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The influence of lead on the growth and development of various mustard types

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Abstract

The article studies the capacity of two types of mustard to accumulate Pb from contaminated sierozem soils. The dependence between the degree of lead contamination of soil (from 150 to 550 mg/kg) and the intensity of its entry in the vegetative and generative organs of brown (Brassica Juncea L.) and white mustard (Sinapis Alba L.) have been thoroughly examined. It has been established that with an increase of Pb content in soil, there is increased content of this metal in organs of the above plants. The effect of vermicompost, sulfur- and perlite-containing waste and their mixtures, the lead behavior in the system of sierozem soil and mustard plants were studied. In conducted experiments, the following soil mass ratios were used: sulfur- and perlite-containing waste:vermicompost = 3:1:0.5. The introduction of vermicompost or its mixture with the sulfur- and perlite-containing waste into the contaminated soil helps to reduce the concentration of Pb, which passes into various plant organs. At the same time, the lead content in mustard organs decreases in the following order: the roots > leaves > stalks > grains. It was revealed that, despite the increased lead content in the soil (from 150 to 550 mg/kg of soil), its translocation amount in the grain portion of mustard does not exceed the standard maximum permissible concentration value for food products (MPC = 0.5 mg / kg).

Keywords: heavy metals, vermicompost, accumulation, sulfur- and perlite-containing waste, mustards, sierozem soils, Brassica Juncea, Sinapis Alba

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INTRODUCTION

Every year, the increasing anthropogenic activities (ores and minerals mining, industrial and agricultural production, development of motor vehicles, etc.) is leading to the intensive pollution of the natural environment by various ecotoxicants. Among them, there are heavy metals of the class 1 – mercury, lead, cadmium, – that represent a great danger to humans, as well as to species of a living and plant world (Van Engelen et al. 2007, Sikka et al. 2010, Bataillard et al. 2003, Mudgal et al. 2010).

Apart from rare specific pollutants, the most massive soil pollutants, especially in urban areas, are hydrocarbons, heavy metals, polycyclic aromatic hydrocarbons, organochlorine compounds (solvents, pesticides). The presence of these toxicants in the soil worsens the environmental situation, for example, leads to the oppression of urban vegetation, suppresses rhizosphere biota, soil toxicants affect the population's health, especially in large cities. Polluted soils represent a great danger to animal world (Yankevich et al. 2015).

The chemistry of metal interaction with soil matrix is central to the phytoremediation concept. In general, sorption to soil particles reduces the activity of metals in the system. Thus, the higher the cation exchange capacity (CEC) of the soil, the greater the sorption and immobilization of the metals. In acidic soils, metal desorption from soil binding sites into solution is stimulated due to H+ competition for binding sites. Soil pH affects not only metal bioavailabilty, but also the very process of metal uptake into roots. This effect appears to be metal specific (Lasat 2000).

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Heavy metals accumulate in the soil, where they bind to its mineral components and can pass into the soil solution when the soil is acidified and then are consumed by plants and soil organisms, affecting their development, as well as washed into groundwater. Soil toxicants, that are used in agricultural production, contaminate the food chain and degrade the quality of drinking water (Yankevich et al. 2015).

High levels of metals in soil can be phytotoxic. Poor plant growth and soil cover caused by metal toxicity can lead to metal mobilization in runoff water and subsequent deposition into nearby bodies of water. Furthermore, bare soil is more susceptible to wind erosion and spreading of contamination by airborne dust. In such situations, the immediate goal of remediation is to reclaim the site by establishing a vegetative cover to minimize soil erosion and pollution spread (Lasat 2000).

Heavy metals are mainly trace chemical elements, hence they contaminate the earth's surface, in particular, the soil covering and hydrosphere, as well as the atmosphere. The increase in their concentration in the environment due to natural or anthropogenic inputs can be global. Natural sources of heavy metals include rocks (from products whose weathering has formed the soil cover), volcanoes, space dust, soil erosion, evaporation from the surface of the seas and oceans. They are widely used in various industrial production, therefore, despite the treatment measures, the content of heavy metals in industrial wastewater is quite high. First of all, of interest are those metals that are most widely and significantly used in production activities and as a result of accumulation in the external medium pose a serious danger in terms of their biological activity and toxic properties. These heavy metals include lead, mercury, cadmium, zinc, bismuth, cobalt, nickel, copper, tin, antimony, vanadium, manganese, chromium, molybdenum and arsenic (Uzakov 2018).

As noted by Chibuike and Obiora (2014), the negative influence heavy metals have on the growth and activities of soil microorganisms may also indirectly affect the growth of plants. For instance, a reduction in the number of beneficial soil microorganisms due to high metal concentration may lead to decrease in organic matter decomposition leading to a decline in soil nutrients. Enzyme activities useful for plant metabolism may also be hampered due to heavy metal interference with activities of soil microorganisms.

Many heavy metals are trace elements, that means that they present in organisms at low concentrations. A significant number of chemical elements, constantly found in organisms, has a certain influence on the course of metabolic processes and a number of physiological functions. The quantitative content of organisms-constituting bioelements varies greatly depending on the habitat, diet, species (Uzakov 2018).

Anthropogenic pollution by heavy metals is generally caused by some form of industry, transport, municipal waste management, landfill and the use of fertilizers. Contaminants can spread in the environment via the air, into which dust and gases are emitted, and through water and soil, onto which particles of contaminants are deposited from the air, or they are carried there by surface runoff and then percolate into the soil (Szczygłowska et al. 2011).

Many studies have noted the particular potential danger of lead contained in environmental objects to the biological resources conditions. Its accumulation in the human body results in an increased risk of development of cancerous disease (Tong et al. 2000a, 2000b, Mudgal et al. 2010, Siddiqui et al. 2002). This is due to the synergistic effect of lead on the manifestation of carcinogenic properties of dioxins, polycyclic hydrocarbons and other harmful substances in organisms with the formation of even more toxic products (Aswood et al. 2018). Deep irreversible denaturation of proteins in the body also occurs with an excess intake of lead and other heavy metals. As a result, the action of most enzymes is suppressed due to the interaction of the functional groups of –SH and –COOH amino acids with metals with the formation of insoluble salts of a complex nature (Crowe and Bradshaw 2014, Robinson 2015).

Lead can accumulate over time, particularly in bone, and the fractional distribution of lead in bone (as contrasted with other body stores) increases with age from about 70 percent of body lead in childhood to as much as 95 percent with advancing age. Lead in bone may contribute a significant amount to blood lead and serves as a key storage site and source of internal lead exposure, particularly in situations involving chronic exposure (Juberg 2000).

Lead causes multiple direct and indirect effects on plant growth and metabolism. As stated by Hanumanth Kumar and Pramoda Kumari (2015), it has extremely low solubility in the soils due to complexes with organic matter sorption on oxide and clay, precipitation as carbonate, hydroxide and phosphate, so there are some limitations for the phytoremediation of Pb. Low availability of Pb limits its uptake by plants. In plants, lead uptake and translocation occur causing toxic effects resulting in a decrease in biomass production (Hanumanth et al. 2015, Dehno Khalaji et al. 2020).

As stated in Voronin's work (2017), the mechanism of lead toxic action is determined according to two main directions:

- blocking of functional sulfhydryl groups of proteins, which leads to inhibition of many vital enzymes. The earliest sign of lead intoxication (saturnism) is a decrease in activity of hydratase - aminolevulinic acid, the enzyme catalyzing the formation of porphobilinogen and heme synthetase;

- Lead penetration to nerve and muscle cells, the formation of lead lactate by the interaction with lactic acid, and then formation of lead phosphates, which create cellular barrier preventing calcium ions from entry in nerve and muscle cells. Developing on the basis of this paresis, paralysis is a sign of lead intoxication. In case of exposure to lead, the main targets are hematologic, nervous, digestive systems and kidneys. The negative impact on sexual function of the organism (inhibition of the activity of steroid hormones, gonadotrophic activity, spermatogenesis, etc.) was observed (Voronin 2017).

The soil system is the main environmental media for deposition of lead and other heavy metals from all biosphere objects. It is through soil that the main quantities of ecotoxicants are involved in the food chain.

Lead is extremely toxic to all intermediates of food chains. In humans, its effects have been thoroughly characterized and include nephropathy saturnism or coliclike abdominal pains. The most serious worldwide lead contamination has been due to introduction of lead (in the form of tetra ethyl and tetra methyl lead) into gasoline, starting in 1923, with billions of tons of lead released into the atmosphere through vehicle exhaust (Hanumanth Kumar and Pramoda Kumari 2015).

Plants react to high concentrations of Pb in soil (100mg/500kg) in the following way: there is inhibition of respiration and inhibition of photosynthesis, sometimes an increase in cadmium content and a decrease in the intake of zinc, calcium, phosphorus, sulfur, reduced yield, deterioration of crop production. External symptoms - the appearance of dark green leaves, twisting of old leaves, stunted leaves (Uzakov 2018).

Currently, there are several methods applied for soil purification from toxic metals, they include soil immobilization, excavation, phytoremediation, extraction. Each of them has own drawbacks along with advantages. Phytoextraction is one of the types of phytoremediation where contaminated soil is treated by using high biomass containing crops and natural hyperaccumulating plants. Metal hyperaccumulators are generally slow growing plant species having low biomass and metal specific too (Kaur et al. 2005).

Biological approach (bioremediation, phytoremediation) encourages the establishment/reestablishment of plants on polluted soils. It is an environmentally friendly approach because it is achieved via natural processes. Bioremediation is also an economical remediation technique compared with other remediation techniques (Chibuike and Obiora 2014).

Phytoremediation is defined as the technology of using plants to clean contaminated soils, being economically advantageous and safe in comparison with other physicochemical methods of purification (Atabayeva 2018).

As noted by Zhao and McGrath (2009), among the various approaches comprising phytoremediation, phytoextraction of metals and metalloids is probably the most challenging task. Where soils are impacted by industrial or mining activities, the degree of pollution is usually severe, making phytoextraction unfeasible within a reasonable time frame because of the high quantity of the pollutants present in the soil. Simple mass-balance calculations show that phytoextraction is potentially feasible only in low or moderately contaminated soils. For more heavily contaminated soils, phytostabilization with tolerant plants may be used to stabilize the contaminated sites and reduce the risk of erosion and leaching of pollutants to water bodies. In the process of phytostabilization, plants convert contaminants to less assimilable forms, as a result of which the pollutants are not transported to the upper parts of the plants but remain locked in the rhizosphere. Whereas in phytodegradation, contaminants are decomposed within the plant following their uptake by the root system or outside the plant under the influence of plant enzymes secreted into the environment. Plants can also transform contaminants to usually less toxic, volatile forms, a process known as phytovolatilization. In phytostimulation, contaminants decompose in the presence of the micro-organisms present in the rhizosphere (Szczygłowska et al. 2011).

According to Miller (1996), major advantages reported for phytoremediation as compared to traditional remediation technologies include the possibility of generating less secondary wastes, minimal associated environmental disturbance, and the ability to leave soils in place and in a usable condition following treatment.

As stated by Hanumanth Kumar and Pramoda Kumari (2015), the phytoremediative plants should have a deep, well-branched root system with or without a symbiosis of mycorrhiza fungi the hyphae of which can better penetrate into small soil pores than roots. Metal bioavailability can be enhanced by rhizosphere organisms. The root and its associates should take up as much metals as possible.

Blaylock and colleagues (1997) noted, that certain plants, known as metal hyperaccumulators, contain unusually high concentrations of heavy metals in their tissue. Phytoremediation as a soil cleanup technology seeks to exploit the ability of metal-accumulating plants to extract metals from the soil with their roots and to concentrate these metals in above-ground plant parts. The metal-rich plant material can be safely harvested and removed from the site without extensive excavation, disposal costs, and loss of topsoil associated with traditional remediation practices. The success of phytoremediation is dependent on several factors. Plants must produce sufficient biomass while accumulating high concentrations of metal. The metal-accumulating plants also need to be responsive to agricultural practices to allow repeated planting and harvesting of the metal-rich tissues. In addition, these plants should preferentially accumulate environmentally important toxic metals.

Atabayeva in her work (2018) highlighted that the main disadvantage of the plants-hyperaccumulators of heavy metals is due to the low growth and low biomass of these plants. From an ecological point, an ideal plant should have a long, well-developed root system and a strong transpiration current, such a plant must intensively form biomass, and this plant biomass should be characterized by tolerance to organic and inorganic toxic compounds.

The conducted study was realized with the use of vermicompost that being an environmentally friendly organic fertilizer, has a multilateral effect on the soil and vegetation. Its distinctive feature is the high content (70-80 %) of well-humified material, which determines its exceptional physical properties: the content of water-stable aggregates 70-95 %, including about 50 % of 1-3 mm aggregates. These properties of vermicompost contribute to the restoration of depleted soils, so it is recommended to “rejuvenate” the soil by its periodic application. In addition, the introduction of biocompost into the soil increases the number of useful groups of microorganisms, ammonifiers, nitrifying bacteria and cellulose-decomposing microorganisms performing the first stage of humification of organic matter. It does not contain weed seeds and pathogens, which means that with this fertilizer it is impossible to make alien flora for the restored area and it is safe, unlike manure and compost prepared with a violation of the technological process (Babenko and Van 2010, Walea et al. 2019).

In view of the above, in order to solve the problem of biosphere objects contamination with lead and other heavy metals, first of all, it is necessary to find the methods of passivating treatment of these chemical elements in the soil.

This work is devoted to the study of lead translocation processes from contaminated soil system to plant organs of white mustard (*Sinapis Alba* L.), and brown mustard (*Brassica Juncea* L.).

MATERIALS AND METHODS

Sierozem and two types of mustard, namely *Brassica Juncea* L. and *Sinapis Alba* L. were chosen as objects of research. As is known from the work of a number of researchers, mustard has a pronounced capacity to accumulate heavy metals (Sikka et al. 2010, Usman et al. 2006, Ghosh and Singh 2005). An easily soluble salt - Pb (CH_3COOH)2·3H2O was chosen as the source of lead. The maximum permissible values – 32 mg/kg of soil and 0.5 mg/kg of dry weight of a plant (Tóth et al. 2016, Kalsi et al. 2016) – were used for lead accumulation experiment.

Soil samples were taken from a layer of 0-20 cm, they had the following physical and chemical parameters: humus content is 1.2 %; pH is 7.1; the exchange capacity of Ca^{2+} and Mg^{2+} is 9.9 and 0.6 mg-eq/100 g of soil, respectively; cation exchange capacity is 22.1 mEq/100 g of soil; K_2O exchange capacity is 10.6 mEq/100 g of soil, physical clay content is 52.6 %, silt content is 29.4 %; mobile P_2O_5 content is 4.5 mg/100 g of soil. Sulfur- and perlite-containing waste (SPW), vermicompost (VC) or their mixtures has been introduced to the investigated soils as a fertilizer ameliorant. The soil ratio: sulfur- and perlite-containing waste:vermicompost = 3:1:0.5. This ratio was found to be optimal in previous studies (Akbasova et al. 2016).

A mixture of vermicompost and sulfur-containing waste of sulfuric production was used for development of non-traditional complex bioorganic fertilizer.

Sulfur- and perlite-containing waste is a known as low-toxic, odorless substance consisting of the following environmentally-friendly components: sulfur and perlite, gypsum, hydrated lime, which is harmless to the health of biota, including humans. Perlite is a highly porous mineral of natural origin. It is widely used as an ameliorant and substrate in agricultural practice to improve the physical and chemical properties of soils, i.e. it helps to create aeration properties in the soil, increases the cation exchange capacity; it prevents the caking and cracking of the soil, helping it to remain friable (loose), providing it with large moisture capacity, absorbs excess water from the soil, and gradually brings it back to the soil. Perlite has chemical inertness, it is not exposed to microorganisms, insects and rodents. On the contrary, as an insecticide, it protects soil against pests. Perlite is a variety of natural silicate rocks, absolutely safe for humans, does not cause allergic reactions and skin irritation. In its composition, perlite contains silicon oxide (78.1 %), aluminum oxide (12.3 %), gypsum and lime (in terms of calcium oxide 0.7 %), sodium oxide (3.2 %), potassium oxide (4.4 %), iron oxide (W) (0.7 %), iron oxide (II) (0.3 %), magnesium oxide (0.06 %), titanium oxide (0.1 %), sulfur oxide (0.1 %). Gypsum and lime are well-known ameliorants.

Sulfur regulates oxidation-regenerative processes in soils, it is used as an ameliorant and as a fertilizer, takes special part in plants microelement consumption. Sulfur is a constituent part of proteins, enzymes, amino acids, it increases plants yield. Sulfur introduced into the soil, under the influence of sulfur bacteria, is oxidized to sulfuric acid. The content of elemental sulfur in combination with its compounds (thiosulfate, sulfate, polysulfide) in sulfur- and perlite-containing waste is 10-20 %.

Full-scale studies were carried out on test plots with a total area of 150 m^2, and with accounting area of 95.5 m^2. The replication of experiments is fourfold. Establishment of trials, observations and biometric measurements were carried out during the growing season according to the known method of conducting experiments with fertilizers (Tsykalov and Shcheglov

Table 1. Scheme of experiments on options with the ratios of soil:VC (3:0.5), soil:SPW (3:1), soil:VC:SPW (3:0.5:1)

Sierozem with Pb introduction mg/kg	Sierozem in the presence of a fertilizer - ameliorant and Pb; mg / kg		
Option 1	Option 2	Option 3	Option 4
0	VC, Pb (0)	SPW, Pb (0)	VC +SPW, Pb (0)
Option 5	Option 6	Option 7	Option 8
Pb – 150	VC, Pb (150)	SPW, Pb (150)	VC + SPW, Pb (150)
Option 9	Option 10	Option 11	Option 12
Pb – 250	VC, Pb (250)	SPW, Pb (250)	VC + SPW, Pb (250)
Option 13	Option 14	Option 15	Option 16
Pb – 350	VC, Pb (350)	SPW, Pb (350)	VC + SPW, Pb (350)
Option 17	Option 18	Option 19	Option 20
Pb – 550	VC, Pb (550)	SPW, Pb (550)	VC + SPW, Pb (550)

2015). Contamination of the sierozem soil was imitated by the introduction of various amounts of lead. Lead was introduced into the 0–20 cm layer of the soil in the form of readily soluble acetic acid at the rate of: 1) control (lead was not introduced); 2) 150 mg/kg; 3) 250 mg/kg; 4) 350 mg/kg; 5) 550 mg/kg of soil. After introduction of lead and fertilizer - ameliorants, the soil was incubated for 10 days. Then these groups of soil were used to grow 2 types of mustard (*Brassica Juncea* L. and *Sinapis Alba* L.).

The experiments scheme on options is presented in **Table 1**. Options 1, 5, 9, 13, 17 are control experiments where fertilizer - ameliorant was not applied to the sierozem soil.

The lead content determination in the soil and in plants was carried out by atomic absorption spectrophotometric analysis (Tüzen 2003).

Fertilizer - ameliorative agent is added by locally nested method, as well as dispersion with subsequent mixing with a layer of soil of 0-20 cm.

RESULTS AND DISCUSSION

Lead presented in the soil system in association a mixture of sulfur- and perlite-containing waste and vermicompost, and without application of a mixture of these substances, easily chemically reacts with both functional groups of humic acids ($COOH^-$, OH^-) and inorganic anions of the soil solution and waste (CO_3^{2-}, SO_4^{2-}, S^{2-}, OH^-). At the same time, insoluble humates, carbonates, oxycarbonates, sulfates, sulfides, hydroxo complexes are formed.

With an increase in the lead content in the soil, within the limits of the concentrations studied by us, a regular increase in its content in all plant organs is observed (**Fig. 1**). Metal concentration was observed (**Fig. 1**) both in the roots and in the aerial part of the studied species of mustard, regardless of the lead content in the soil (150 - 550 mg/kg of soil). The data obtained indicate the mustard's capacity to accumulate and translocate lead, to tolerate high concentrations of lead, and to maintain productivity. At the same time, bioaccumulation of lead

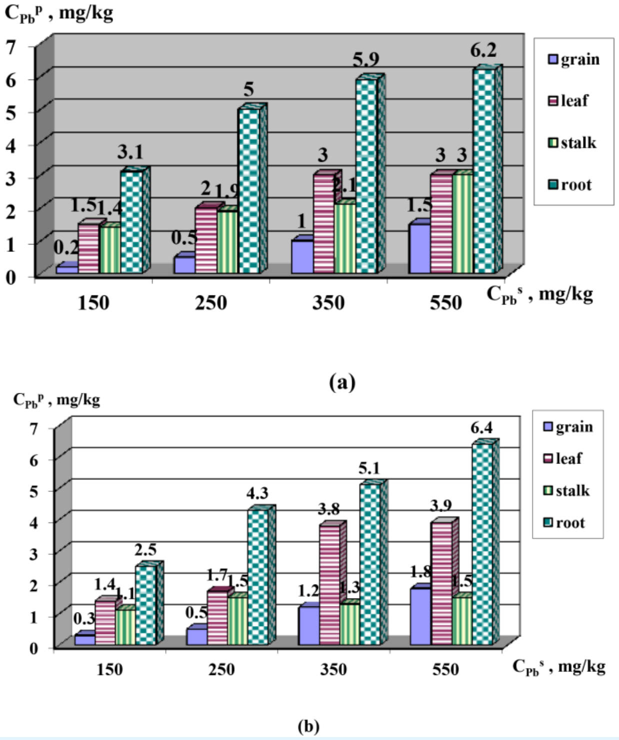

Fig. 1. Dependence between the concentrations of lead in the soil and in the organs of *Brassica Juncea* L. (a) and *Sinapis Alba* L. (b)

in high concentrations proceeded without visible symptoms of toxicity.

The results of our experimental studies indicate the possibility of attributing the studied species of mustard to accumulator plants, which is consistent with the literature data obtained by other researchers (Van Engelen, Sharpe-Pedler & Moorhead, 2007; Kalsi, Sikka & Singh, 2016; Prasad & Freitas, 2003; Amini, et al., 2019). However, it is not advisable to recommend these plants for phytoextraction of lead from highly contaminated soils of industrial, agricultural and urban areas. The method of extracting Pb using the studied mustard species is suitable only for areas with a low level of contamination. The reason stems from the low value of the absorption coefficient (<1), which is determined by the ratio of the lead content in plants to its content in the soil, and the low value of the translocation coefficient (<1). The translocation coefficient is the ratio of the metal content in the aerial part to its content in the roots. Thus, the studied species of mustard cannot act as a phytoextractant for cleaning highly contaminated soils, since the use of this phytoremediation method requires a very long time (several years), although this requires lesser time than natural reclamation.

When introducing a mixture of vermicompost with sulfur- and perlite-containing waste into the soil, an increase in the soil absorption capacity from 22.1 to 35.7 mEq/100 g of soil was revealed. Sulfur- and perlite-

Table 2. Biometric data characterizing the growth and development of mustard

Options	Number of days: 2	3	4	5	7	8	11	13	Total number of sproutings	Root, cm: length, cm	Root, cm: width, cm	g	stalk, g
	Number of sprouts appearing												
***Brassica Juncea* L.**													
Soil	-	-	-	2	3	10	4	-	19	19.4 ± 0.2	6.2 ± 0.4	4.0 ± 0.1	1.5 ± 0.2
soil:SPW= 3:1	-	-	6	16	3	17	7	1	50	9.2 ± 0.2	5.5 ± 0.2	5.1 ± 0.3	2.4± 0.2
soil:VC= 3:0.5	-	5	13	18	7	8	4	2	57	11.3 ± 0.1	4.5 ± 0.1	6.4± 0.3	2.3 ± 0.1
Soil:SPW:VC = 3:1 :0.5	-	15	29	33	7	3	16	5	108	7.1±0.2	20.5± 0.7	11.6± 0.4	4.9± 0.3
***Sinapis Alba* L.**													
Soil	-	3	2	4	10	4	8	6	37	8.5 ± 0.1	5.5 ± 0.1	4.8 ± 0.2	0.8 ± 0.1
soil:SPW= 3:1	-	1	3	3	10	12	11	3	43	11.5 ± 0.4	6± 0.4	4.2± 0.1	2.5 ±0.3
soil:VC= 3:0.5	-	2	9	3	15	17	12	6	64	22.3 ± 0.7	9.0 ± 0.5	4.7 ± 0.4	2.1± 0.2
soil:SPW:VC = 3:1:0.5	-	4	12	9	6	39	20	35	125	32.0 ± 0.5	13.0 ± 0.4	8.8 ± 0.5	2.6 ± 0.2

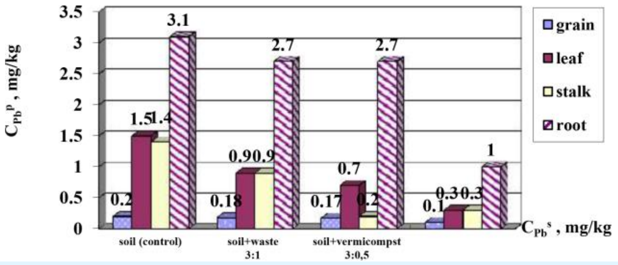

Fig. 2. Change in Pb translocation concentration in organs of *Brassica Juncea* L. with application of the fertilizer-ameliorants in soil containing 150 mg/kg Pb

containing waste, as an ameliorant, had a negligible effect on the absorption capacity (24.8 mg-eq/100 g of soil). A change in the soil absorption capacity towards an increase indicated an improvement in the potential fertility of the soil by introducing a mixture of vermicompost with sulfur- and perlite-containing waste.

As can be seen from **Table 2**, the introduction of a vermicompost mixture and sulfur- and perlite-containing waste contributed to improving the growth of mustard and obtaining higher yields as compared with the control experiments. These results confirm the fertilizing, ameliorative, growth-promoting properties of the studied composition. As compared with the control experiment, visual observation revealed the early appearance of mustard processes in soils into which vermicompost and its mixture with waste were introduced separately (for 4-5 days and for 5-7 days, respectively). Besides, the use of this mixture made it possible to avoid the formation of dense crusts on the surface layer of sierozem soils. The disappearance of crust formation is associated with the formation of a cloddy granular structure favorable for the water-air conditions. The soil acquires agronomic value, the number of water-intensive units increases. In the presence of a fertilizer-ameliorant, normalization and enhancement of exchange and other processes occur

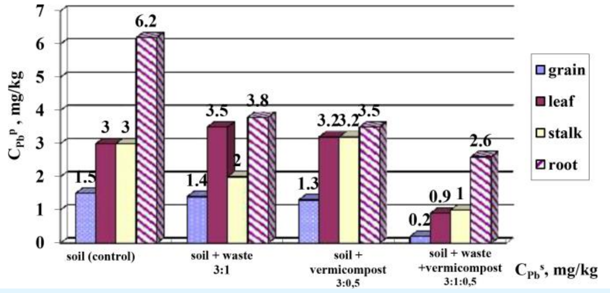

Fig. 3. Change in Pb translocation concentration in organs of *Brassica Juncea* L. with application of the fertilizer - ameliorants in soil containing 550 mg / kg Pb

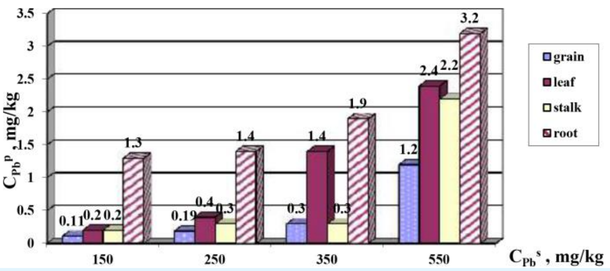

Fig. 4. Dependence of Pb concentration in organs of *Sinapis Alba* L. on the degree of soil contamination, which included a mixture of vermicompost and sulfur- and perlite-containing waste

not only in the soil system, but also in the adjacent soil systems.

Data characterizing the transition of lead to plant organs depending on the metal content in the soil is presented in **Figs. 2**-**3**.

The largest amount of lead is concentrated in the roots, then mainly in the leaves, stalks and the smallest amount in the grains. As results of the studies show, the growth of the lead concentration in the soils results in an increase of its content in the roots and, accordingly, in other mustard organs.

When applying the studied fertilizer – ameliorant in soil with a Pb content of 150 to 550 mg/kg, a decrease in the mobility and biological availability of the metal in the aerial parts (stalks, leaves) of *Brassica Juncea* L. was observed. At the same time, the amount of accumulated Pb below the standard value of MPC was observed only in a grain part (MPC = 0.5 mg/kg), which shows the suitability of the grains for the use as a food product.

When a mixture of vermicompost and sulfur- and perlite-containing waste was introduced into the contaminated soil, the accumulation of Pb in the organs of *Sinapis Alba* L. differed from a *Brassica Juncea* L. In the case of *Sinapis Alba* L., the lead content below the MPC is established for the entire aerial part when a mixture of vermicompost and sulfur- and perlite-containing waste is introduced into the soil (**Fig. 4**). This was observed only at lead concentration in the soil of up to ≤ 250 mg/kg, and at lead concentrations in the soil in the range of 250-350 mg/kg, the lead content lower than

MPC was found only in stalks and grains. At Pb contents in soils of > 350 mg/kg, the phyto-deposited amount of Pb in all aerial organs of mustard exceeded the values of the standard maximum permissible concentration.

Accordingly, bioaccumulation and distribution of Pb in vegetative and generative organs of mustard are determined by their species and biological features. The separate application of the sulfur- and perlite-containing waste, vermicompost or their mixture into the soil led to a decrease in the availability of lead and to increasing yields. The reduction of mobility, biological availability and toxicity of lead in contaminated soils can be attributed to the binding of Pb with humic acids of vermicompost with the formation of strong complexes, as well as adsorption and the formation of a number of inorganic lead compounds with anions contained in the waste. In consequence of these interactions, the Pb becomes inactive and loses its accessibility in plants. In all experiments, when introducing vermicompost and sulfur- and perlite-containing waste, the Pb content in the studied mustard species decreases in the series of roots > leaves > stalks > grains.

CONCLUSIONS

Lead, like many other heavy metals, may adversely affect the growth of plants. In case of its high concentration, there may occur a decrease in favorable soil microorganisms which results in the insufficient number of soil nutrients, as well as plant metabolism may be affected.

As a result of experimental studies, the mustard accumulating capacity of the main amount of lead in vegetative organs was revealed. The least amount of lead passes into grains. This is due to the presence of a protective mechanism that prevents the penetration of ions Pb^{2+} into the generative organs.

The study showed that application of the sulfur-perlite-containing waste, vermicompost or their mixture into the soil led to a decrease in the lead content in the soil and contributed to improved yields. Pb binding with humic acids of vermicompost followed by the formation of strong complexes, and adsorption and the formation of a number of inorganic lead compounds with anions contained in the waste, resulted in Pb being inactive and inaccessible for plant uptake.

In the presence of a mixture of vermicompost and sulfur- and perlite-containing waste, the lead content in the mustard organs is reduced in the following order: the roots> leaves> stalks >grain. The mustard growth inhibition was established in soils containing ≥550 mg of lead per 1 kg of soil.

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