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The Content of Heavy Metals and Trace Elements in Different Soils Used under the Conditions of Homestead Plots and Field Agricultural Lands of Ukraine

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ABSTRACT

The soils of agricultural lands of Ukraine have different features of use for growing agricultural crops. In particular, under the conditions of homesteads in urbanized areas, the use of soils is observed mainly for monoculture (extensive agriculture). Usually, such soils are used primarily for the cultivation of potatoes and a small amount of vegetable crops: beets, cucumbers, cabbage, tomatoes, carrots, parsley, dill, etc. Organic fertilizers and a small amount of mineral fertilizers are used to fertilize the soils of homestead plots. Polycultures (intensive agriculture) such as: sunflower, winter rapeseed, winter wheat, corn, barley, sugar beet, peas, etc. are grown under the conditions of field crop rotation. With the creation of conditions for obtaining the maximum yield, mainly mineral fertilizers and a small amount of organic fertilizers are used. That is, these features of soil use can be reflected to one degree or another in the level of accumulation of heavy metals and trace elements in them. The content of heavy metals and trace elements in black soil typical medium loamy, sod-podzolic sandy loamy and gray medium loamy soils were investigated for their use in homestead plots and field crop rotation for growing various agricultural crops. A higher content of mercury, lead, cadmium, zinc and copper was found in black soil typical medium loamy, gray forest medium loamy and sod-podzolic sandy loamy soils under the conditions of homesteads compared to the soils of field crop rotations. The highest difference in the content of Pb, Hg, Cd, Zn, and Cu in the soils of homestead plots and field crop rotations was found in sod-podzolic sandy soil.

Keywords: heavy metals, black soil typical medium loamy, gray forest medium loamy, sod-podzolic sandy loamy, field soil, crop rotation, homestead plots.

INTRODUCTION

One of the most dangerous threats to the environment are heavy metals, which are an integral part of industrial emissions (Myslyva et al., 2019). When heavy metals enter the environment, they become part of the biogeochemical cycle, join in the composition of trophic chains, and over time accumulate in the structural elements of ecosystems. Some types of heavy metals at low concentrations play an important role in the life processes of plant cells, but in excess, these toxicants enter physiological processes that rapidly disrupt the growth and development of living organisms (Hrabak et al., 2016). For example, Zn and Cu are classified as essential microelements, but increasing of their concentration in the cell will lead to stress indicators, which will further affect the biogeochemical reactions taking place in it (Ivanova, 2014). Heavy metals occupy a particularly important place among pollutants due to their high toxicity, ability to accumulate during movement along trophic chains, and rapid spread in the environment. There are various ways in which heavy metals enter the environment, both natural and artificial. Weathering of rocks and minerals, soil erosion, smoke from forest fires, meteorite dust, etc. are natural sources of heavy metals that enter the environment (Hrabak et al., 2016). Human economic activity, high-temperature processes with industrial emissions (ferrous and non-ferrous metallurgy, burning of cement raw materials, combustion of liquid and solid fuels), removal of heavy metals from the dumps of mines or metallurgical enterprises by water and air currents, waste water discharge, constant application of high doses of organic and mineral fertilizers, as well as pesticides that contain impurities of heavy metals are all types of anthropogenic sources of environmental pollution with heavy metals (Lisova et al., 2020). The rates of dispersion and involvement of chemical elements in the biogenic cycle have recently increased significantly. This is explained by the fact that heavy metals are highly toxic, they accumulate in separate links of the trophic chain and thus create a long-term negative effect on the vital activity of living organisms (Dydiv et al., 2023). A large number of scientific studies confirm that the further increase in the level of toxicity in the environment leads to the deterioration of the functioning of biological systems (Razanov et al., 2022).

Heavy metal contamination of soils intended for agricultural activities has recently become particularly dangerous, which subsequently leads to their accumulation in food raw materials, and later in the human body. Accumulation of heavy metals in the soil occurs quite easily, but their elimination takes tens or even hundreds: the half-life of Cu can last from 310 to 1500 years, Zn from 70 to 150 years, Pb from 40 to 5900 years, Cd from 13 to 110 years (Razanov et al., 2023a). It is known that the occurrence and localization of heavy metals in soils depend on the chemical forms in which they are in the parent rock or fall into the soil. The heavy metals that enter the soil with atmospheric dust are in an inorganic form – oxides, carbonates, silicates, sulfides, and sulfates (Razanov et al., 2022). Zn usually enters the soil in the form of poorly soluble compounds, while Cu in the form of chemically active substances capable of interacting with humic acids. According to some authors, Cu is the best accumulated in the alluvial part of the profile, while Zn in the upper transitional horizon during the transition to the rock (Tiecher et al., 2016).

Adding organic fertilizers to soil is also a source of accumulation of heavy metals in it and a rather powerful source that contributes to the accumulation of Zn, Cu, Fe, Cd, and Pb in it (Rai et al., 2019). The available literature data indicate that pH increase in soil within the range of 6–8 leads to the formation of insoluble complexes of Cu with fulvic acids, which in turn leads to their accumulation in soils to toxic levels for biological systems (Zhao et al., 2015). The migration ability of Cu, Ni and Co increases with acidification of the soil environment. A decrease of the pH of the soil environment leads to an increase in the mobility of Zn from 3.8 to 5.4 times, and Cu from 2 to 3 times (Zheng et al., 2020).

It has been found that the level of toxicity of soils contaminated with heavy metals is determined not only by the gross content, but also by mobile forms that participate in biogenic migration (Khan et al., 2019). The appearance of toxicants often occurs along the system: soil-plant-human, soil-plant-animal-human, soil-water-human, and soil-air-human (Emam et al., 2021, Razanov et al., 2023b).

Every year, the rate of development of technogenic activity of the population increases, which in turn leads to an increase in the entry of various harmful substances, including heavy metals, into the environment. Heavy metals, being in an exchangeable form, move along trophic chains from the soil to vegetation, reducing the quality characteristics and safety of food raw materials (Zheng et al., 2020). Mining, metallurgical, machine-building, chemical, transport, agro-industrial, housing, etc. complexes are the most prominent sources of environmental pollution with heavy metals (Belon et al., 2014). Today, motor vehicles, agricultural production and industrial waste are rapidly growing types of environmental pollution, including soil (Luo et al., 2019).

Among the sources of environmental pollution with heavy metals, much attention is paid to motor vehicles, the number of which has increased rapidly in recent years; this has significantly increased the power of technogenic impact on the environment (Zhao et al., 2015). Along with this, the number of facilities servicing it, including motor vehicle enterprises, bases of road construction equipment, garages, parking lots, gas stations and maintenance stations, is growing, which are also a source of environmental pollution with various toxic substances (Nicholson et al., 2016). The majority of emissions from motor vehicles are concentrated on the soil surface, from where they are included in trophic chains in the form of mobile forms, accumulating in phytomass (Yu et al., 2018).

Mineral fertilizers constitute the sources of heavy metals entering the environment specifically in agricultural production, especially in crop production (Ni et al., 2018). The largest number of them is contained in phosphoric fertilizers, and relatively less – in potash and nitrogen fertilizers (Belon et al., 2014). It was found that about 908 kg of Pb and 214 kg of Cd enter the soil annually during the cultivation of winter rapeseed and sunflower on a total area of 405,370 hectares with the application of mineral fertilizers (Peng et al., 2020). In Ukraine, more than 4.5 million hectares of soil are contaminated with man-made waste, which includes: heavy metals, petroleum products, radionuclides, etc. The negative consequences of long-term intensive anthropogenic influences on soils are the development of degradation processes in them (Belon et al., 2014). Anthropogenic soil degradation involves its secondary changes caused by human activity and accompanied by partial and/or complete loss of soil fertility; it is a consequence of its destruction. However, if the loss of soil fertility is partial, it can be restored. However, the process of soil destruction is an irreversible phenomenon that leads to the loss of stability and the death of the landscape (Wan et al., 2020). A component of anthropogenic soil degradation is its biological degradation as a result of its chemical pollution. Biological degradation of soils contaminated with heavy metals is a complex process of persistent changes in the biological properties of the soil, which leads to a decrease and loss of its productivity. Therefore, the use of land resources in technogenesis zones requires a detailed assessment of the condition of the soil cover, implementation of prevention measures, elimination of its degradation phenomena associated with pollution, as well as restoration of soil productivity (Wan et al., 2020).

Also, pollution with heavy metals affects the mycorrhiza of the soil. It was found that microbiological indicators are the first to respond to pollution, but their response correlates poorly with the content of heavy metals in the soil, compared to the response of biochemical indicators. There are different types of heavy metals entering the environment. For example, Pb enters environmental objects mainly in the form of gases, aerosols and industrial wastewater (Nziguheba et al., 2018). According to its chemical properties, it belongs to weak migrants, so it is concentrated in large particles in the soil. Due to the intensive entry into the environment and the high toxicity of Pb, it is classified as a highly dangerous toxicant (Loganathan et al., 2017). Also, highly toxic heavy metals include Cd, which, compared to Pb, has a high migration capacity. Cd has a low intensity of removal from living organisms. It accumulates in blood, in particular in erythrocytes, liver and kidneys. Cd is highly toxic to both animal and plant organisms. The content of Cd in the soil ranges from 0.01 to 1 mg/kg, from where it migrates into vegetation by assimilation (Lugon-Moulin et al., 2016).

According to the Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky, about 20% of agricultural land in Ukraine is contaminated with heavy metals. Excessive entry of heavy metals into the environment causes significant problems in agricultural production and animal husbandry, especially under the conditions of industrial and metallurgical enterprises. After all, it is known that the soil has great sanitary and hygienic importance for the life of both the animal and plant world (Yu et al., 2018). Negative natural and anthropogenic processes have a permanent impact on agricultural lands in the form of deterioration of their productivity. Gradually, pollutants accumulate in the soil, causing its physical destruction. Today, the issue of soil contamination with heavy metals in the territories adjacent to large cities is an urgent issue. Currently, the anthropogenic impact on soils is excessive and long-term, and the pursuit of productivity leads to disruption of the natural balance and deterioration of the ecological situation, which, in turn, leads to a significant decrease in the productivity of agroecosystems. Private auxiliary farms of the population produce more than 60% of crop production, but at the same time there is almost no information about the agro-ecological condition of homestead plots and the level of their contamination with toxicants. That prevents providing a comprehensive assessment of food contamination, in particular, vegetables and fruits grown and harvested on these soils (Mu et al., 2023). The causes of degradation processes occurring in soils are excessive application of organic and mineral fertilizers and uncontrolled use of pesticides, which, in turn, leads to their contamination with nitrates and heavy metals

(Romheld et al., 2021). The peculiarity of suburban settlements is that, being close to sales markets, they are producers of a significant amount of agricultural products. The question of contamination of the lands of private farms remains outside the attention of researchers, since in Ukraine control is carried out only on agricultural lands that are used by enterprises of various forms of ownership. Cultivation of agricultural crops in private farms is carried out without sufficient scientific knowledge and in the absence of environmentally safe technologies (Riaz et al., 2021).

The purpose of the research was to study the level of soil contamination with heavy metals and trace elements due to their use in field crop rotation and homestead plots for growing agricultural crops.

MATERIALS AND METHODS

The research was conducted on the soils of homestead plots and field crop rotation areas under the conditions of forest steppe and Polissia of Ukraine.

Under the conditions of forest steppe of Ukraine, it was conducted on the territory of Tyvriv community of Vinnytsia region (GPS coordinates: 49.01567 north latitude, 28.50969 east longitude, gray forest medium loamy soil), Pohrebyshche community of Vinnytsia region (GPS coordinates: 49.2913 north latitude, 29.1624 east longitude, black soil typical medium loamy soil) and Korosten district of Zhytomyr region (GPS coordinates: 51.1928 north latitude, 28.4829 east longitude, sod-podzolic sandy loamy soil).

Under the conditions of homestead plots, monoculture, mainly vegetables, in particular potatoes, was grown on the soils during the last several decades. The soil was fertilized with organic fertilizer (humus) from animal husbandry waste (Honcharuk, 2020). Under the conditions of field territories, the soil was used for polyculture, in particular, the cultivation of grain, fodder and industrial crops (winter wheat, spring wheat, spring barley, winter barley, soybeans, peas, sunflower, corn, winter rapeseed, sugar beet, oats, pink clover). The main soil fertilization was the application of mineral fertilizers.

The selection of soils to study the content of heavy metals (Hg, Pb, Cd) and trace elements (Zn, Cu) was carried out using the envelope method, the essence of which consists in the selection of four soil samples per square and one in the center. Soil sampling points per square were located at a distance of no closer than 100 m to the edge of the field territory. The selection of soils was carried out at a depth of 25–28 cm. The content of Hg, Pb, Cd, Zn and Cu in the soil was determined using an atomic absorption method.

The MPC indicator (maximum permissible concentration) is regulated by the state standard of Ukraine. In particular, for mercury – DSTU 16772:2005, mobile forms of lead – DSTU 4770.3:2007, for cadmium – DSTU 4770.3:2007, for zinc DSTU – 4770.2:2007 and for copper – DSTU 4770.6:2007 (DSTU 2009). The hazard ratio of heavy metals and microelements was determined by the formula:

$$H\ rat. = \frac{\mathrm{ACP}}{\mathrm{MPC}} \qquad (1)$$

where: *H rat* – pollutant hazard ratio, *ACP* – actual pollutant concentration in the soil, *MPC* – maximum permissible concentration of heavy metals and trace elements according to DSTU. The results of the study were statistically analyzed using ANOVA. The data in the tables are presented as M ± m (average value and error), n = 4 (the number of studied areas under the conditions of one type of soil).

The hazard ratio of heavy metals and trace elements was determined by the formula: Hazard ration = content in soil/MPC, the results of the study were statistically analyzed using ANOVA. The data in the tables are presented as M ± m (mean and error).

RESULTS AND DISCUSSION

The results of the studies in Table 1 showed that the black soil typical medium loamy of homestead plots had a higher content of Pb by 11.6%, Cd by 12.3%, Hg by 44.3%, and Cu and Zn by 9.8% and 10.6 %, respectively, compared to the same type of soil of the field crop rotation. Characterizing the hazard ratio of heavy metals and trace elements, it is necessary to note also the increase of this indicator on the soil of homestead plots compared to field crop rotation. Thus, a hazard ratio of accumulation of Pb by 37.5%, Cd by 30%, Hg by 17.6%, and Zn by 5.2% was observed in black soil typical medium loamy of homestead

Table 1. Indicators of the content of heavy metals and trace elements in black soil typical medium loamy, (M ± m, n = 4)

Indicators	Soils of homestead plots			Field crop rotation soils		
	Content in the soil	MPC	Hazard ratio	Content in the soil	MPC	Hazard ratio
Pb, mg/kg	0.693 ± 0.032	6.0	0.11	0.621 ± 0.023	6.0	0.08
Cd, mg/kg	0.091 ± 0.0014	0.7	0.13	0.081 ± 0.0016	0.7	0.10
Hg, mg/kg	0.140 ± 0.022	2.1	0.06	0.097 ± 0.0021	2.1	0.04
Cu, mg/kg	0.067 ± 0.0017	3.0	0.02	0.051 ± 0.0011	3.0	0.017
Zn, mg/kg	1.451 ± 0.124	23.0	0.006	1.312 ± 0.121	23.0	0.057

plots, compared to the soil of field crop rotation. The hazard ratio of Pb, Cd, Hg, Cu, and Zn in black soil typical medium loamy both in homestead plots and under the field crop rotation conditions it was lower than the limit value of 1.0.

The content of heavy metals and trace elements in black soil typical medium loamy both under the conditions of homestead plots and field crop rotation did not exceed the maximum permissible indicators (MPC), which were the following: Pb – 6.0 mg/kg, Cd – 0.7 mg/kg, Hg – 2.1 mg/kg, Cu – 3.0 mg/kg and Zn – 23 mg/kg. In particular, the content of Pb was 8.6 times lower than the MPC in the soils of homestead plots, while it was 9.6 times lower in the soils of field crop rotation. The content of Cd was 7.7 times lower than the MPC in the soils of homestead plots, while it was 8.6 times lower in the soils of field crop rotation. The content of Hg was 15.0 times lower than the MPC in the soils of homestead plots, while it was 21.6 times lower in the soils of field crop rotation. The content of Cu was 44.0 times lower than the MPC in the soils of homestead plots, while it was 58.8 times lower in the soils of field crop rotation. The content of Zn was 15.8 times lower than the MPC in the soils of homestead plots, while it was 17.5 times lower in the soils of field crop rotation. In the gray forest medium loamy soil of homestead plots (Table 2), there was also a higher content of Pb by 7.7%, Cd by 12.9%, Hg by 29.0%, Cu by 24.5% and Zn by 14.1% compared to the soils of field crop rotation.

As a result of the analysis of the hazard ratio of heavy metals and trace elements in gray forest medium loamy soil, it was found that this indicator was higher in homestead plots compared to field crop rotation for Pb by 22.2%, Cd by 14.2%, Hg by 75.0%, Cu by 23.5% and Zn by 13.6%.

According to the research results, it was found that the content of Pb in the gray forest medium loamy soil of homestead plots was 8.4 times lower compared to the MPC, while it was 9.2 times lower in the soil of field crop rotation. The content of Cd was 11.4 times lower compared to the MPC in the soil of homestead plots, while it was 12.9 times lower in the soil of field crop rotation. The content of Hg was 13.1 times lower compared to the MPC in the soil of homestead plots, while it was 16.9 times lower in the soil of field crop rotation. The content of Cu was 23.5 times lower compared to the MPC in the soil of homestead plots, while it was 29.4 times lower in the soil of field crop rotation. The content of Zn was 13.6 times lower compared to the MPC in the soil of homestead plots, while it was 22.7 times lower in the soil of field crop rotation.

The results of research (Table 3) indicate that the content of Pb, Cd, Hg heavy metals as well as trace elements Cu and Zn in the soils of homestead plots and field crop rotation was lesser than the MPC. Thus, the concentration of heavy

Table 2. Indicators of the content of heavy metals and trace elements in gray forest medium loamy soil, (M ± m, n = 4)

Indicators	Soils of homestead plots			Field crop rotation soils		
	Content in the soil	MPC	Hazard ratio	Content in the soil	MPC	Hazard ratio
Pb, mg/kg	0.713 ± 0.016	6.0	0.11	0.662 ± 0.0014	6.0	0.09
Cd, mg/kg	0.061 ± 0.0014	0.7	0.08	0.054 ± 0.017	0.7	0.07
Hg, mg/kg	0.160 ± 0.017	2.1	0.07	0.124 ± 0.034	2.1	0.04
Cu, mg/kg	0.127 ± 0.024	3.0	0.042	0.102 ± 0.009	3.0	0.034
Zn, mg/kg	1.155 ± 0.22	23.0	0.050	1.012 ± 0.011	23.0	0.044

Table 3. Indicators of the content of heavy metals and trace elements in sod-podzolic sandy loamy soil, (M ± m, n = 4)

Indicators	Soils of homestead plots			Field crop rotation soils		
	Content in the soil	MPC	Hazard ratio	Content in the soil	MPC	Hazard ratio
Pb, mg/kg	0.624 ± 0.024	6.0	0.10	0.534 ± 0.018	6.0	0.09
Cd, mg/kg	0.102 ± 0.010	0,7.	0.14	0.087 ± 0.013	0.7	0.12
Hg, mg/kg	0.110 ± 0.024	2.1	0.05	0.062 ± 0.0023	2.1	0.03
Cu, mg/kg	0.080 ± 0.0031	3.0	0.026	0.054 ± 0.0026	3	0.018
Zn, mg/kg	2,798 ± 0,21	23.0	0.12	2.023 ± 0.10	23.0	0.08

metals in homestead plots soils was 9.6 times lower in Pb, 6.8 times lower in Cd, 19.0 times lower in Hg, 35.5 times lower in Cu and 8.2 times lower in Zn, compared to the MPC. In the soils of field crop rotation it was 11.2 times lower in Pb, 8.0 times lower in Cd, by 33.8 times lower in Hg, 35.5 times lower in Cu and 11.3 times lower in Zn, compared to the MPC. It was found the higher content of Pb by 16.8%, of Cd by 17.4%, of Hg by 77.4%, of Cu by 48.1% and of Zn by 38.3% in the soils of homestead plots compared to the soils of field crop rotation. The soils of homestead plots were characterized by a higher hazard ratio of Pb by 11.1%, of Cd by 16.6%, of Hg by 66.6%, of Cu by 44.4% and of Zn by 50.0%, compared to the soil of the field crop rotation. The hazard ratio of heavy metals and trace elements in black soil typical medium loamy, gray forest medium loamy, sod-podzolic sandy loamy soils, both under the conditions of homestead plots and under the conditions of field crop rotation, did not exceed the maximum allowable indicator of 1.0. According to the results of the study, it was determined (Table 4) that the highest difference in the content of Pb, Cd, Hg and Cu between the soils of homestead plots and field crop rotation was found on sod-podzolic sandy loamy soil. Thus, the difference in the content of Pb, Cd, Hg, Cu and Zn in the sod-podzolic sandy loamy soil of homestead plots and field crop rotation was higher, compared to the black soil typical medium loamy by 25.0%, by 50.0%, by 11.6%, by 62.6% and by 7.5 times, respectively. It was higher by 214.0%, by 33.3%, by 0.4% and by 5.4 times, respectively, compared to the gray forest medium loamy soil. It is known that a high amount of heavy metals can accumulate in soil. As a rule, they accumulate the most in the arable layer (Belon et al., 2014; Loganathan et al., 2017). The highest amount of heavy metals enters agricultural soils with precipitation and with the introduction of mineral as well as organic fertilizers (Luo et al., 2019; Huang et al., 2020). It has been determined that most of the heavy metals are concentrated in the soil, and relatively less of them are removed by plants and their products (Zheng et al., 2020; Hussain et al., 2021). There is a constant migration of heavy metals in soils, which changes their level of pollution. The intensity of migration of heavy metals in the soil environment depends on the content of humus, trace elements, mineral composition, acidity, soil properties and other factors (Lugon-Moulin et al., 2016; Liu et al., 2020). The task of the conducted research included the study of heavy metal contamination of homestead plots soils, the characteristics of which were the cultivation of mainly the same vegetable crops with organic fertilizers during the last 100 years, and field crop rotation soils, which were used during the same period of time for the cultivation of cereals, oil and

Table 4. Characteristics of the difference in the content of heavy metals in the soils of homestead plots and field crop rotation, (M ± m, n = 4)

Indicators	The difference of heavy metals between the soils of homestead plots and field crop rotation		
	Black soil typical medium loamy	Gray forest medium loamy	Sod-podzolic sandy loamy soil
Pb, mg/kg	0.072 ± 0.0013**	0.051 ± 0.0017***	0.090 ± 0.0020
Cd, mg/kg	0.010 ± 0.0012***	0.007 ± 0.0012***	0.015 ± 0.0017
Hg, mg/kg	0.043 ± 0.0023	0.036 ± 0.0016**	0.048 ± 0.0014
Cu, mg/kg	0.016 ± 0.0010**	0.025 ± 0.0016	0.026 ± 0.0018
Zn, mg/kg	0.103 ± 0.021***	0.143 ± 0.0011***	0.775 ± 0.021

industrial crops under intensive technologies using mainly mineral fertilizers (Abou, 2019).

The studies of the migration of heavy metals in the soil-plant system have determined that it is possible to change their amount in the soil environment and that these processes are significantly influenced by the organic component of soils. When heavy metals enter the soil, they combine with its organic component, which contributes to the reduction of removal of these toxicants by vegetation (Abu Khatita, 2020). The obtained research results showed that the highest difference in the content of Hg, Pb, Cd, Zn and Cu under the conditions of homestead plots and field crop rotation was found in the sod-podzolic sandy loamy soil, which was characterized by a low content of organic matter. The difference was comparatively lower in the gray forest medium loamy and black soil typical medium loamy soils, which had a higher content of organic matter, confirming previous research results (Abuzaid et al., 2021). A number of scientists, both in Ukraine and in European countries, devoted themselves to the study of heavy metal contamination of the soils of urban areas. These authors note the high level of accumulation of heavy metals in the soils of agro-residential areas. This phenomenon depends on the level of technogenic load of industry and the intensity of use of soil fertilization with organic and mineral fertilizers under the conditions of homestead plots (Binggan and Linsheng, 2010; Karim et al., 2014). Under the conditions of Ukraine, in the Zhytomyr region in particular, the content of lead up to 50 mg/kg, cadmium up to 0.60 mg/kg and zinc up to 200 mg/kg was found in the soils of urbanized areas, in particular in agricultural zones. According to the conducted research, it was established that the content of mobile forms of lead, cadmium, zinc and copper in the soils of homestead plots of agro- residential urbanized territories is higher compared to the soils of field crop rotation.

CONCLUSIONS

It was determined that under the conditions of homestead plots, a higher content of Hg, Pb, Cd, Zn and Cu was observed in the black soil typical medium loamy by 44.3%, by 11.6%, by 12.3%, by 10.6% and by 9.8%, respectively, compared to soils of field crop rotation. The content of Hg, Pb, Cd, Zn and Cu in the gray forest medium loamy soil was higher by 29%, by 7.7%, by 12.9%, by 14.1% and by 24.5%, respectively, in the the conditions of homestead plots, compared to soils of field crop rotation. The content of Hg, Pb, Cd, Zn and Cu in the sod-podzolic sandy loamy soil was higher by 77.4%, by 16.8%, by 17.4%, by 38.3% and by 38.3%, respectively, compared to the soils of field crop rotation.

The highest difference in the content of Hg, Pb, Cd, Zn and Cu in the soils of homestead plots and field crop rotation was found on sod-podzolic sandy loamy soil. The hazard ratio of Pb, Cd, Hg, Zn, and Cu in all three types of soil in both homestead plots and field crop rotation conditions did not exceed the limit of 1.0.

REFERENCES

1. Abou El-Anwar E.A. 2021. Mineralogical and geochemical studies on soils and Nile bottom sediments of Luxor–Aswan area, South Egypt. Bul.l Natl. Res. Cent. 45(1), 1. https://doi.org/10.1186/s42269- 021-00573-3
2. Abou El-Anwar. 2019. Assessment of heavy metal pollution in soil and bottom sediment of upper Egypt: Comparison study. Bul.l Natl. Res. Cent., 43(1), 1. https://doi.org/10.1186/s42269-019-0233-4.
3. Abu Khatita, Koch R., Bamousa A.O. 2020. Sources identification and contamination assessment of heavy metals in soil of Middle Nile Delta, Egypt. Journal. of Taibah University for Science, 14(1), 750–61. https://doi.org/10.1080/16583655.2020.1771833
4. Abuzaid A.S., Jahin H.S., Asaad A.A., Fadl M.E., Abdelrahman M.A.E., Scopa A. 2021. Accumulation of potentially toxic metals in Egyptian alluvial soils, berseem clover (Trifolium alexandrinum L.), and groundwater after long-term wastewater irrigation. Agric, 11(8), 713.
5. Belon E., Boisson M., Deportes I.Z., Eglin T.K., Feix I., Bispo A.O., Galsomies L., Leblond S., Guellier C.R. 2014. An inventory of trace elements inputs to French agricultural soils. Science of The Total Environment Journal, 439, 87–95. https://doi.org/10.1016/j.scitotenv.2012.09.011
6. Binggan W., Linsheng Ya. 2010. A review of heavy metal contaminations in urban soils, urban road dusts and agricultural soils from China. Microchemical Journal, 94(2), 99–107. https://doi.org/10.1016/j.microc.2009.09.014
7. DSTU 4770.1:2007 - DSTU 4770.9:2007. Soil quality. Determination of the content of mobile manganese compounds (zinc, cadmium, iron, cobalt, copper, nickel, chromium, lead) in the soil in a buffered ammonium-acetate extract

with pH 4.8 by the method of atomic absorption spectrophotometry. [Effective from 01.01.2009]. K.: Derzhspozhivstandard of Ukraine 2009. 117 (in Ukrainian).
8. Dydiv A., Piddubna A., Gucol G., Vradii O., Zhylishchych Y., Titarenko O., Razanova A., Odnosum H., Postoienko D., Kerek S. 2023. Accumulation of lead and cadmium by vegetables at different levels of gray forest soil moistening in the conditions of the Right Bank Forest Steppe of Ukraine. Journal of Ecological Engineering, 24(10), 198–204. https://doi.org/10.12911/22998993/170291
9. Emam W.W.M., Soliman K.M. 2021. Geospatial analysis, source identification, contamination status, ecological and health risk assessment of heavy metals in agricultural soils from Qallin city, Egypt. Stochastic Environmental Research and Risk Assessment, 11:1264. https://doi.org/10.1007/s00477-021-02097-8
10. Honcharuk I. 2020. Use of wastes of the livestock industry as a possibility for increasing the efficiency of aic and replenishing the energy balance. Visegrad Journal on Bioeconomy and Sustainable Development, 9(1), 9–14. https://doi.org/10.2478/vjbsd-2020-0002
11. Hrabak N.H., Topiha I.N., Davydenko V.M., Shevel I.V. 2016. Basics of agriculture and land protection: a study guide. VD Professional, Kyiv (in Ukrainian).
12. Huang B., Yuan Z., Li D., Zheng M., Nie X., Liao Y. 2020. Effects of soil particle size on the adsorption, distribution, and migration behaviors of heavy metal(loid)s in soil: A review. Environmental Science Proceedings and Impacts, 22, 1596. https://doi.org/10.1039/D0EM00189A.
13. Hussain B., Ashraf M.N., Rahman S.U., Abbas A., Lia J., Farooq M. 2021. Cadmium stress in paddy fields: Effects of soil conditions and remediation strategies. Science Total Environment Journal, 754, 142188. https://doi.org/10.1016/j.scitotenv.2020.142188
14. Ivanova O.S. 2014. Local heavy metal contamination of residential areas of Brusyliv district. Collection of scientific works of Kharkiv National Pedagogical University named after H.S. Frying pans Series «Biology and valeology», 12, 135–140 (in Ukrainian).
15. Zahida K., Bilal Q,, Majid, M., Salman Q. 2014. Heavy metal content in urban soils as an indicator of anthropogenic and natural influences on landscape of Karachi – A multivariate spatio-temporal analysis. Ecological Indicators, 42, 20–31. https://doi.org/10.1016/j.ecolind.2013.07.020
16. Khan S., Naushad M., Lima E.C., Zhang S., Shaheen S.M., Rinklebe J. 2019. Global soil pollution by toxic elements: Current status and future perspectives on the risk assessment and remediation strategies – A review. Journal of Hazardous Materials, 417, 126039. https://doi.org/10.1016/j.jhazmat.2021.126039
17. Lisova A.P., Kravchenko S.M. 2020. Fertilizer application system: textbook, Higher School, Kyiv (in Ukrainian).
18. Liu N., Huang X., Sun L., Li S., Chen Y., Cao X., Wang W., Dai J., Rinnan R. 2020. Screening stably low cadmium and moderately high micronutrients wheat cultivars under three different agricultural environments of China. Chemosphere, 241, 125065. https://doi.org/10.1016/j.chemosphere.2019.125065
19. Loganathan P., Hedley M.J., Gregg P.E.H., Currie L.D. 2017. Effect of phosphate fertiliser type on the accumulation and plant availability of cadmium in grassland soils. Nutrient Cycling Agroecosystems, 46, 169–178. https://doi.org/10.1007/BF00420551
20. Lugon-Moulin N., Ryan L., Donini P., Rossi L. 2016. Cadmium content of phosphate fertilizers used for tobacco production. Agronomy for Sustainable Development, 26, 151–155. https://doi.org/10.1051/agro:2006010
21. Luo L., Ma Y., Zhang S., Wei D., Zhu Y. 2019. An inventory of trace element inputs to agricultural soils in China. Journal of Environmental Management, 90, 2524–2530. https://doi.org/10.1016/j.jenvman.2019.01.011
22. Mu D., Zheng S., Lin D., Xu Y., Dong R., Pei P., Sun Y. 2023. Derivation and validation of soil cadmium thresholds for the safe farmland production of vegetables in high geological background area. Science Total Environment Journal, 873, 162171. https://doi.org/10.1016/j.scitotenv.2023.162171
23. Myslyva T.M., Onoprienko L.O. 2019. Heavy metals in urboedaphatopes and phytocenoses and the territory of Zhytomyr. KHNAU Bulletin, 2, 134–142 (in Ukrainian).
24. Myslyva T.M., Trembitskyi V.A., Dovbysh L.L. 2016. Heavy metals in forest-agrarian landscapes of Zhytomyr Polissia. Agrochemistry and soil science, special edition, 260–263 (in Ukrainian).
25. Ni R.X., Ma Y.B. 2018. Current inventory and changes of the input/output balance of trace elements in farmland across China. PLoS ONE, 13, 0199460. https://doi.org/10.1371/journal.pone.0199460
26. Nicholson F.A., Smith S.R., Alloway B.J., Carlton-Smith C., Chambers B.J. 2016. An inventory of heavy metals inputs to agricultural soils in England and Wales. Science of The Total Environment Journal, 311, 205–219. https://doi.org/10.1016/S0048-9697(03)00139-6
27. Nziguheba G., Smolders E. 2018. Inputs of trace elements in agricultural soils via phosphate fertilizers in European countries. Science Total Environment Journal, 390, 53–57. https://doi.org/10.1016/j.scitotenv.2018.09.031

28. Peng M., Zhao C., Ma H., Yang Z., Yang K., Liu F., Li K., Yang Z., Tang S.Q., Guo F. 2020. Heavy metal and Pb isotopic compositions of soil and maize from a major agricultural area in Northeast China: Contamination assessment and source apportionment. Journal of Geochemical Exploration, 208, 106403. https://doi.org/10.1016/j.gexplo.2019.106403
29. Rai P.K., Lee S.S., Zhang M., Tsang Y.F., Kim K.H. 2019. Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International Journal, 125, 365–385. https://doi.org/10.1016/j.envint.2019.01.067
30. Rasanov S.F, Tkachuk O.P. 2017. Intensive chemistry of earth – as a precondition for the pollution of grain production by high-speed metals. Technology of production and processing of livestock products, 1(134), 70–75.
31. Razanov S., Husak O., Hnativ P., Dydiv A., Bakhmat O., Stepanchenko V., Pryshchepa A., Shcherbachuk V., Mazurak O. 2023a. The influence of the gray forest soil moisture level on the accumulation of Pb, Cd, Zn, Cu in spring barley grain. Journal of Ecological Engineering, 24(7). 285–292. https://doi.org/10.12911/22998993/164747
32. Razanov S., Melnyk V., Symochko L., Dydiv A., Vradii O., Balkovskyi V., Khirivskyi P., Panas N., Lysak H., Koruniak O. 2022. Agroecological assessment of gray forest soils under intensive horticulture. International Journal of Ecosystems and Ecology Science (IJEES), 12(4), 459–464. https://doi.org/10.31407/ijees12.4
33. Razanov S., Piddubna A., Gucol G., Symochko L., Kovalova S., Bakhmat, M., Bakhmat O. 2022. Estimation of heavy metals accumulation by vegetables in agroecosystems as one of the main aspects in food security. International Journal of Ecosystems and Ecology Science (IJEES), 12(3), 159–164. https://doi.org/10.31407/ijees12.320
34. Razanov S., Tkachuk O., Lebedieva N., Shkatula Yu., Polishchuk M., Melnyk M., Krektun B., Razanova A. 2023b. Phytoremediation of heavy metal contamination by perennial legumes. International Journal of Environmental Studies, 1–7. https://doi.org/10.1080/00207233.2023.2296764
35. Riaz M., Kamran M., Rizwan M., Ali S., Parveen A., Malik Z., Wang X. 2021. Cadmium uptake and translocation: Synergetic roles of selenium and silicon in Cd detoxification for the production of low Cd crops: A critical review. Chemosphere, 273, 129690. https://doi.org/10.1016/j.chemosphere.2021.129690
36. Romheld V. 2021. The role of phytosiderophores in acquisition of iron and other micronutrients in graminaceous species: An ecological approach. Plant Soil, 130, 127–134. https://doi.org/10.1007/BF00011867
37. Tiecher T.L., Ceretta C.A., Tiecher T., Ferreira P.A., Nicoloso F.T., Soriani H.H., Rossato L.V., Mimmo T., Cesco S., Lourenzi C.R.. 2016. Effects of zinc addition to a copper-contaminated vineyard soil on sorption of Zn by soil and plant physiological responses. Ecotoxicology and Environmental Safety Journal, 129, 109–119. https://doi.org/10.1016/j.ecoenv.2016.03.016
38. Wan Y., Huang Q., Wang Q., Ma Y., Su D., Li H. 2020. Ecological risk of copper and zinc and their different bioavailability change in soil-rice system as affected by biowaste application. Ecotoxicology and Environmental Safety Journal, 192, 110301. https://doi.org/10.1016/j.ecoenv.2020.110301
39. Wan Y., Huang Q., Wang Q., Yu Y., Su D., Qiao Y., Li H. 2020. Accumulation and bioavailability of heavy metals in an acid soil and their uptake by paddy rice under continuous application of chicken and swine manure. Journal of Hazardous Materials, 384, 121293. https://doi.org/10.1016/j.jhazmat.2019.121293
40. Yu Y., Zhu L., Guo T., Huang Q., Wang Q., Li H. 2018. Risk assessment of cadmium and arsenic in phosphate fertilizer. Journal of Agro-Environment Science, 37, 1326–1331.
41. Zhao F.J., Ma Y., Zhu Y.G., Tang Z., McGrath S.P. 2015. Soil contamination in China: Current status and mitigation strategies. Environmental Science and. Technology, 49, 750–759. https://doi.org/10.1021/es5047099
42. Zheng S., Wang Q., Yuan Y., Sun W. 2020. Human health risk assessment of heavy metals in soil and food crops in the Pearl River Delta urban agglomeration of China. Food Chemestry, 316, 126213. https://doi.org/10.1016/j.foodchem.2020.126213