of coagulants and flocculants is to increase the particle size due to their adhesion (aggregation) and, as a result, to increase the efficiency of purification due to filtration, precipitation, and flotation of water. We recommend using the culture liquid of Acidithiobacillus ferrooxidans bacteria as a coagulant for wastewater treatment of enterprises from metal ions and some organic pollutants. A.ferrooxidans uses Fe^{2+} as an energy source, so the concentration of Fe^{2+} in the medium can affect the growth of bacteria. In the process of oxidation of ferrous iron to trivalent iron, bacteria receive the energy necessary for their metabolism. Trivalent iron obtained during the oxidation process can be used as a biocoagulant in wastewater treatment. The article shows the optimal temperature for biochemical oxidation of iron by bacteria.

Key words: *coagulation, wastewater, thion bacteria, oxidation, Acidithiobacillus ferrooxidans.*

Авторлар туралы мәліметтер

Маржан Нурлановна Сыздыкова* – жаратылыстану ғылымдарының магистрі, «Экология» кафедрасының докторанты; М. Әуезов атындағы ОҚУ, Казахстан, Шымкент; e-mail: maksat.marzhan@mail.ru. ORCID: https://orcid.org/0000-0002-9603-9743.

Акмарал Умирбековна Исаева – биология ғылымдарының докторы, «Экология» кафедрасының профессоры; М. Әуезов атындағы ОҚУ; Казахстан, Шымкент; e-mail: akissayeva@bk.ru. ORCID: https://orcid.org/0000-0001-8323-3982.

Сведения об авторах

Маржан Нурлановна Сыздыкова – Южно-Казахстанский Университет им. М. Ауэзова; Казахстан, Шымкент; магистр естественных наук, докторант кафедры «Экология»; e-mail: maksat.marzhan@mail.ru. ORCID: https://orcid.org/0000-0002-9603-9743.

Акмарал Умирбековна Исаева – доктор биологических наук, профессор кафедры «Экология»; Южно-Казахстанский Университет им. М. Ауэзова; Казахстан, Шымкент; e-mail: akissayeva@bk.ru. ORCID: https://orcid.org/0000-0001-8323-3982.

Information about the authors

Маржан Нурлановна Сыздыкова* – M. Auezov South Kazakhstan University; Republic of Kazakhstan, Shymkent; master of Natural Sciences, Doctoral student of the Department of Ecology; e-mail: maksat.marzhan@mail.ru. ORCID: https://orcid.org/0000-0002-9603-9743.

Акмарал Умирбековна Исаева – Doctor of Biological Sciences, Professor of the Department of Ecology; M. Auezov South Kazakhstan University; Republic of Kazakhstan, Shymkent; e-mail: akissayeva@bk.ru. ORCID: https://orcid.org/0000-0001-8323-3982.

Редакцияға енуі 04.10.2024
Өңдеуден кейін түсуі 23.01.2025
Жариялауға қабылданды 24.01.2025

https://doi.org/10.53360/2788-7995-2025-1(17)-50

IRSTI: 87.21.09; 87.21.23

D.Kh. Yuldashbek*, D.K. Sunakbaeva
Khoja Ahmed Yasawi International Kazakh-Turkish University,
016200, Republic of Kazakhstan, Turkestan, 29/3 Sattarkhanov Avenue
*e-mail: davlat.yuldashbek@ayu.edu.kz

EFFECTS OF PHYTOREMEDIATION ON ENZYMATIC ACTIVITY AND FERTILITY RESTORATION IN CADMIUM-CONTAMINATED SOIL

Abstract: *This study is dedicated to the investigation of phytoremediation of cadmium-contaminated soil using carrot (Daucus carota L.) and vermicompost. The paper discusses methods for modeling soil contamination and determining cadmium translocation in plants, as well as the impact of phytoremediation on the activity of soil enzymes, such as catalase, urease, dehydrogenase, and protease. The experiment showed that Daucus carota L. effectively accumulates cadmium in the roots, especially at high concentrations of contamination. The introduction of vermicompost into the soil helps reduce cadmium accumulation in the plant, which may be related to the improvement of soil structure and its ability to neutralize toxic substances. Furthermore, the addition of vermicompost helps maintain higher levels of soil enzyme activity, alleviating the toxic effects of cadmium on microorganisms and the soil ecosystem. The results of the study confirm that carrots (Daucus carota L.), as a phytoremediant, in combination with vermicompost can be used to clean the soil of pollutants (Cd) and restore its biological activity.*

Key words: *soil, cadmium pollution, enzymatic activity, vermicompost, phytoremediation, carrot (Daucus carota L.,).*

Introduction

Heavy metal contamination is a prevalent form of pollution around the world and has emerged as a significant global concern due to its potential dangers to both ecosystems and human health [1, 2].

Cadmium (Cd) is widely recognized as a highly toxic heavy metal that poses significant biological risks to both terrestrial and aquatic organisms [3]. It enters ecosystems through various human activities and environmental emissions. When plants grow in contaminated soils, they absorb Cd, which can lead to serious health risks for animals and humans due to its high mobility in polluted environments [4]. Cd toxicity affects multiple organs in the human body, with the kidneys being the primary site of accumulation, leading to severe conditions such as emphysema, damage to renal tubules, and kidney stones [5]. Because Cd can replace calcium (Ca) in minerals, due to their similar ionic radius, charge, and chemical behavior [6], it is easily absorbed by the human body and accumulates in various organs at high concentrations.

Chlorosis and stunted growth are common signs of cadmium (Cd) toxicity in plants [7]. Increased levels of toxicity hinder plant development and cause necrosis. Cadmium's harmful effects on plants involve the disruption of carbon fixation, a decrease in chlorophyll levels, and reduced photosynthetic efficiency [8]. Exposure to Cd in soil induces osmotic stress, lowering the relative water content in leaves, as well as reducing stomatal conductance and transpiration, which results in physiological harm to the plants [9].

Cd is a relatively mobile heavy metal, and plant roots are highly efficient at absorbing and transporting it to the aboveground parts [10]. Even at low concentrations, Cd can interfere with plant metabolism, leading to phytotoxicity and potentially plant death. However, certain Cd-accumulating plants can tolerate higher Cd levels and store it in their tissues without exhibiting toxicity symptoms [11, 12].

Cd typically exists as Cd^{2+} in soil and is considered its most toxic form. The uptake of Cd by plant shoots is mainly determined by how Cd is absorbed through the roots, stored in vacuoles, and transported via the xylem and phloem. The plant's above-ground parts generally contain lower concentrations of Cd than the below-ground parts, meaning that the roots accumulate the highest levels of Cd, with smaller amounts transferred to the xylem and seeds. The higher mobility of Cd is facilitated by the roots, which absorb it from the soil and transport it to the xylem through either apoplastic or symplastic routes, or by binding it to organic acids or phytochelatins.

Soil contamination with cadmium not only impacts soil fertility [13], but also disrupts microbial and enzymatic functions. Additionally, significant amounts of cadmium can accumulate in crops or plants, presenting a major health hazard [14].

Soil enzymes are the most active components of the soil ecosystem and play a crucial role in the cycling of soil materials and energy [15]. The presence of heavy metals in the soil can influence the activity of these enzymes. Changes in enzyme activity can reflect important ecological processes within the soil, and the level of this activity can serve as an indicator for assessing the ecological safety of heavy metals in the soil [16, 17]. Studies have shown that increasing concentrations of cadmium lead to a decrease in the activity of soil dehydrogenase, catalase, protease, and urease [18, 19].

Phytoremediation is a method of cleaning contaminated soils that uses specific plant species to absorb and accumulate heavy metals, helping to restore the polluted soil [20]. This process is gaining popularity due to its cost-effectiveness, simplicity, and eco-friendly nature [21].

In this study, we selected carrot *(Daucus carota L.)* as a model root vegetable to examine how realistic levels of soil Cd contamination affect Cd accumulation, absorption, and the distribution of essential mineral nutrients.

Vegetables are highly susceptible to heavy metals, which can accumulate in their roots, stems, and leaves [22]. The carrot *(Daucus carota L.)*, a key vegetable with a cultivation history of over 1000 years and widespread popularity, is predominantly grown in Europe and Asia today [23]. Research has revealed concerning levels of cadmium (Cd) in the roots of carrots *(Daucus carota L.)* cultivated in contaminated soils [24]. This study investigated how carrots *(Daucus carota L.)* developed in soil contaminated with cadmium compared to those grown in uncontaminated soil. The research specifically aimed to explore the physiological and metabolic changes in carrots *(Daucus carota L.)* exposed to Cd from seed planting to the point of consumer maturity, in comparison with the control group.

Organic fertilizers, such as vermicompost, are widely recognized for their ability to improve soil structure and fertility by supplying vital nutrients and boosting the microbial activity in the soil [25]. The application of organic fertilizers is a widespread practice globally to enhance soil nutrition, leading to increased crop productivity [26]. Vermicompost has long been utilized both as a nutrient source and a soil enhancer to promote the growth and yield of agricultural crops [27].

The incorporation of vermicompost into soil improves natural processes like sedimentation, complexation, adsorption, and absorption, which helps decrease the bioavailability of pollutants [28]. Additionally, vermicompost promotes plant growth in contaminated soil by binding pollutants, boosting nutrient levels, and stimulating the local microbial community [29].

The aim of this study is to assess the impact of phytoremediation and the application of vermicompost on the restoration of soil fertility and enzymatic activity in soil contaminated with cadmium.

Objects and Methods of Research.

The objects of the study were the soil of the Turkestan region, vermicompost made from agricultural waste, and the carrot culture *(Daucus carota L.)* used as a phytoremediator. The chemical analysis of soil composition was conducted using voltammetric, qualitative, and quantitative methods of analysis.

Experimental work was carried out using the box method (Figure 1). Soil and soil with vermicompost contamination with cadmium (Cd) was artificially carried out by adding cadmium acetate ($Cd(CH_3COO)_2$) at maximum allowable concentration (MAC): 0,5 MAC (0,25 mg/kg of soil), 2,5 MAC (1,25 mg/kg of soil), 5,0 MAC (2,5 mg/kg of soil), and 10,0 MAC (5,0 mg/kg of soil) (based on cadmium ions in the soil). Acetic acid salts were chosen for modeling soil contamination due to their good solubility and ability to quickly and completely interact with the soil mass. After the addition of cadmium, the soil and soil with vermicompost were incubated in plastic containers for 21 days at a temperature of 23±2℃. Control experiments used original soils without the addition of cadmium and with the addition of vermicompost, but no cadmium was present. Carrots *(Daucus carota L.)* were planted in the artificially contaminated boxes.

The growth and development phases of carrots *(Daucus carota L.)* are shown in the following Figure 1.

Figure 1 – Growth and development phases of carrot *(Daucus carota L.)*

After the end of the growing season, green shoots and root crops of Daucus carota L. were collected, along with soil samples. These samples were then dried under laboratory conditions, followed by analytical testing.

The total cadmium content in the soil and carrot *(Daucus carota L.)* was determined using the voltammetric method on the "TA-Lab" instrument, nitrogen content was measured by the titrimetric method, the mobile form of phosphorus in the soil was determined using the Machigin method, humus content was analyzed by the Tyurin method, and the quantity of exchangeable bases was measured using the Kappen-Gilkovich method.

The humus content in the soil is approximately 1.1%, total nitrogen is around 0.16%, mobile phosphorus ranges from 10.8 to 25.3 mg/kg, and the total exchangeable bases content is between 22.1 and 25.4 mg-equiv/100 g. Soils in the Turkestan region are characterized by low humus content and moisture levels, indicating insufficient water for plant growth. The soil color in the region is gray or gray-brown.

Methods for determining the enzymatic activity of soils and plants. The activity of oxidation-reduction enzymes (catalase, dehydrogenase) and hydrolytic enzymes (urease, protease) was analyzed in the soil. Enzyme activity was measured in triplicate, with an average sample used for the analysis [30].

Catalase activity in soils and plants was measured using the gasometric method developed by A.sh. Galstyan, which involves determining the volume of O_2 released during the breakdown of hydrogen peroxide. The catalase enzyme activity was expressed as the volume of O_2 released in one minute per gram of soil or plant [30].

Urease activity was measured using the method developed by I.N. Romeyko and S.M. Malinskaya, which involves determining the amount of ammonia produced during urea hydrolysis. In this procedure, the Nessler reagent is employed, which forms a colored complex with ammonia. The concentration of ammonia is then measured using the «Concentration photovoltaic photometer» (KPP-3-«ZOMZ») produced in Russia by JSC «ZOMZ», equipped with a blue light filter at a wavelength of 400 nm. The photometer uses a cuvette with a 10 mm path length, and the permissible basic absolute error for the wavelength is ± 3 nm. Urease activity is reported as mg $NH_4^{+} \cdot g^{-1}$ of soil $24h^{-1}$ [30].

To measure *dehydrogenase* activity, colorless tetrazolium salts, specifically 2,3,5-triphenyltetrazolium chloride (TTC), were used as hydrogen acceptors, which are reduced to red formazan compounds (triphenylformazan – TPF). The dehydrogenase activity based on TPF formation was assessed using A.Sh. Galstyan's spectrophotometric method, with a green light filter in the range of 500-560 nm and a 10 mm cuvette. The activity was reported in milliliters of triphenylformazan (TPF) per 10 grams of soil after 24 hours [31].

Proteases (also known as peptidases) are enzymes that catalyze the hydrolysis of peptide bonds (CO-NH) in proteins or peptides, breaking them down into smaller peptides or free amino acids. The activity of proteases was measured using A.Sh. Galstyan's method and is expressed as milligrams of glycine per gram of soil over a 24-hour period [32].

Results and Discussion

The cadmium (Cd) translocation rates in the green shoots and roots of *Daucus carota L.* in the soil system are presented in Table 1.

Table 1 – Cadmium (Cd) translocation in the green shoots and roots of *Daucus carota L.*

Cadmium (Cd) concentration, MAC	Translocation of Cd in carrot *(Daucus carota L.)*, mg/kg			
	Green shoots		Root crops	
	Soil	Soil + Vermicompost	Soil	Soil + Vermicompost
0	0,0042 ± 0,0012	0,0030 ± 0,0010	0,0063 ± 0,0021	0,0057 ± 0,0016
0,5	0,0089 ± 0,0016	0,0066 ± 0,0014	0,049 ± 0,0024	0,025 ± 0,0019
2,5	0,0163 ± 0,0026	0,0112 ± 0,0022	0,192 ± 0,0032	0,119 ± 0,0026
5,0	0,0544 ± 0,0030	0,0461 ± 0,0036	0,350 ± 0,0037	0,206 ± 0,0035
10,0	0,125 ± 0,0033	0,0893 ± 0,0041	0,667 ± 0,0045	0,441 ± 0,0047

The results of the study on cadmium (Cd) translocation in carrots *(Daucus carota L.)* when used as a phytoremediator for soil decontamination showed that carrots are capable of accumulating cadmium in their tissues, particularly in the roots, when the soil is contaminated with this metal. In the control soil, where the cadmium level was minimal, the concentration in the green shoots was 0.0042 mg/kg, and in the roots – 0.0063 mg/kg. This indicates a minimal accumulation of cadmium in the plant at low levels of contamination.

When the cadmium concentration in the soil is increased to 0.5 MAC, *Daucus carota L.* begins to actively accumulate cadmium, especially in the root crops, where the concentration reaches 0.049 mg/kg. The highest cadmium translocation was recorded at a cadmium concentration of 10.0 MAC in the soil, with the concentration in the root crops reaching 0.667 mg/kg, indicating the plant's high capacity to accumulate cadmium under severe contamination.

The addition of vermicompost to the soil helped reduce cadmium accumulation in *Daucus carota L.* For instance, at a contamination level of 0.5 MAC, the cadmium concentration in the green shoots was 0.0066 mg/kg, and in the root crops – 0.025 mg/kg, both lower than in the soil without vermicompost. At a higher contamination level (10.0 MAC), the addition of vermicompost also contributed to a reduction in the cadmium content in the root crops – down to 0,441 mg/kg compared to 0.667 mg/kg in the soil without vermicompost.

Thus, *Daucus carota L.* demonstrated a significant ability to accumulate cadmium in the root crops, making it a promising phytoremediator. At the same time, the addition of vermicompost to the soil reduces cadmium accumulation, which may be related to the improvement of soil structure and its ability to neutralize toxic substances.

The influence of phytoremediation on catalase activity in cadmium-contaminated soil.

The presented data reflect the influence of phytoremediation using carrot *(Daucus carota L.)* as a phytoremediator on catalase activity in cadmium-contaminated soils (Figure 2). Two options are considered for analysis: control soil and soil supplemented with vermicompost (VC).

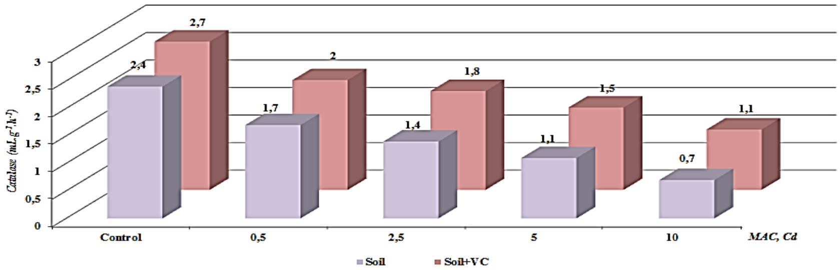

Figure 2 – Effect of phytoremediation using carrot *(Daucus carota L.)* on catalase enzymatic activity in soils contaminated with different concentrations of Cd

In the control soil, which is not contaminated with cadmium, the catalase activity is 2.4 mL·g^{-1}·h^{-1}, serving as the baseline for further comparison. In the soil with vermicompost, the catalase activity is slightly elevated at 2.7 mL·g^{-1}·h^{-1}, indicating a stimulating effect of vermicompost, which supports the activity of antioxidant enzymes such as catalase.

When the soil is contaminated with cadmium at a concentration of 0.5 MAC, the catalase activity in the control soil decreases to 1.7 mL·g^{-1}·h^{-1}, which indicates that low concentrations of cadmium begin to inhibit catalase activity, though the effect is not yet strong. In soil with vermicompost, the catalase activity remains slightly higher – 2.1 mL·g^{-1}·h^{-1} – confirming that vermicompost helps maintain a higher level of catalase activity even at low cadmium doses, partially mitigating the toxic effects.

When the soil is contaminated with cadmium at a concentration of 2.5 MAC, catalase activity in the control soil decreases to 1.4 mL·g^{-1}·h^{-1}, indicating a more pronounced suppression of enzymatic activity. In soil with vermicompost, the catalase activity is 1.8 mL·g^{-1}·h^{-1}, which further confirms that the addition of vermicompost continues to have a positive effect, maintaining higher levels of catalase activity compared to the control soil under moderate contamination.

At higher concentrations of cadmium (5 and 10 MAC), catalase activity in the control soil significantly decreases. At 5 MAC Cd, it is 1.1 mL·g^{-1}·h^{-1}, and at 10 MAC – 0.7 mL·g^{-1}·h^{-1}, which confirms the strong inhibitory effect of cadmium on the activity of antioxidant enzymes. In soil with vermicompost, catalase activity also decreases but remains higher than in the control soil: 1.5 mL·g^{-1}·h^{-1} at 5 MAC and 1.1 mL·g^{-1}·h^{-1} at 10 MAC. This indicates that vermicompost helps maintain catalase activity, alleviating the toxic effects of cadmium, though the effectiveness of this effect decreases with the increasing concentration of cadmium.

The results demonstrate that phytoremediation using carrot *(Daucus carota L.)* combined with vermicompost addition positively affects catalase activity in cadmium-contaminated soils. The addition of vermicompost helps maintain higher levels of catalase activity, indicating the ability of vermicompost to reduce the toxic effects of cadmium and improve conditions for microorganisms involved in antioxidant defense.

The influence of phytoremediation on urease activity in cadmium-contaminated soil.

The data represent the impact of phytoremediation using carrot *(Daucus carota L.)* as a phytoremediator on urease activity in soils contaminated with cadmium. Two options are presented for analysis: control soil and soil supplemented with vermicompost (Figure 3).

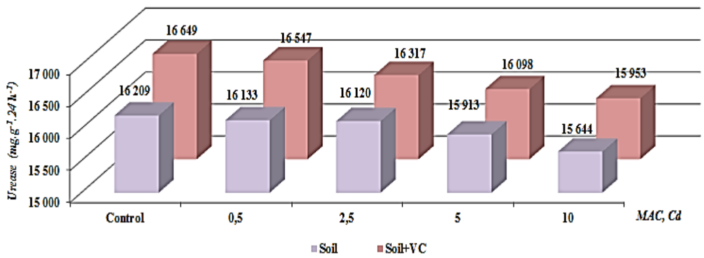

Figure 3 – Effect of phytoremediation using carrot *(Daucus carota L.)* on urease enzymatic activity in soils contaminated with different concentrations of Cd

In the control soil without cadmium contamination, urease activity is 16.209 mg·g^{-1}·24 h^{-1}. This is the baseline level of urease activity for further comparison. In the soil with vermicompost, urease activity is slightly higher at 16.649 mg·g^{-1}·24 h^{-1}, indicating a positive effect of vermicompost on enzyme activity, stimulating microorganisms involved in the nitrogen cycle.

When the soil is contaminated with cadmium at a concentration of 0.5 MAC, urease activity in the control soil decreases to 16.133 mg·g^{-1}·24 h^{-1}, indicating a slight impact of low cadmium concentration on urease activity. In the soil with vermicompost, the activity remains similar at 16.547 mg·g^{-1}·24 h^{-1}, suggesting that at low cadmium concentrations, vermicompost does not have a significant impact on urease activity, maintaining it at a level close to the control.

When the cadmium concentration is increased to 2.5 MAC, the urease activity in the control soil decreases to 16.120 mg·g^{-1}·24 h^{-1}, indicating moderate inhibition of enzyme activity associated with contamination. In the soil with vermicompost, the urease activity slightly decreases to 16.317 mg·g^{-1}·24 h^{-1}, suggesting a protective effect of vermicompost, which helps maintain a higher urease activity in the soil under moderate cadmium contamination.

At higher cadmium concentrations (5 MAC and 10 MAC), urease activity in the control soil significantly decreases. At 5 MAC Cd, it is 15.913 mg·g^{-1}·24 h^{-1}, and at 10 MAC – 15.644 mg·g^{-1}·24 h^{-1}. This confirms that increasing cadmium concentration exerts an inhibitory effect on enzyme activity, reducing urease activity levels. In the soil with vermicompost, urease activity also decreases, but remains at a higher level compared to the control soil: 16.098 mg·g^{-1}·24 h^{-1} at 5 MAC and 15.953 mg·g^{-1}·24 h^{-1} at 10 MAC. This indicates that vermicompost helps maintain higher urease activity, mitigating the toxic impact of cadmium on soil microorganisms.

The results show that phytoremediation using carrot *(Daucus carota L.)* in combination with vermicompost addition has a positive effect on urease activity in soils contaminated with cadmium. Despite the decrease in urease activity due to cadmium contamination, the addition of vermicompost helps maintain higher levels of this enzyme activity, especially at higher cadmium concentrations (5 and 10 MAC). This confirms that vermicompost contributes to alleviating the toxic effects of cadmium, improving conditions for microorganisms involved in the nitrogen cycle.

The influence of phytoremediation on dehydrogenase activity in cadmium-contaminated soil.

The data presented in Figure 4 reflect the impact of phytoremediation using carrot *(Daucus carota L.)* as the phytoremediator on dehydrogenase activity in soil contaminated with cadmium. In combination with vermicompost, which helps improve conditions for microorganisms, the phytoremediator aids in restoring soil activity, even in the presence of pollutants.

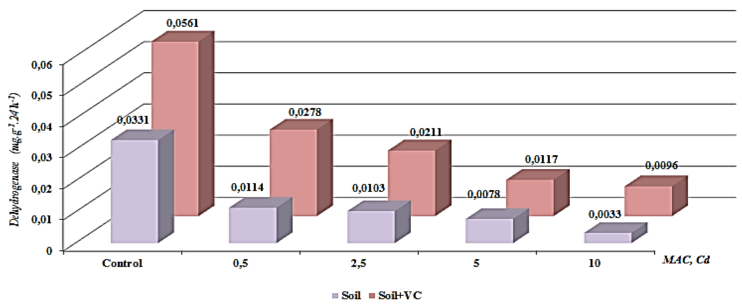

Figure 4 – Effect of phytoremediation using carrot (*Daucus carota L.)* on dehydrogenase enzymatic activity in soils contaminated with different concentrations of Cd

In the control soil, which is not contaminated with cadmium, the dehydrogenase activity is 0.0331 mg·g^{-1}·24 h^{-1}, which is considered normal for healthy soil. In soil supplemented with vermicompost, the enzyme activity increases to 0.0561 mg·g^{-1}·24 h^{-1}, indicating a positive effect of vermicompost that stimulates microbial activity.

When the soil is contaminated with cadmium at a concentration of 0.5 MAC, the dehydrogenase activity in the control soil decreases to 0.0114 mg·g^{-1}·24 h^{-1}, confirming the toxic impact of cadmium on microbial processes in the soil. In the soil with vermicompost, the activity remains higher at 0.0278 mg·g^{-1}·24 h^{-1}, indicating that the addition of vermicompost combined with phytoremediation (using carrots) helps maintain a higher enzyme activity despite the presence of cadmium.

When the soil is contaminated with cadmium at a concentration of 2.5 MAC, the dehydrogenase activity in the control soil decreases to 0.0103 mg·g^{-1}·24 h^{-1}. In the soil with vermicompost, the activity remains at a higher level of 0.0211 mg·g^{-1}·24 h^{-1}, which confirms the ability of phytoremediation and vermicompost to maintain higher microbial activity even at higher cadmium concentrations.

At higher cadmium concentrations (5 MAC and 10 MAC), dehydrogenase activity in the control soil significantly decreases: to 0.0078 mg·g^{-1}·24 h^{-1} at 5 MAC and to 0.0033 mg·g^{-1}·24 h^{-1} at 10 MAC. This indicates a substantial toxic effect of cadmium, which suppresses the activity of soil microorganisms. In the soil with vermicompost, the enzyme activity remains higher: 0.0117 mg·g^{-1}·24 h^{-1} at 5 MAC and 0.0096 mg·g^{-1}·24 h^{-1} at 10 MAC. This demonstrates that the phytoremediator *(Daucus carota L.)* in combination with vermicompost can partially mitigate the toxic effects of cadmium, maintaining higher dehydrogenase activity compared to the control soil.

The results show that phytoremediation using carrot *(Daucus carota L.)* in combination with the addition of vermicompost has a positive effect on dehydrogenase activity in soils contaminated with cadmium. Vermicompost helps maintain microbial activity, while carrot *(Daucus carota L.)* contributes to reducing cadmium concentration in the soil, partially restoring enzymatic activity.

The influence of phytoremediation on protease activity in cadmium-contaminated soil.

The presented data illustrate the impact of phytoremediation using carrot *(Daucus carota L.)* as a phytoremediator on protease activity in soils contaminated with cadmium. Two variants are considered for analysis: control soil and soil supplemented with vermicompost (Figure 5).

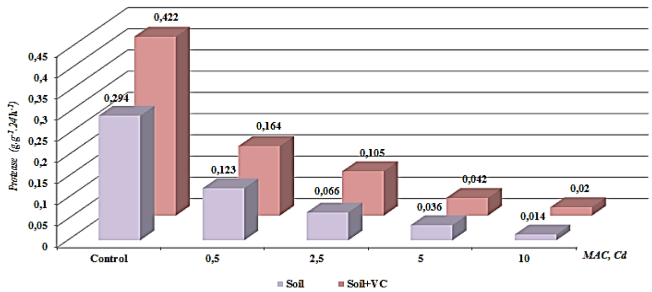

Figure 5 – Effect of phytoremediation using carrot *(Daucus carota L.)* on protease enzymatic activity in soils contaminated with different concentrations of Cd

In the control soil, protease activity is 0.294 g·g^{-1}·24 h^{-1}, which serves as the baseline for comparison. In the soil with vermicompost, protease activity increases to 0.422 g·g^{-1}·24 h^{-1}, indicating a positive effect of vermicompost, which stimulates microbial activity and protease activity in the soil.

When the soil is contaminated with cadmium at a concentration of 0.5 MAC, protease activity decreases to 0.123 g·g^{-1}·24 h^{-1}. This suggests the toxicity of cadmium to soil microorganisms, leading to a reduction in protease activity. In the soil with vermicompost, protease activity remains somewhat higher – 0.164 g·g^{-1}·24 h^{-1}. This indicates that the addition of vermicompost helps partially mitigate the negative effects of cadmium and maintain enzyme activity.

At a cadmium concentration of 2.5 MAC, the protease activity in the control soil decreases to 0.066 g·g^{-1}·24 h^{-1}. This confirms that the increased cadmium concentration significantly inhibits microbiological processes in the soil. In soil with vermicompost, the protease activity remains at a higher level – 0.105 g·g^{-1}·24 h^{-1}. This again demonstrates that vermicompost helps maintain enzyme activity despite soil contamination.

At higher cadmium concentrations (5 and 10 MAC), protease activity in the control soil significantly decreases. At 5 MAC Cd, it is 0.036 g·g^{-1}·24 h^{-1}, and at 10 MAC, it drops to 0.014 g·g^{-1}·24 h^{-1}. This indicates the high toxicity of cadmium, which has a suppressive effect on microorganism activity. In soil with vermicompost, protease activity also decreases but remains higher than in the control soil: 0.042 g·g^{-1}·24 h^{-1} at 5 MAC and 0.020 g·g^{-1}·24 h^{-1} at 10 MAC. This confirms that vermicompost partially mitigates the toxic impact of cadmium, maintaining higher protease activity compared to contaminated soil without additives.

The results show that phytoremediation using carrot *(Daucus carota L.)* in combination with vermicompost addition positively affects protease activity in soils contaminated with cadmium. Vermicompost helps alleviate the toxic effects of cadmium, supporting higher protease activity in the soil. At low and medium cadmium concentrations (0.5 and 2.5 MAC), protease activity remains relatively high, indicating a partial recovery of enzymatic activity due to phytoremediation and improved soil conditions.

Conclusion

The research has shown that the addition of vermicompost to the soil significantly reduces the accumulation of cadmium in *Daucus carota L.,* both in the aerial and underground parts of the plant.

Vermicompost acts as a blocking material, reducing the translocation of cadmium from the soil into the plants. This occurs due to the formation of insoluble complex compounds with cadmium, which convert it into less mobile forms, thereby reducing its availability for absorption by the plants. As a result, the cadmium contamination level in *Daucus carota L.* is significantly reduced, especially at high soil contamination levels (5.0, 10.0 MAC). These findings confirm that vermicompost can be an effective tool for reducing heavy metal contamination in plants, such as cadmium, and may be used in phytostabilization technologies and the reclamation of contaminated lands.

The results of the study showed that *Daucus carota L.,* grown in cadmium-contaminated soil, has a high ability to accumulate cadmium. It has been proven that *Daucus carota L.* can be used as a phytoremediator for soil decontamination from heavy metals.

References

1. Clemens S. Safer food through plant science: reducing toxic element accumulation in crops / S. Clemens // Journal of Experimental Botany. – 2019. – V. 70, Iss. 20. – P. 5537-5557. https://doi.org/10.1093/jxb/erz366.

2. Effect of cadmium accumulation on mineral nutrient levels in vegetable crops: potential implications for human health / D. Yang et al // Environ Sci Pollut Res Int. – 2016. – V. 23(19). – P. 19744-53. https://doi.org/10.1007/s11356-016-7186-z.

3. Chellaiah E.R. Cadmium (heavy metals) bioremediation by Pseudomonas aeruginosa: a mini-review / E.R. Chellaiah // Appl. Water Sci. – 2018. – V. 8, 154. https://doi.org/10.1007/s13201- 018-0796-5.

4. Modeling and evaluation of urban pollution events of atmospheric heavy metals from a large Cu-smelter / B. Chen et al // Sci. Total Environ. – 2016. – V. 539. – P. 17-25.

5. Agricultural Strategies to Reduce Cadmium Accumulation in Crops for Food Safety / S. Mubeen et al // Agriculture. – 2023. – V. 13, № 471. https://doi.org/ 10.3390/agriculture13020471.

6. Kubier A. Cadmium in soils and groundwater: a review / A. Kubier, R.T. Wilkin, T. Pichler // Appl. Geochem. – 2019. – V. 108, 104388. https://doi.org/10.1016/j.apgeochem.2019.104388.

7. Jali P. Effects of cadmium toxicity in plants: a review article / P. Jali, C. Pradhan, A.B. Das // Sch. Acad. J. Biosci. – 2016. – V. 4. – P. 1074-1081. https://doi.org/10.21276/ sajb.2016.4.12.3.

8. Unravelling cadmium toxicity and tolerance in plants: insight into regulatory mechanisms / S.M. Gallego et al // Environ. Exp. Bot. – 2012. – V. 83. P. 33-46.

9. Cadmium minimization in wheat: a critical review / M. Rizwan et al // Ecotoxicol. Environ. Saf. – 2016. – V. 130. – P. 43-53.

10. Bioaccumulation and Health Risk Assessment of Heavy Metals in the Soil-Rice System in a Typical Seleniferous Area in Central China / C. Chang et al // Environ Toxicol Chem. – 2019. – V. 38(7). – P. 1577-1584. https://doi.org/10.1002/etc.4443. PMID: 30994945.

11. Phylogenetic variation in heavy metal accumulation in angiosperms / M.R. Broadley et al // New Phytol. – 2001. – V. 152(1). P. – 9-27. https://doi.org/10.1046/j.0028-646x.2001.00238.x.

12. Plant science: the key to preventing slow cadmium poisoning / S. Clemens et al // Trends Plant Sci. – 2013. – V. 18(2). – P. 92-9. https://doi.org/10.1016/j.tplants.2012.08.003.

13. Effect of bovine bone meal on immobilization remediation and fertility of Cd contaminated soil / Y. Ji et al // Acta Sci. Circumstantiae. – 2019. – V. 39. – P. 1645-1654.

14. Soo H. Removal of heavy metals in contaminated soil by phytoremediation mechanism: A review. / H. Soo, H. Tony // Water Air Soil Pollut. – 2020. – V. 231. – P. 2638-2647.

15. Heavy mental concentration, potential ecological risk assessment and enzyme activity in soils affected by a lead-zinc tailing spill in Guangxi / K .Liu et al // China. Chemosphere. – 2020. – V. 251. – P. 126415.

16. Trifolium repens L. regulated phytoremediation of heavy mental contaminated soil by promoting soil enzyme activities and beneficial rhizosphere associated microorganisms / H. Lin et al // J. Hazard. Mater. – 2021. – V. 402. – P. 123829.

17. The role of urban park's tree stand in shaping the enzymatic activity, glomalin content and physicochemical properties of soil / J. Lemanowicz et al // Sci. Total Environ. – 2020. – V. 741. – P. 140446.

18. Effects of exogenous Cd on microbial biomass and enzyme activity in red paddy soil / B. Guo et al // J. Agro-Environ. Sci. – 2018. – V. 37. – P. 1850-1855.

19. Effects of oxalic acid on oil sunflower biomass, enzyme activity, and the Cd speciation of Cd-polluted soils / Y. Han et al // J. Agro-Environ. Sci. – 2020. – V. 39. – P. 1964-1973.

20. Guo X. Repairation of Five Species of Herbaceous Plants to Lead (Pb) Pollution in Mining Soil / X. Guo // Shanxi Normal University: Linfen, China, 2015.
21. Remediation techniques for heavy metal-contaminated soils: Principles and applicability / L. Liu et al // Sci. Total Environ. – 2018. – V. 633. – P. 206-219.
22. Effects of cadmium and copper mixtures to carrot and pakchoi under greenhouse cultivation condition / S. Hou et al // Ecotoxicol. Environ. Saf. – 2018. – V. 159. – P. 172-181.
23. Root vegetables-Composition, health effects, and contaminants / E. Knez et al // Int. J. Environ. Res. Public Health. – 2022. – V. 19. – P. 15531.
24. Roy M. Metal uptake in plants and health risk assessments in metal-contaminated smelter soils / M. Roy, L.M. McDonald // Land Degrad. Dev. – 2015. – V. 26. – P. 785-792.
25. Land application of organic waste effects on the soil ecosystem / M. Oldare et al // J. Appl Energy. – 2011. – V. 88. – P. 2210-2218.
26. Muhammad S. Compost and P amendments for stimulating microorganisms and maize growth in a saline soil from Pakistan in comparison with a nonsaline soil from Germany / S. Muhammad, T. Mu¨ller, R.G. Joergensen // J Plant Nutr Soil Sci. – 2007. – V. 170. – P. 745-751.
27. Use of compost an environment friendly technology for enhancing rice wheat production in Pakistan / G. Sarwar et al // Pak J Bot. – 2007. – V. 39. – P. 1553-1558.
28. Amend ments and plant cover influence on trace element pools in a contaminated soil / A. Pe´rez-de-Mora et al // Geoderma. – 2007. – V. 139. – P. 1-10.
29. Direct and secondary effect of liming and organic fertilization on cadmium content in soil and in vegetables / A. Zaniewicz-Bajkowska et al // Plant Soil Environ. – 2007. – V. 53. – P. 473-481.
30. The Influence of Vermicompost and Various Concentrations of Lead on the Enzymatic Activity of Sierozem Soils of Kazakhstan / G.A. Sainova et al // Scientifica (Cairo). – 2023. – P. 8490234. https://doi.org/10.1155/2023/8490234.
31. Yuldashbek D.Kh. The effect of zinc on the activity of the enzyme dehydrogenase in sierozem / D.Kh. Yuldashbek. // Bulletin of Shakarim University. Technical Sciences, 2024. – № 1(13). – P. 393-400. https://doi.org/10.53360/2788-7995-2024-1(13)-48.
32. Khaziev F.H. Methods of Soil Enzymology / F.H. Khaziev. – M.: Science, London, UK, 2005.

Д.Х. Юлдашбек*, Д.К. Сунакбаева
[1]Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті,
161200, Қазақстан Республикасы, Түркістан, Саттарханов даңғылы, 29/3
*e-mail: davlat.yuldashbek@ayu.edu.kz

ФИТОРЕМЕДИАЦИЯНЫҢ КАДМИЙМЕН ЛАСТАНҒАН ТОПЫРАҚТЫҢ ҚҰНАРЛЫЛЫҒЫН ҚАЛПЫНА КЕЛТІРУГЕ ЖӘНЕ ФЕРМЕНТАТИВТІ БЕЛСЕНДІЛІККЕ ӘСЕРІ

Бұл зерттеу жұмысы сәбіз (Daucus carota L.) дақылы мен вермикомпостты қолдана отырып, кадмиймен ластанған топырақтың фиторемедиациялық қабілетін анықтауға арналған. Жұмыста топырақтың ластануын модельдеу және кадмийдің өсімдіктерге транслокациялануын анықтау әдістері, сондай-ақ фиторемедиацияның каталаза, уреаза, дегидрогеназа және протеаза сияқты топырақ ферменттерінің белсенділігіне әсері қарастырылған. Тәжірибелік жұмыстар көрсеткендей, Daucus carota L. кадмийді тамыр дақылдарында, әсіресе ластанудың жоғары концентрациясы кезінде тиімді жинақтайды. Вермикомпостты топыраққа енгізу өсімдікте кадмийдің жиналу дәрежесін азайтуға көмектеседі, бұл топырақ құрылымының жақсаруына және оның улы заттарды бейтараптандыру қабілетіне байланысты болуы мүмкін. Сонымен қатар, вермикомпостты топыраққа қосу кадмийдің микроорганизмдер мен топырақ экожүйесіне уыттылық әсерін азайту арқылы топырақ ферменттерінің белсенділік деңгейін бір қалыпты сақтап қалуға көмектеседі. Зерттеу нәтижелері бойынша сәбіздің (Daucus carota L.) фиторемедиант ретінде вермикомпостпен бірге топырақты ластаушы заттардан (Cd) тазарту және оның биологиялық белсенділігін қалпына келтіру үшін қолдануға болатындығын растайды.

Түйін сөздер: *топырақ, кадмиймен ластану, ферментативті белсенділік, вермикомпост, фиторемедиация, сәбіз (Daucus carota L.,).*

Д.Х. Юлдашбек*, Д.К. Сунакбаева
[1]Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави,
161200, Республика Казахстан, Туркестан, проспект Саттарханова, 29/3
*e-mail: davlat.yuldashbek@ayu.edu.kz

ВЛИЯНИЕ ФИТОРЕМЕДИАЦИИ НА ВОССТАНОВЛЕНИЕ ПЛОДОРОДИЯ И ФЕРМЕНТАТИВНУЮ АКТИВНОСТЬ ПОЧВЫ, ЗАГРЯЗНЕННОЙ КАДМИЕМ

Данное исследование посвящено изучению фиторемедиации почвы, загрязненной кадмием, с использованием культуры моркови (Daucus carota L.) и вермикомпоста. В работе представлены методы моделирования загрязнения почвы и определения транслокации кадмия в растения, а также влияние фиторемедиации на активность почвенных ферментов, таких как каталаза, уреаза, дегидрогеназа и протеаза. Эксперимент показал, что Daucus carota L. эффективно накапливает кадмий в корнеплодах, особенно при высоких концентрациях загрязнения. Введение вермикомпоста в почву способствует снижению накопления кадмия в растении, что может быть связано с улучшением структуры почвы и её способности к нейтрализации токсичных веществ. Кроме того, добавление вермикомпоста помогает поддерживать более высокие уровни активности почвенных ферментов, смягчая токсическое воздействие кадмия на микроорганизмы и экосистему почвы. Результаты исследования подтверждают, что морковь (Daucus carota L.), как фиторемедиант, в сочетании с вермикомпостом может быть использована для очистки почвы от загрязняющих веществ (Cd) и восстановления её биологической активности.

Ключевые слова: *почва, загрязнение кадмием, ферментативный активность, вермикомпост, фиторемедиация, морковь (Daucus carota L.).*

Авторлар туралы мәліметтер

Давлат Хасанұлы Юлдашбек* – химия магистрі, Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті, Түркістан, Қазақстан; e-mail: davlat.yuldashbek@ayu.edu.kz. ORCID: https://orcid.org/0000-0001-9342-7502.

Дилара Кахаровна Сунакбаева – техника ғылымдарының кандидаты, Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті, Түркістан, Қазақстан; e-mail: dilara.sunakbayeva@ayu.edu.kz. ORCID: https://orcid.org/0000-0002-1182-7113.

Сведения об авторах:

Давлат Хасанулы Юлдашбек* – магистр химии, Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави, Туркестан, Казахстан; e-mail: davlat.yuldashbek@ayu.edu.kz. ORCID: https://orcid.org/0000-0001-9342-7502.

Дилара Кахаровна Сунакбаева – кандидат технических наук, Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави, Туркестан, Казахстан; e-mail: dilara.sunakbayeva@ayu.edu.kz. ORCID: https://orcid.org/0000-0002-1182-7113.

Information about the authors

Davlat Khasanuly Yuldashbek – Master of Chemistry, International Kazakh-Turkish University named after Khoja Ahmed Yasawi, Turkestan, Kazakhstan; e-mail: davlat.yuldashbek@ayu.edu.kz. ORCID: https://orcid.org/0000-0001-9342-7502.

Dilara Kakharovna Sunakbaeva – candidate of technical sciences, International Kazakh-Turkish University named after Khoja Ahmed Yasawi, Turkestan, Kazakhstan; e-mail: dilara.sunakbayeva@ayu.edu.kz. ORCID: https://orcid.org/0000-0002-1182-7113.

Received 03.02.2025
Revised 03.03.2025
Accepted 04.03.2025

https://doi.org/10.53360/2788-7995-2025-1(17)-51

МРНТИ: 31.21.01

BY 4.0

Check for updates

И.О. Сапаргали[1], К.С. Бексеитова[1], У.Е. Жантикеев[1], Н.Н. Нургалиев[2]*, С. Азат[1]

[1]Казахский национальный исследовательский технический университет им. К.И. Сатпаева, 050013, Республика Казахстан, г.Алматы, , ул.Сатпаева 22

[2]Университет имени Шакарима города Семей, 071412, Республика Казахстан, г. Семей, ул.Глинки 20

*e-mail: n.nurgaliyev@shakarim.kz

КОМПЛЕКСНЫЙ МЕТОД ОЧИСТКИ МИКРОПЛАСТИКА В ВОДЕ С ИСПОЛЬЗОВАНИЕМ СОРБЕНТОВ

Аннотация: *Поступление вредных веществ в водную систему приводит к загрязнению воды. Загрязняющие вещества могут быть микроорганизмами, химическими добавками или пластиками. В настоящее время увеличение производства пластиковых изделий составляет 80% отходов в мировом океане. Микропластики различаются по цвету и плотности в зависимости от типа полимера и делятся на первичные и вторичные по происхождению. Около 54,5% микропластиков, найденных в океане, состоят из полиэтилена, а 16,5% – из полипропилена;*