

THE EFFECT OF INCREASING DOSE OF VERMICOMPOST APPLICATION ON CADMIUM CONTAMINATED SOILS ON SOME SOIL ENZYME ACTIVITIES

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Abstract: Contamination of agricultural soils with heavy metals is a major problem in soil quality. When heavy metals reach food chain through agricultural soils and plants, they pose a great threat to the health of humans and other living organisms. The enzymes are generally less active in contaminated soils due to exposure to heavy metals. The aim of this research was to investigate the effect of increasing vermicompost doses on some biological soil properties in artificially contaminated soils. In the study, increasing doses of vermicompost (0-2.5-5-10%) were added to soil artificially polluted with Cd (0, 5 and 10 mg.kg⁻¹). Untreated soil was used as a control. After the vermicompost application, the soils were brought to 70% of the field capacity and incubated at 28-30°C in laboratory conditions. Samples were taken from the incubated soils at 0-5-10-15-30-45-60-75-90-120th days. Alkaline phosphatase, arylsulfatase, dehydrogenase, urease, catalase enzyme activities were analyzed in soil samples at the end of each incubation period. The effects of increasing doses of vermicompost application to artificially contaminated soils on some biological properties of the soil showed differences, and these differences were found to be statistically significant ($p < 0.01$). The lowest values of soil enzyme activities (alkaline phosphatase, arylsulfatase, dehydrogenase, urease and catalase enzyme activities) were determined in soil samples contaminated with Cd and not treated with vermicompost until the end of incubation. The highest enzyme activities values were found in soils contaminated with 5 and 10 mg.kg⁻¹ Cd that were treated with 10% vermicompost. Enzyme activities in incubated soil increased with increasing doses of vermicompost. It was determined that the addition of vermicompost to soils contaminated with Cd significantly reduced the toxic effects of Cd.

Key words: Cadmium, enzyme activities, incubation, soil, vermicompost,

1. INTRODUCTION

Cadmium is one of the most toxic heavy metals, and heavy metals are generally not biodegradable. Among them, Cd has an important place in agricultural soils due to its high toxicity and mobility. Therefore, soils contaminated with Cd need to be rehabilitated. It is very difficult to remove from the soil (Rizwan et al., 2016) and can be transferred to crops via the soil-plant-food chain. Consequently, it may pose a danger to human health (Seleiman et al., 2020a, 2020b). They reported that the microbial population and enzyme activities of the soils were affected by the high concentration of Cd (Karaca et al., 2002; Moreno et al., 2006). Recently, various applications have been carried out to reduce the uptake of Cd by plant and soil microorganisms. In this case, various materials such as

rock phosphate were tested, (Basta et al., 2001), apatite, hydroxyapatite (Knox et al., 2001, 2003). However, in recent years, the addition of organic matter to the soil has become widespread in order to rehabilitate soils contaminated with heavy metals. Vermicompost, the end organic matter products, is frequently used to increase product yield due to its high organic matter content with water holding and aeration capacity (Tejada et al., 2010). In addition, it can be considered as a good breeding material for heavy metal stabilization in soil due to its high specific surface area, high cation exchange capacity and abundance of active functional groups (Ding et al., 2021; Wang et al., 2018). Addition of different organic substances to soils, sewage sludge (Moreno et al., 2003), poultry manure and crushed cotton gin compost (Tejada et al., 2007; 2008) etc. This can be explained by the

immobilization of heavy metals and reducing their negative effects on the microbial population and enzyme activities in the soil. Tejada (2009); studied the effect of several organic wastes (poultry manure, crushed cotton gin compost, sewage sludge and municipal organic solid waste) on the biological properties of soil artificially contaminated with Cd. In the study, the soil samples were mixed with the following organic matter sources: 10% poultry manure, 17.2% cotton compost, 23.1% sewage sludge and 13.1% municipal garbage to were mixed into the soil samples to apply the same amounts of organic matter to the soil. Enzymatic activities in soils, nematode population, earthworm weight, Cd concentration in earthworm tissues and extractable Cd and other organic wastes were measured in the same soils treated with 2 different (3 and 90 days) incubation times. The biggest loss in the biological properties of the soil occurred at the highest dosage of Cd at the end of the incubation period in unimproved polluted soils. The concentration of Cd in earthworm tissues and inhibition percentage of soil enzyme activities in polluted soils treated with organic wastes were lower than in control soils, and it was determined that nematode population and earthworm weight were higher. Kandeler et al., (1996 and 1999), in comparison to uncontaminated soils, experimentally contaminated soils with Zn, Cu, Ni, V and Cd showed lower urease, alkaline phosphatase and xylanase activity. Effron et al. (2004) found that the activities of arylsulfatase, acid phosphatase, protease and urease are inhibited by heavy metal. According to Renella et al., (2005) found that Cd inhibited alkaline phosphatase, arylsulfatase and protease activities, but did not affect acid phosphatase, β -glucose and urease activities. Lorenz et al., (2006) determined that Cd pollution had a negative effect on protease, urease, alkaline phosphatase and arylsulfatase activities, however, the activity of the enzyme invertase was not significantly affected. On the other hand, Khan et al., (2007) concluded that heavy metals have an inhibiting influence on soil enzyme activities and microbial community structure. They found that Cd is more toxic to enzymes than Pb, due to its lower affinity and greater mobility for soil colloids. Yang et al., (2007a, b) reported that the inhibition of soil enzyme activities caused by metal pollution and the reduction of soil microorganisms negatively affect soil fertility. In contaminated soils, the activity of the microbial population is intertwined with the abiotic properties of the soil (Krčmar et al., 2018). Yeboah et al., (2021) set up an incubation experiment in laboratory conditions using natural and artificially contaminated soil samples to determine the effects of Cd on soil enzyme activities. Soil samples were analyzed after 0, 5, 10, 20, 30 and 45 days of

incubation. They found that the dehydrogenase and urease enzyme activity increased when the Cd content raised from 0 to 5 mg.L⁻¹ over the duration of the days, even though no additional nutrients were supplied to the soils. However, there were significant differences between naturally and artificially polluted soils in terms enzyme activity. They observed that dehydrogenase enzyme activity was more resistant to Cd. A greenhouse study was conducted to investigate the effects of biochar application on the growth and nutrient uptake of tobacco plants in a Cd contained soil. Cherry seed shell biochar was added to a Cd-contaminated soil at four application rates (0, 1, 2 and 3% (v/v)). It was determined that while biochar application reduced the amount of toxic Cd in tobacco shoots, Fe, Zn, Mn and Cu concentrations of shoots were also significantly reduced with the highest 3.0% biochar application (Erdem et al., 2017). The distribution of heavy metals and minerals in various size fractions in Romanian Copșa Mică soil was investigated, (Damian et al., 2018). According to Romanian legislation, it was determined that the concentrations of Pb, Zn, Cd, Cu, Sb and as exceeded the legally regulated values for soils. In the coarser size fractions the predominant minerals were quartz and alkaline feldspar, while in the finer size fractions, the clay minerals and total carbon were predominant. Illites and montmorillonites in the fine fraction composition were determined to hold heavy metals due to high levels of cation exchange capacity. The good correlation between heavy metals and total carbon in the topsoil could be an indicator of heavy metal pollution level (Damian et al., 2018). In this study, increasing doses of vermicompost were applied to artificially contaminated soils with Cd under laboratory conditions. It is aimed to reduce and minimize the negative effects of Cd pollution by leaving the soil samples to incubate after applying vermicompost. During the incubation period of four months, the effects of vermicompost application against Cd pollution on alkaline phosphatase, arylsulfatase, dehydrogenase, urease and catalase enzyme activities in the soil were observed.

2. MATERIAL AND METHOD

2.1. Preparation of soil samples and incubation phase

The soil sample used in this study was taken from the Selcuk University Campus at a depth of 0-30 cm. After the soil samples were passed through a 2 mm sieve, 2 kg of soil was weighed into the pots on the basis of oven-dry weight, and 0, 5 and 10 mg.kg⁻¹ doses of Cd were added to the pots to create artificial

pollution. The soils in the pots were treated with vermicompost at a rate of 0-2.5-5-10% and after the soils were brought to 70% of the field capacity, they were left to incubate at 28-30°C in laboratory conditions. Throughout the incubation phase, soil moisture was maintained. Soil samples were taken from the pots left for incubation at 0-5-10-15-30-45-60-75-90-120th days. Soil samples were kept closed at +4°C until analysis. Soil samples were collected at the end of each incubation period; The enzyme activity of urease, dehydrogenase, catalase, alkaline phosphatase and arylsulfatase were analyzed in the soil.

2.2. Some physical and chemical analyzes of soil samples

Before the incubation experiment is established; the following analyzes were carried out for soil samples: texture, Bouyoucos (1951) (Demiralay, 1977), soil reaction (pH): 1:2.5 soil: in pure water suspension (Richards, 1954), electrical conductivity (EC): 1:5 in soil-water mixture (U.S. Salinity Lab. Staff 1954), organic matter: according to Smith Weldon method (Smith & Weldon, 1941), lime (CaCO₃): using Sheibler calcimeter (Hızalan & Ünal, 1966), total nitrogen: according to Kjeldahl method (Bremner, 1965), available phosphorus: according to the molybdophosphoric blue color method (Olsen et al., 1954), available Ca, Mg, Na, K: 1 N was determined by ammonium acetate extraction (Richards, 1954). Receivable Fe, Zn, Mn, Cu and Cd: after soil samples were extracted in diethylenetriaminepentaacetic acid (DTPA) solution (Lindsay & Norvell, 1978), and then the Fe, Cu, Zn, Mn, Cd in the filter were read in the ICP-AES (Inductively Coupled Plasma Atomic Emission Spectrometer) device (Soltanpour & Workman, 1981). Some physical and chemical properties of the soil and

vermicompost sample used in the incubation experiment are given in Table 1.

2.3. Some enzyme activity analyzes in soil samples

Alkaline phosphatase enzyme activity; was measured according to Tabatabai & Bremner (1969). Arylsulfatase enzyme activity, was determined according to Tabatabai & Bremner (1970). Dehydrogenase enzyme activity; according to Thalmann (1966), was determined as a result of incubation for 24 hours at 25°C using TTC. Urease enzyme activity: the amount of NH₃ formed by the decomposition of urea with the effect of urease and dissolved in the soil solution was measured by colorimetric determination (Hoffman & Teicher, 1961). Catalase enzyme activity, was determined by gasvolumetric method by using hydrogen peroxide (Beck, 1971).

2.4. Statistical analysis

The differences in the variables attributed to treatments were analyzed with ANOVA using SPSS 10.0 software for Windows (SPSS Inc., USA). Duncan's multiple range test was used to determine significant differences in response to parameters. Statistical significance is indicated at 1% and 5% probability levels.

3. RESULTS

3.1. Alkaline phosphatase enzyme activity (AFEA)

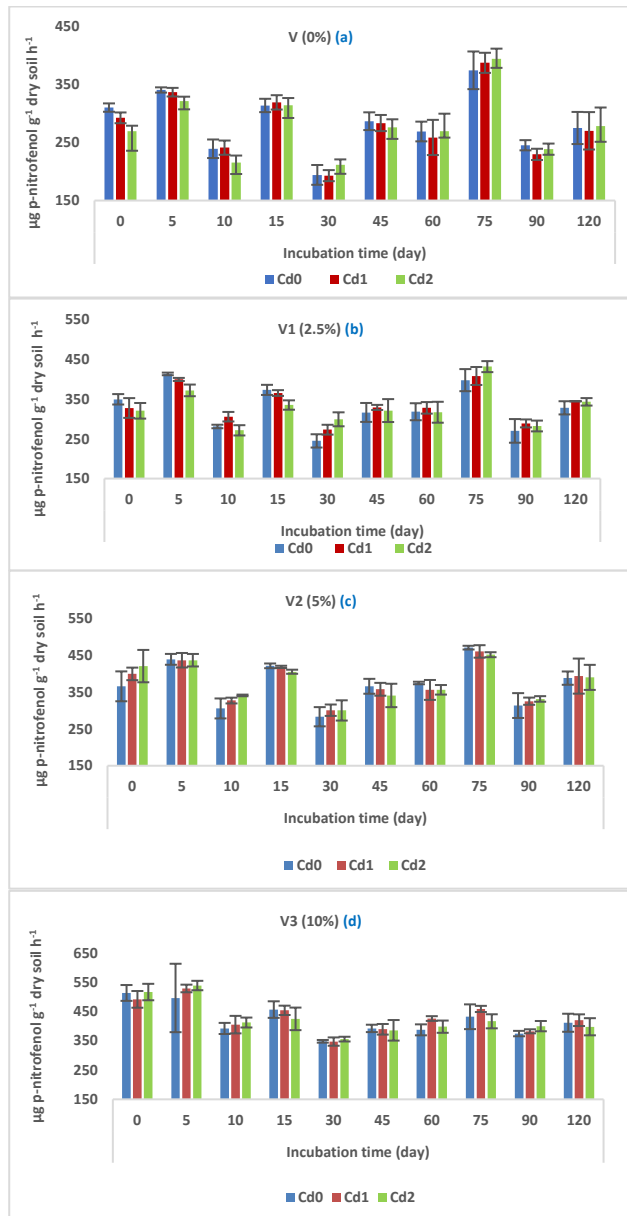
The results from the current study showed that the AFEA was lower in soils that were not applied

Table 1. Some physical and chemical properties of the soil and vermicompost sample used in the incubation experiment

Soil		Vermicompost	
Properties	Value	Properties	Value
Texture Class	loamy	pH	7.55
pH (1:2.5)	7.85	EC (1:5) dSm ⁻¹	2.12
EC (1:5) dSm ⁻¹	0.25	O.M.	42.00
CaCO ₃ (%)	25.70	C	24.20
O.M. (%)	1.56	C/N	14.90
NH ₄ +NO ₃ -N	129.00	N	1.63
P	26.60	P	1.50
K	247.00	K	1.80
Ca	3247.00	Ca	5.20
Mg	338.00	Mg	1.10
Mn	11.90	Fe	0.90
Zn	0.64	Zn	82.00
Cu	0.72	Mn	432.00
Fe	2.23	Cu	56.00
Cd	0.03		

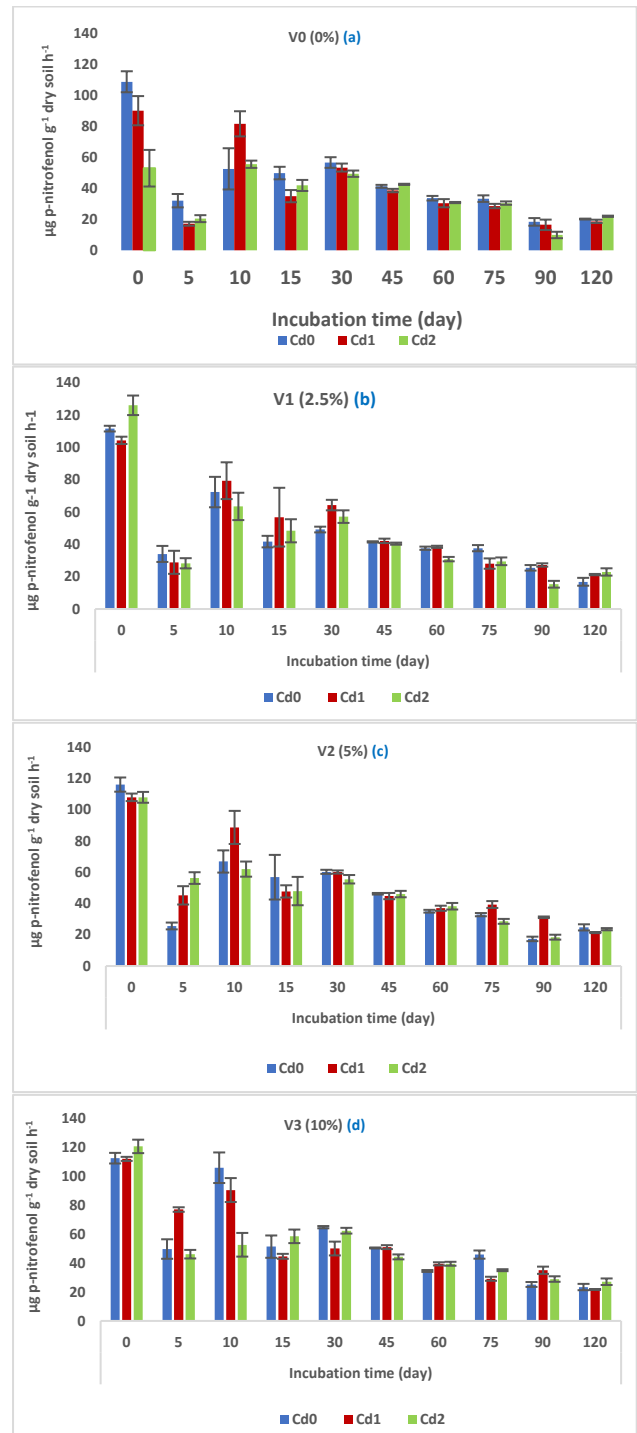
vermicompost compared to those that applied vermicompost, and generally, as the Cd dose increased, AFEA values decreased. The highest AFEA value was determined on the 5th day of incubation in soil treated with 528.33 $\mu\text{g p-nitrophenol g}^{-1} \text{FKT h}^{-1}$ and 10% vermicompost and added 10 mg.kg^{-1} Cd.

AFEA values generally decreased during the four-month incubation period. The alkaline phosphatase enzyme activity of the soil was affected differently by vermicompost applied in varying dosages on artificially contaminated soils and the Cd was statistically significant ($p < 0.01$).



Figures 1a, 1b, 1c, 1d. The effect of application of increasing doses of vermicompost on alkaline phosphatase enzyme activity in soils contaminated with Cd (V0: Vermicompost 0%; V1: 2.5%; V2:5%; V3:10%) (Cd0: Cd 0 mg.kg^{-1} ; Cd1: 5 mg.kg^{-1} ; Cd2: 10 mg.kg^{-1}).

The lowest AFEA was determined as 192.92 $\mu\text{g p-nitrophenol g}^{-1} \text{FKT h}^{-1}$ on the 30th day of incubation in soil without vermicompost application and with 5 mg.kg^{-1} of Cd added. It was determined that the AFEA values increased along with an increase in the vermicompost application dose. However, it was determined found that



Figures 2a, 2b, 2c, 2d. The effect of application of increasing doses of vermicompost on arylsulfatase enzyme activity in soils contaminated with Cd (V0: Vermicompost 0%; V1: 2.5%; V2:5%; V3:10%) (Cd0: Cd 0 mg.kg^{-1} ; Cd1: 5 mg.kg^{-1} ; Cd2: 10 mg.kg^{-1}).

3.2. Arylsulfatase enzyme activity (ASEA)

It was determined that the effect of vermicompost used in the study on the ASEA values of the soil changed depending on the application doses and incubation times, and that the ASEA values decreased as the applied Cd dose increased. The highest ASEA value was determined on the 0th day of incubation in soil treated with 125.99 μg p-nitrophenol g^{-1} FKT h^{-1} 2.5% vermicompost dose and added 10 $\text{mg}\cdot\text{kg}^{-1}$ Cd. The lowest ASEA was determined as 9.91 μg p-nitrophenol g^{-1} FKT h^{-1} on the 90th day of incubation in soil that was not treated with vermicompost and added 10 $\text{mg}\cdot\text{kg}^{-1}$ of Cd. It was observed that ASEA values generally increased as the dose of vermicompost increased.

The ASEA values were found to be high at the beginning of the incubation, and the ASEA values generally decreased after four months of incubation. The ASEA values were found to be lower in soils that were not treated with vermicompost than in soils treated with vermicompost. Related to Cd-contaminated soils the effects of vermicompost treatments applied at increasing concentrations on the arylsulfatase enzyme activity (ASEA) of the soil showed differences, and the interaction of vermicompost, Cd and vermicompost x Cd was statistically significant ($p < 0.01$).

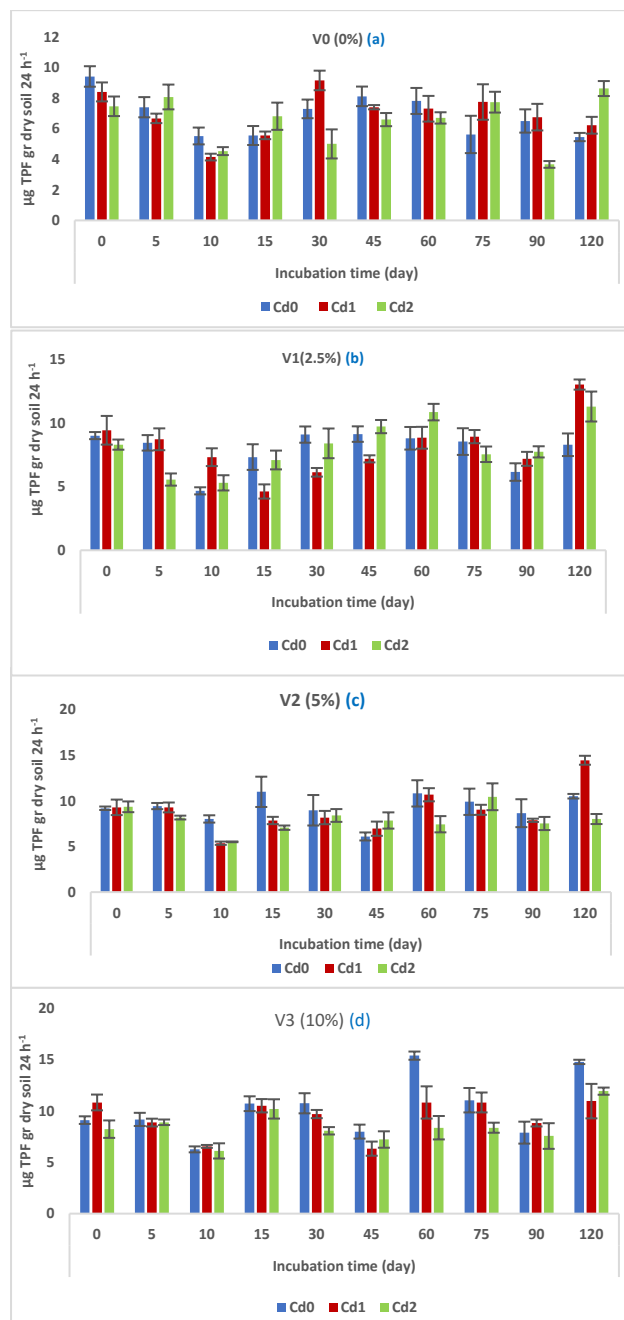
3.3. Dehydrogenase enzyme activity (DEA)

It was determined that the effect of vermicompost used in the study on the DEA values of the soil varies depending on the application doses and incubation times. It was observed that DEA values decreased with increasing Cd doses whereas, DEA values increased with increasing vermicompost doses applied. DEA values were found to be high at the beginning of incubation, and after four months of incubation, DEA values generally decreased. The highest DEA value was detected on the 60th day of incubation in 15.39 μg TPF g dry soil 24h^{-1} and soil without added vermicompost and Cd. The lowest DEA was determined as 4.14 μg TPF g dry soil 24h^{-1} on the 10th day of incubation in soil without vermicompost applied and with 5 $\text{mg}\cdot\text{kg}^{-1}$ Cd added. The effects of increasing doses of vermicompost applications on soils contaminated with Cd on the soil's dehydrogenase enzyme activity (DEA) showed differences, and the interaction of vermicompost, Cd and vermicompost x Cd was statistically significant ($p < 0.01$).

3.4. Urease enzyme activity (UEA)

Generally, as the applied Cd dose increased,

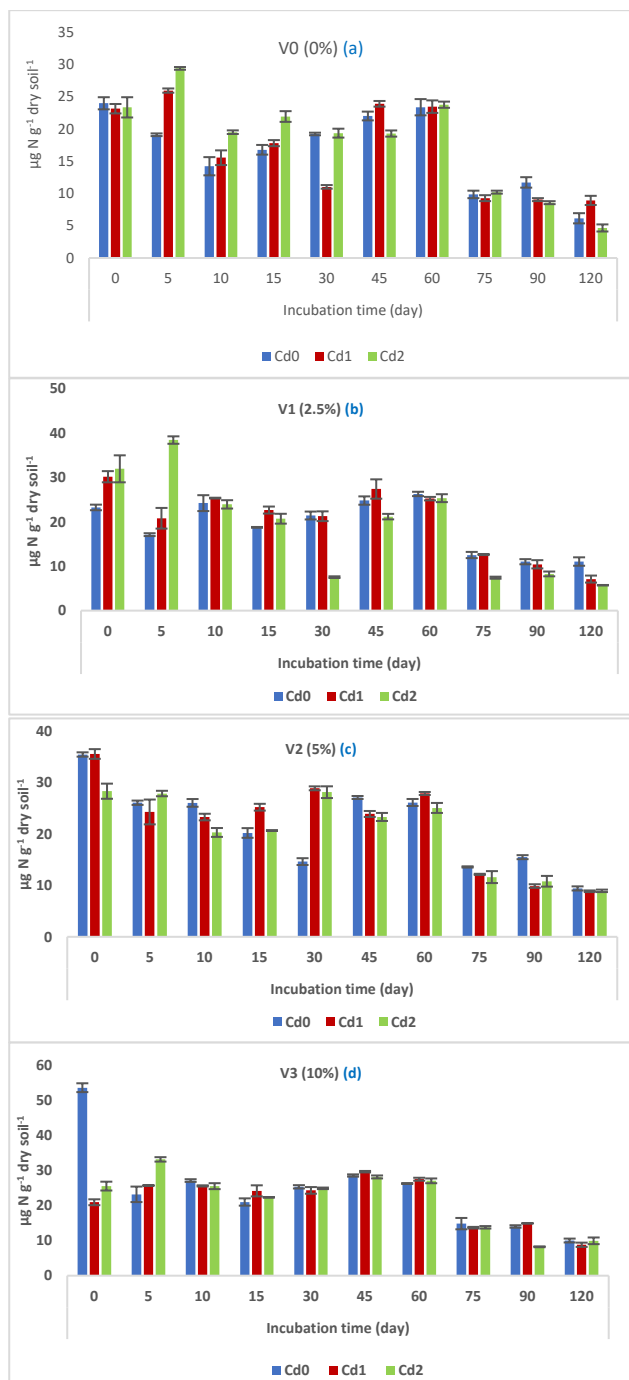
the UEA values decreased, on the contrary, as the vermicompost dose increased, the UEA values increased.



Figures 3a, 3b, 3c, 3d. The effect of application of increasing doses of vermicompost on dehydrogenase enzyme activity in soils contaminated with Cd (V0: Vermicompost 0%; V1: 2.5%; V2: 5%; V3: 10%) (Cd0: Cd 0 $\text{mg}\cdot\text{kg}^{-1}$; Cd1: 5 $\text{mg}\cdot\text{kg}^{-1}$; Cd2: 10 $\text{mg}\cdot\text{kg}^{-1}$)

The highest UEA value was determined on day 0 of incubation in soil treated with 53.63 μg N g^{-1} FKT⁻¹ 10% vermicompost and no Cd added. The lowest UEA was determined as 4.66 μg N g^{-1} FKT⁻¹ on the 120th day of incubation in soil that did not apply vermicompost and contained 10 $\text{mg}\cdot\text{kg}^{-1}$ cadmium. UEA values were

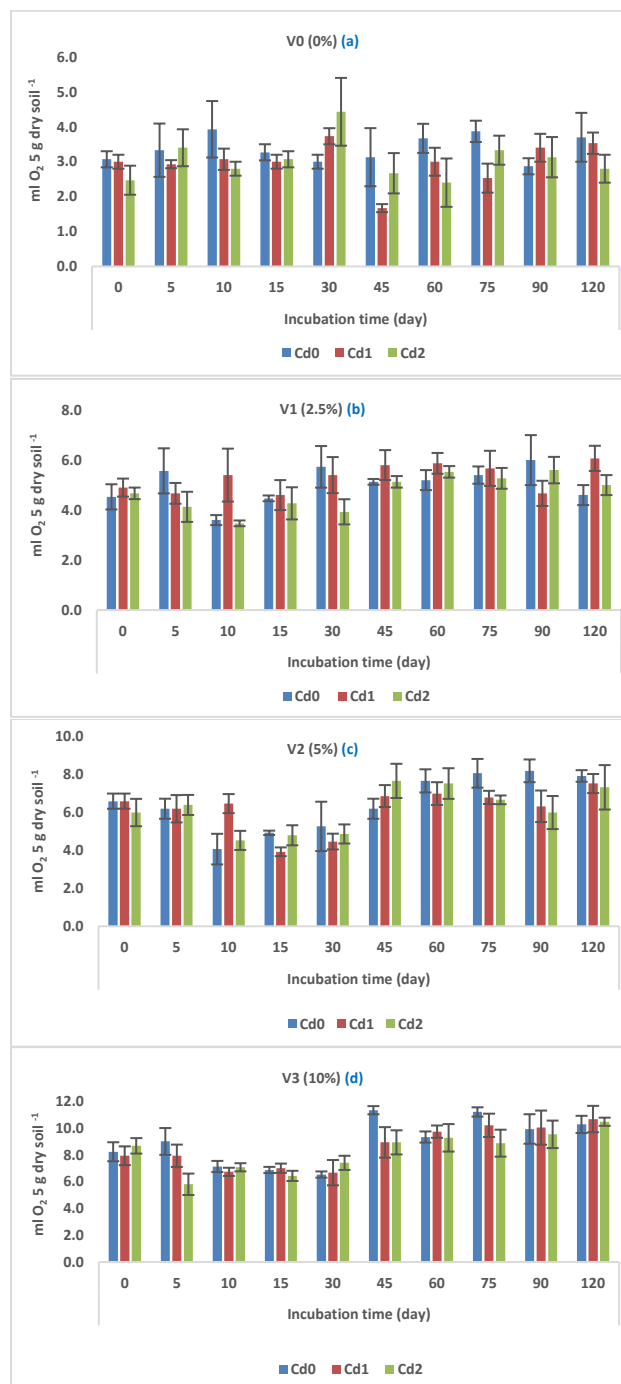
found to be high at the beginning of incubation, and after four months of incubation, UEA values generally decreased.



Figures 4a, 4b, 4c, 4d. The effect of application of increasing doses of vermicompost on urease enzyme activity in soils contaminated with Cd (V0: Vermicompost 0%; V1: 2.5%; V2:5%; V3:10%) (Cd0: Cd 0 mg.kg^{-1} ; Cd1: 5 mg.kg^{-1} ; Cd2: 10 mg.kg^{-1})

The highest value among vermicompost doses was determined at 10% application dose on day 0 of incubation. The effect of vermicompost applied at increasing doses on urease enzyme activity (UEA) in soils contaminated with cadmium showed differences,

and the interaction of vermicompost, Cd and vermicompost x Cd was statistically significant ($p < 0.01$). In contrast to soils where vermicompost was treated, lower UEA values were found in soils where vermicompost was not applied. UEA values showed differences between Cd doses, and these differences were statistically significant ($p < 0.01$) except for the 10th and 60th days of incubation.



Figures 5a, 5b, 5c, 5d. The effect of application of increasing doses of vermicompost on catalase enzyme activity in soils contaminated with Cd (V0: Vermicompost 0%; V1: 2.5%; V2:5%; V3:10%) (Cd0: Cd 0 mg.kg^{-1} ; Cd1: 5 mg.kg^{-1} ; Cd2: 10 mg.kg^{-1}).

3.5. Catalase enzyme activity (CEA)

It was determined that the values of CEA increased as the application dose of vermicompost increased from the beginning to the end of the incubation.

It was determined that as the Cd dose applied to the soil increased, the CEA values decreased. According to research, CEA values were lower in soils without vermicompost than those with vermicompost. The effect of increasing the doses of vermicompost applied soils contaminated with Cd on the activity of catalase enzyme (CEA) in the soil showed differences, and the interaction of Cd, vermicompost and vermicompost x Cd was statistically significant ($p < 0.01$). The highest CEA value was determined on the 45th day of incubation in soil treated with 11.33 ml O₂ 5 g⁻¹ and 10% vermicompost and without adding Cd. The lowest CEA was determined on the 45th day of incubation when no vermicompost was added to the soil and 5 mgkg⁻¹ Cd was applied as 1.67 ml O₂ 5 g⁻¹.

4. DISCUSSION

Our results showed that adding increasing doses of vermicompost to artificially contaminated soil and incubating it under laboratory conditions affected some enzyme activities (alkaline phosphatase, arylsulfatase, dehydrogenase, urease and catalase) in the soil. In this study, the enzyme activities of vermicompost and cadmium applications applied at increasing doses in the soil samples left for incubation showed differences in the soil, and these differences were found to be statistically significant. As the dose of vermicompost increased, enzyme activities generally increased in the incubated soils. It was determined that the addition of vermicompost to soils contaminated with Cd significantly reduced the toxic effects of Cd. Previous studies have reported that the combined application of vermicompost and biochar can stimulate the activity of soil enzymes by reducing the bioavailability and of heavy metal toxicity to microorganisms through microorganisms present in excess in the soil (Wang et al., 2018, Huang et al., 2018, Li et al., 2020). The addition of organic waste containing a higher concentration of humic acid is more beneficial for the remediation of Cd-contaminated soils (Tejada, 2009). According to Karaca et al., 2002, phosphatase enzyme activity decreased as the concentration of Cd in the soil increased. According to Kızılkaya et al., 2004, differences in the structure of microbial communities among soils and differences in sensitivity to heavy metal toxicity may be important factors in explaining these differences. They reported that adding organic matter to polluted soils may have reduced the toxicity of Cd by

positive effect on the microorganism population (Karaca et al., 2002; Moreno et al., 2003). They found that the soil microbial activity increased after adding a mixture of manure and sawdust to soils contaminated with Cu and Ni (Kiikkila et al., 2001). Also, Tejada et al., 2007 observed that after the adding poultry manure and crushed cotton compost to the soils contaminated with Pb, the inhibitory effect of lead decreased and had a positive effect on the biological properties of the soil. Castaldi et al., (2004) found that with the increase of heavy metal content in soil, the dehydrogenase, sulfatase, glucosidase and respiration activity in the soil decreased exponentially. On the other hand, Khan et al., (2010) observed that Cd has a negative effect on both microorganisms and phosphatase and urease enzyme activity. Liu et al., (2007), in a study they carried out, noticed that Cd administered at doses of 5 to 200 mg.kg⁻¹ inhibited urease and phosphatase enzyme activities; however, they reported that Cd at doses of 5 and 10 mgkg⁻¹ stimulated catalase activity. The decrease in the activity of catalase with the increase of Cd concentration in the soil showed that higher Cd concentrations are harmful to microorganisms and have a higher effect on enzyme activities (Yeboah et al., 2021). Chen et al., (2012) and Gao et al., (2010) determined that the catalase enzyme activity in the soil decreased with the increase of heavy metal presence. Hu et al., (2014) observed that catalase, urease and acid phosphatase enzyme activities were only slightly affected when heavy metal concentration was low. Humic substances affect the biological properties of toxic ions by acting as an accumulation phase of heavy metals, followed by the formation of metal humate complexes (chelates) with varying degrees of stability, possibly as a result of several major functional groups (such as carboxyl, phenolic, alcohol, and carbonyl) contained in humic substances (Dar, 1996; Datta et al., 2001). It has been reported that chelate formation may have reduced extractable Cd in the soils and therefore reduced the availability of Cd in microorganisms. However, the formation of chelates depends on the chemical composition of organic substances applied to the soil, and therefore the effect of organic substances on the biological properties of toxic ions is due to their chemical composition. In this context, Tejada et al. 2007; they found that the inhibition percentage of soil enzyme activities in lead-contaminated and poultry manure added soils were lower than in soils reclaimed with crushed cotton compost. Our results depend on the increase in Cd dose, and differences in enzyme activities in the soil were determined. These results are consistent with previous studies that reported that heavy metal content can influence soil enzyme activities through direct and indirect mechanisms (Cui et al., 2013; Hu et al., 2014; Papa et al., 2010; Yang et al., 2016). In

general, urease and dehydrogenase activities are inhibited by heavy metals (Wiatrowska et al., 2015; Xian et al., 2015). Other researchers have reported that the activities of soil enzymes decrease with an increase in the presence of heavy metals (Xian et al., 2015). Similarly, Cd has been shown to have a significant inhibitory effect on urease, acid phosphatase and catalase enzyme activities (Mao et al., 2015; Xin et al., 2017). It has been determined that the vermicompost applied to the soil changes the development of the enzyme-producing microbial population, and that the vermicompost added encourages the growth of microorganisms in the soil depending on the incubation time, and inhibits the growth of some of them. In our study, it is thought that the fluctuations that occur depending on the incubation time in the applied vermicompost soil may be caused by changes in the population of soil microorganisms may be caused by the decreased enzyme activity secreted by the altered microbial assemblies by suppressed enzyme production. The increase in activity with increasing doses of vermicompost applied to the soil may have been used as a substrate for the enzyme activity of vermicompost. We can attribute the fluctuations in enzyme activities seen during the incubation period to the decrease in the populations of microorganisms responsible for the decomposition in the soil as a result of a decrease in nitrogen from the environment.

5. CONCLUSION

In laboratory conditions, increasing doses of vermicompost (0-2.5-5-10%) were applied to soils that had been artificially contaminated by Cd (0, 5 and 10 mg.kg⁻¹) and allowed to incubate. Depending on the vermicompost dose, it was determined that some of the enzyme activities of the soils (AFEA, ASEA, DEA, UEA and CEA) increased. However, it was determined that the enzyme activities in the soil decreased during the incubation period. The highest reductions were detected in soil samples that had not applied vermicompost and were contaminated with Cd. During 120 days of incubation, the microorganisms showed that when exposed to Cd, they inhibit enzyme activities in response (inhibition). We can probably attribute the increase in the inhibition of microbial activity in the soil to the sensitivity and adaptability of microorganisms, the degree of contamination and the concentration of Cd. In this study, the toxic effects of Cd on the activity and composition of soil microorganisms were highly dependent on the Cd content, vermicompost and incubation time. The addition of vermicompost to soils with Cd pollution significantly reduced the toxic effects of Cd. However, the effect of each compost on the biological properties of the soil may vary depending on

its chemical composition. Our study showed that the addition of increasing vermicompost doses can be considered a good strategy for the remediation of Cd-contaminated soils. The addition of compost with high content of organic matter may be beneficial for the treatment of heavy metal pollution.

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