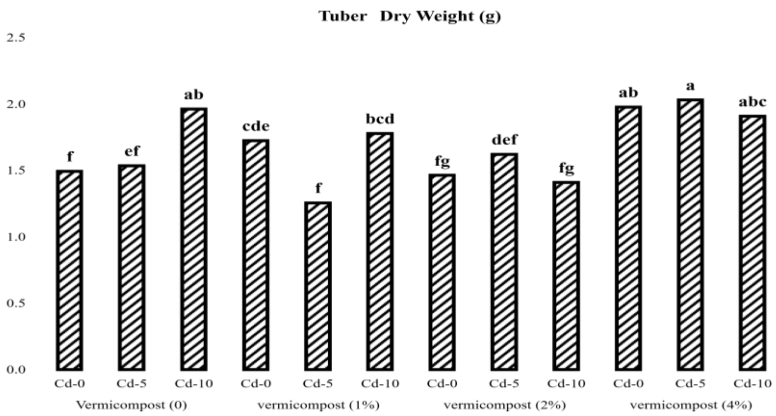

Figure 7. Effects of increasing doses of VC applications on the dry weight of radish tuber grown in Cd-contaminated soil. Different letters above the bars indicate statistically significant differences between treatments according to Tukey's test at $p \leq 0.01$. Values sharing the same letter are not significantly different

reducing environmental pollution. It has been shown to stimulate growth, flowering, and productivity in a wide range of vegetable crops (Oyege and Balaji Bhaskar, 2023; Mohite, 2024; Muslim, 2025; Sonone, 2025).

Conclusions

The application of VC significantly mitigated the adverse effects of Cd contamination on the growth of radish (*Raphanus sativus*). Under non-contaminated conditions, the highest VC dose (4%) resulted in substantial improvements: shoot fresh weight increased by 44.2%, shoot dry weight by 22.2%, tuber diameter by 66.5%, and tuber fresh weight by 22.1% compared to the most stressed treatment (0% VC + 10 mg Cd kg^{-1}). These enhancements are attributed to improved soil biological activity, nutrient availability, and physical structure induced by VC application. However, under high Cd stress (10 mg Cd kg^{-1}), the 4% VC treatment led to a slight decrease (5.0%) in tuber dry weight, suggesting that the effectiveness of VC may vary depending on the growth parameter and severity of contamination. Overall, the results highlight VC as a promising and environmentally sustainable soil amendment for improving plant growth in Cd-contaminated soils. Further studies across different environmental conditions and crop species are recommended to validate and extend these findings.

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Author Contributions

F.U., M.N., and U.Ç.K.: conceptualized and designed the study. **F.U., M.N., Ö.F.Ö., O.A.H.C.H., İ.G., and S.U.:** conducted the experiments and performed data analysis. **F.U., M.N., and U.Ç.K.:** drafted the manuscript, carried out the statistical analysis, and finalized the manuscript for submission.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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