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SOIL CONTAMINATION WITH HEAVY METALS AND REMEDIATION MEASURES

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Analysis of soil contamination with heavy metals showed that the concentration was lead – 2.52 mg/kg, cadmium – 0.22, zinc and copper – 3.53 mg/kg in the field crop rotation, forest plantations – 1.20 mg/kg, 0.12, 4.30 and 2.27 mg/kg, respectively. The use of organic fertilizers reduces lead honey by 1.11 times in soil, cadmium by 2.75, zinc by 1.42 and copper by 1.42 times, respectively. The use of microfertilizers reduced the intensity of contamination of melliferous with heavy metals, namely, lead – by 2.31 times, cadmium – by 11 times, zinc – 1.42 and copper – by 1.25 times. The intensity of soil contamination was reduced by the introduction of lead residue – by 3.2 times, cadmium – by 2.75 times, zinc – by 1.25 and copper – by 1.42 times. It is also necessary to note a decrease in the intensity of soil contamination of agricultural honey plants by heavy metals for the use of siderates, in particular lead – by 3.15 times, cadmium, zinc, copper, 2.44, 2.9 and 1.8 times compared to similar indicators on soils without fertilizer.

The use of green manure resulted in a 3.15, 2.44, 2.9 and 1.8-fold reduction in the intensity of soil pollution of agricultural land with lead, cadmium, zinc and copper compared to the same indicators on soils without fertilisation.

When using manure, the efficiency of lead reduction was 2.8 times lower compared to organic fertilisers, 1.4 times lower for microfertilisers, and 1.03 times lower for green manure. When using microfertilisers, the effectiveness of cadmium reduction was 4 times lower compared to the use of organic fertilisers and manure, and the use of green manure was 4.5 times lower.

The effectiveness of zinc reduction in the soil with the use of green manure was 2.3 times lower compared to the use of manure, microfertilisers and organic fertilisers, and the effectiveness of copper reduction with the use of green manure was 1.2 times lower compared to the application of manure and organic fertilisers, and 1.4 times lower compared to the use of microfertilisers.

Key words: *soil, heavy metals, lead, zinc, copper, cadmium, humus, monitoring, pollution, concentration, All-Ukrainian Scientific and Educational Consortium.*

Гуцол Г.В., Мазур О.В. Забруднення ґрунтів важкими металами та ремедіаційні заходи

Аналіз забруднення ґрунту важкими металами показав, що концентрація свинцю становила 2,52 мг/кг, кадмію – 0,22, цинку та міді – 3,53 мг/кг та 1,20 мг/кг відповідно. Внесення органічних добрив та мікропрепаратів сприяє зниженню вмісту важких металів у грунтах сільськогосподарських угідь. Застосування органічних добрив знижує вміст *свинцю в ґрунті медоносних угідь в 1,11 рази, кадмію – в 2,75, цинку – в 1,42 і міді – в 1,42 раза відповідно. Застосування мікродобрив знизило інтенсивність забруднення медоносних угідь важкими металами, а саме свинцем – у 2,31 рази, кадмієм – в 11 разів, цинком – 1,42 та міддю – в 1,25 рази. Також слід відмітити зниження інтенсивності забруднення ґрунту сільськогосподарських медоносів важкими металами за використання сидератів, зокрема свинцем – у 3,15 рази, кадмієм, цинком, міддю – у 2,44, 2,9 та 1,8 рази порівняно з аналогічними показники на ґрунтах без добрив.*

Застосування сидератів призвело до зниження інтенсивності забруднення ґрунтів сільськогосподарських угідь свинцем, кадмієм, цинком і міддю у 3,15, 2,44, 2,9 та 1,8 раза порівняно з такими ж показниками на ґрунтах без внесення добрив.

При застосуванні гною ефективність зниження вмісту свинцю була в 2,8 раза нижчою порівняно з органічними добривами, в 1,4 раза – з мікродобривами, в 1,03 раза – з сидератами. При застосуванні мікродобрив ефективність зниження кадмію була в 4 рази нижчою порівняно з використанням органічних добрив і гною, а використання сидератів – у 4,5 рази.

Ефективність зниження вмісту цинку в ґрунті при застосуванні сидератів була в 2,3 рази нижчою порівняно з використанням гною, мікродобрив та органічних добрив, а ефективність зниження вмісту міді при застосуванні сидератів – у 1,2 рази порівняно із застосуванням гною та органічних добрив, а порівняно з використанням мікродобрив – у 1,4 раза.

Ключові слова: *ґрунт, важкі метали, свинець, цинк, мідь, кадмій, гумус, моніторинг, забруднення, концентрація.*

Problem statement. The current state of soil is a matter of concern for the entire civilised world. Increasing areas of degraded soils and deterioration in their quality are forcing the global community to raise issues of soil protection and sustainable use at the highest political level. Soil is one of the most important environments subject to significant anthropogenic impact. The accumulation of toxic substances in the soil leads to their migration into plants and their products, and subsequently with food into the human body [1].

Heavy metals are one of the most toxic soil pollutants. They can enter the soil with mineral fertilisers, limestone materials, pesticides, vehicle exhaust gases, and industrial emissions. Therefore, a system for monitoring the state of the soil cover is an important task today [2].

Analysis of recent research. V.M. Hryshko points out that natural soil contamination with heavy metals is the result of their intake from parent rocks and deep ore deposits. Under conditions of intense anthropogenic impact, the intake of heavy metals into soils exceeds their ability to self-purify. This leads to a decrease in the yield and quality of crop production and the production of food products that are, in some cases, unfit for human consumption [3].

V.M. Grishko [3], E.Y. Zhovinsky, I.V. Kuraeva argue that heavy metals are currently one of the first places among man-made environmental pollutants. Large industrialised regions are powerful sources of pollution of all environmental components [4].

According to scientists V.M. Hryshko [3], E.Y. Zhovynskyi, I.V. Kuraieva soil contamination with elements such as lead, zinc, copper and cadmium is a great danger in the modern ecosystem. Their adverse effects lead to an increase in morbidity and mortality, so the topic under study is relevant. Due to the intensive use of land, it is necessary to systematically monitor the state of its fertility and the level of heavy metal pollution [5].

Scientists V.P. Gudz, I.A. Shuvar et al. describe the peculiarity of the profile distribution of heavy metals in natural and man-made areas, which are characterised by a regressive-accumulative type of distribution, manifested in the increased accumulation of metals in the humus horizon and a sharp decrease in their content in the lower horizons [6].

The peculiarities of heavy metals redistribution in the soil profile are influenced by a complex of soil factors: particle size distribution, soil solution reaction, organic matter content, cation absorption capacity, drainage, and others [7].

According to the results of research by A.I. Breslavets, but also on the ecosystem as a whole, taking into account the organic links between the level of metal content at which plant growth decline and other negative effects begin to appear can vary several times on sandy and clay soils, cultivated and uncultivated. This takes into account not only their direct effect on living organisms, its components and possible individual effects of pollutants entering the biosphere [8].

According to scientists E.Y. Zhuvinsky and I.V. Kuraev [5], lead is a very weak migrant in soil, rarely appearing in soil solutions as a Pb^{2+} ion.

According to the research of S.F. Razanov, lead is very easily adsorbed by silt minerals, iron and aluminium hydroxides, and organic substances. It is released from the soil solution in the form of carbonates and phosphates, which indicates its stable location in the soil, in particular where the soil pH is greater than 6.5 [8].

According to scientists E.I. Kuzmenko and A.S. Kuzmenko [6], the total copper content in soils is about 0.002 %, and the soluble part is about 1.0 % of this amount. Soils contain different forms of copper that are not equally absorbed by plants: a) water-soluble copper, b) exchangeable copper absorbed by organic and mineral substances, c) hardly soluble copper, d) copper-containing minerals, e) complex organometallic copper compounds.

According to research by V.M. Grishko [3], the movement of copper and its supply to plants are reduced by liming of soils, binding of copper in the form of organic compounds and fixation by soil humus. Soil microorganisms play an important role in copper fixation. The copper content of soils is strongly bound to soil humus acids, and in this form it is indigestible for plants. Copper deficiency for plants is more pronounced on sandy and peaty soils. At the same time, the availability of copper to plants on acidic soils is higher than on soils with neutral and alkaline reactions. Fertilisers containing copper are most effective on limestone soils [5; 9].

The content of this heavy metal in the soil is very low, and the intensity of plant uptake of the trace element is affected by soil conditions, for example, with increasing pH, its absorption decreases. Therefore, liming of soils often leads to a deterioration in its absorption by plants. The presence of zinc in the soil also reduces its content in plants. The need for cadmium in plants has not been determined, but it is known that excess cadmium is toxic and has a negative impact on physiological processes, in particular on photosynthesis [10].

V.M. Hryshko and D.V. Syschykov [3] point out that the zinc content in the soil helps plants better withstand high temperatures and various fungal diseases. In addition, zinc helps to accelerate various chemical processes in plants [3].

O.P. Tkachuk [9] points out that with a lack of zinc in the soil, the leaves and the plant itself are deformed, and growth slows down. Zinc fertilisation helps to restore plant growth. Plants such as potatoes, beetroot, hops, and perennial legumes are most susceptible to zinc deficiency [9].

Excessive zinc content in the soil, in turn, leads to negative consequences, as a significant amount of this element has been found in poisonous mushrooms. Zinc and zinc fertilisers have a positive effect on the soil and plants when its content is optimal [6].

In agriculture, the intensive use of fertilisers, especially mineral and chemical ameliorants, causes changes in the quantitative composition of heavy metals. These elements contained in mineral fertilisers are natural impurities, and their amount depends on the raw materials and processing technologies. Heavy metals are well absorbed by soils, forming highly insoluble compounds with phosphates and hydroxides, which contributes to their gradual accumulation in the soil environment. This leads to an increase in the toxic potential of the soil, affects its biological activity, and causes pathological changes in biological processes [11].

Heavy metals are monitored by the following indicators: the level of metal toxicity, which is characterised by the value of the MPC; physical and chemical properties of the metal that determine its behaviour in soils, migration into natural waters and plants; correlation between the regional background metal content in the soil and its entry into the soil as a result of anthropogenic activities [12].

The problem of environmental pollution by heavy metals has been growing in recent years and has now reached alarming proportions. Such pollution leads to negative consequences for living organisms. Therefore, the issue of studying the ways in which heavy metals enter the air, soil and water, as well as the means of protection against them, is of great importance in today's environment [13].

In agriculture, the intensive use of fertilisers, especially mineral and chemical ameliorants, causes changes in the quantitative composition of heavy metals. These elements are naturally occurring impurities in mineral fertilisers, and their amount depends on the raw material (agricultural commodity) and its processing technology [3; 12; 13].

Heavy metals are well absorbed by soils, forming highly insoluble compounds with phosphates and hydroxides, which contributes to their gradual accumulation in the soil environment. This leads to an increase in the toxic potential of the soil, affects its biological activity, causes pathological changes in biological processes, and accumulation of harmful substances in crops. The accumulation of heavy metals in the soil affects its fertility and microbiological activity. Heavy metal contamination is one of the factors that determine crop productivity and the quality of agricultural products. The toxicity of heavy metals to plants is determined not by their gross content in the soil, but mainly by the content of their mobile compounds [14].

Heavy metals and their compounds can migrate and redistribute in the environment. The main ones are heavy metals such as cadmium, zinc, lead, copper, mercury, etc. It is known that these metals, due to their inclusion in the cycle and migration into living organisms, accumulate in significant quantities, which contributes to an increased risk of various types of diseases [15].

Heavy metal contamination of food raw materials that provide food for the population is a particular danger. Among the food raw materials, bee products, which are in high demand among the population, play an important role [16].

Soil pollutants in agricultural areas where honey plants grow pose a great danger. In the context of growing environmental pollution by heavy metals, it is becoming increasingly important to study the impact of these factors on the condition of honey-growing lands and beekeeping products [16].

The basis of the honeybee base, including pollen-bearing bees, is the cover-seeded plants of forests, meadows, marshes and agricultural lands. The flora of honey plants in Ukraine includes about 900 different plant species, providing bees with nectar and pollen, which are the food base for bees and raw materials for the production of commercial products, including honey, bee pollen, perg, drone larvae homogenate, royal jelly, etc [17].

The territory of the Forest-Steppe and Polissya of Ukraine has about 70 % of the same species of honey and pollen-bearing plants. The honey-bearing base of these areas includes herbaceous plants, trees, shrubs, and shrubs [18].

Agricultural honey plants are a powerful source of nectar and pollen, which are the raw materials for the production of bee products. The main representatives are winter and spring rape, sunflower, buckwheat, and sweet clover. These honey plants provide the bees with sufficient food and create conditions for the production of marketable products, including protein [4].

Crops suitable for honey production include: sunflower is a well-known honey plant that is grown on large areas as a leading oilseed crop, as well as for green fodder and silage, with an area of about 6 million hectares in Ukraine. The plant is a member of the Asteraceae family, with a mature orange corolla enveloping five stamens and a pistil with a two-part stigma. The nectar-bearing tissue is located at the bottom of the flower. Each flower lasts for two days, or even longer if it is not pollinated. The flowering period of sunflower is 25–30 days, and at different sowing dates – up to 1.5 months. Honey harvesting begins in late June or early July. Bee colonies produce 2–3 kg of nectar per day. The honey productivity of sunflower grown for oilseeds is 35 kg/ha, and 15 kg/ha when grown for green fodder and silage. Sunflower provides bees with a lot of pollen, which is especially important in late summer to prepare families for wintering [8]. Seed buckwheat is of great economic importance as a cereal and honey crop. Every year, this crop is sown in the country on an area of about 500 thousand hectares. The plant belongs to the buckwheat family. Buckwheat begins flowering 30–35 days after sowing and lasts an average of 25–30 days. The nectar is available for bees, but in dry, hot and cold weather it dries up and honey production decreases, and in rainy weather, buckwheat nectar production decreases sharply. Bees collect nectar and pollen from buckwheat. A long flowering period of buckwheat ensures a long honey collection – from mid-June to September [1; 4].

In addition to the main crops, buckwheat is increasingly being grown in stubble and stubble cropping, which provides additional grain harvest and improves the food supply for bees at the end of the season, when they are in great need of fresh nectar and pollen [9].

Winter rape is grown as an oilseed and fodder crop. In recent years, the area under this crop has increased due to exports for biofuel production. Rapeseed is an early honey plant, which provides apiaries with marketable products and helps to build up bees for the summer. It belongs to the cruciferous family and is characterised by a typical flower structure, with golden yellow petals. After overwintering, it grows intensively, forms juicy branched stems that end in multi-flowered clusters. It blooms for 25–30 days at the same time as fruit trees. Nectar is released in clearly visible droplets between the ovary and stamens. The flower lasts for two days. The honey yield is 50–120 kg/ha, and it also produces a lot of pollen. The area under rapeseed for animal feed is expanding, and its importance for increasing honey yields is growing [14].

At present, all honey and pollen-bearing plants are separated into separate groups, in particular, honey plants of field and fodder crop rotations, vegetable and bean honey crops, fruit and berry honey plants, honey plants of forests, parks and protective plantations, and herbaceous honey plants [12].

The group of forest park honey plants includes trees, shrubs and herbs. Among the main representatives of these honey plants are linden, Tatar and sharp-leaved maple, white and yellow acacia, raspberry, hazel, creeping blackberry, goat willow, willow-herb and others. The flora of forest park honey plants provides bees with sufficient quantities of high-quality protein food, creating conditions for the production of commercial bee products [12].

The group of fruit and berry honey plants includes: apple, apricot, cherry, sweet cherry, plum, peach, gooseberry, currant and others. Plants of this group bloom in April – May. The flowering period is 8–15 days. The maximum amount of pollen from

1 hectare of fruit and berry honey plants reaches 70 kg. These honey plants produce a relatively small amount of pollen, which only partially satisfies their needs due to the short flowering period [9, 10].

The flora of herbaceous honey plants includes a wide range of plants, the main representatives of which are: common bruise, medicinal dandelion, dog's crook, yellow sweet clover, field mustard, stinging nettle, yellow field thistle, thyme and others. The flowering period of these plants lasts from May to August. Under favourable conditions, these plants can fully provide bees with food and, in some cases, create conditions for the production of marketable products. Up to 370 kg of pollen can be obtained from 1 hectare of grass. Based on the pollen productivity of plants, the period and duration of their flowering, the most promising for the production of bee pollen are the honey plants of field and fodder crop rotations, honey plants of forests, parks and protective plantations [9, 10].

Among the main honey plants of field and fodder crop rotations that create conditions for the commercial production of bee protein products, it is necessary to highlight: buckwheat, winter rape, mustard, white clover, echinacea. The most promising honey plants for the production of bee pollen, royal jelly, and drone larvae homogenate are linden, willow, maple, white acacia, and heather in forests, parks, and protective belts [2].

Honey plantations are land areas occupied by cultivated or wild honey plants growing as a continuous cover or in a mixture with non-honey plants. Honey-bearing lands include: field – most of the field areas are occupied by non-melliferous plants – root crops, wheat cereals, and some of them are under fallow, while the other part of them is used for growing the strongest honey plants: buckwheat, sunflower, rape, sainfoin, phacelia, mouse peas, fodder beans, sweet clover, clover, etc [6].

Melons and gourds are essential in honey harvesting. All types of melons, watermelons, pumpkins, and zucchini provide bees with a good amount of food. In contrast to melons, the fields occupied by vegetable crops are not as significant. Among garden plants, various varieties of cucumbers are notable for their honey production. Cruciferous vegetables such as cabbage, rape, radish, etc. also provide good honey yields. Onions are considered to be the strongest honey plants [9].

Orchards and berry gardens – various types of fruit trees, such as apple, pear, plum, apricot, peach, cherry, cherry, etc. – provide pollen and nectar. Berry and shrub plantations, such as currants, raspberries, blackberries, and gooseberries, are particularly honey-bearing. Fruit and berry plants provide bees with a spring forage, which stimulates bee colonies to develop more rapidly. The exception is raspberries, which bloom in summer and provide bees with a lot of nectar. Forest belts – usually located around fields and very important for beekeeping. They complement the field capture and significantly "brighten up" the spring non-capture periods [8].

Scientific and economic research on heavy metal pollution (lead, cadmium, zinc and copper) in the context of technogenic pollution of honey-growing lands and the impact of agrochemical and environmental measures on the quality of beekeeping products was carried out in the agricultural lands of Vasylivka village, Tyvriv district, Vinnytsia region [5].

Generally accepted methods were used to monitor heavy metal contamination of the test material. To study the concentration of lead, cadmium, zinc and copper in the soil, samples were taken from each field using the envelope method at the depth of ploughing. Four soil samples were taken from each site. They were then placed in polyethylene bags with labels indicating the number of the original sample, field number, depth of sampling and the name of the farm and sent to the laboratory [17].

Task setting. The research was carried out on soils obtained from the territory of the Research and Development Group “Agronomic”, which are part of the land resources of the All-Ukrainian Scientific and Primary Consortium and are located in the central part of Vinnytsia region. The territory of the experimental field has a flat relief. The soil cover of the experimental plot is represented by grey forest medium loamy soils. According to morphological characteristics, physical and physical and chemical parameters, they are typical for Vinnytsia region and for the Forest-Steppe in general and are favourable for growing various crops [18].

Soil sampling was carried out using the envelope method. Soil samples were collected from each field and sent to the laboratory in plastic bags with labels indicating the number of the original sample, field number, name of the material under study and the place of collection [19–23].

Presentation of the material of research. In the studied soils obtained from the territory of the Research and Development Group “Agronomic”, which are part of the land resources of the NSC “All-Ukrainian Scientific and Primary Consortium” and are located in the central part of Vinnytsia region, the following agrochemical indicators were found: the average humus content in soils is 3.0 %, hydrolytic acidity s 2.93 mg. eq. per 100 g of soil, easily hydrolysed nitrogen – 10, 72 mg per 100 g of soil, mobile phosphorus and exchangeable potassium – 19.8 and 14.05 mg per 100 g of soil, respectively, pH of the salt extract 5.1 – acidic.

The content of easily hydrolysed nitrogen in the field soils was 1.57, 1.08, 3.12 and 1.75 times lower than normal, respectively, mobile phosphorus was 1.70, 3.64, 2.90 and 2.30 times higher than normal, and exchangeable potassium in the field soils was 1.03, 2.31, 1.6 and 4.35 times higher than normal, respectively (Table 1).

Table 1

Agrochemical parameters of soil in the research and development centre “Agronomic” of Vinnytsia National Agrarian University

Area, ha	N, easy – Kornfield hydrolysable mg per 100 g of soil	P_2O_5	K_2O	Calcium, mg.eq. 100 g of soil	Acidity:		Humus, %
		by the Cherikov method mg per 100 g of soil			hydrolytic, mg.equiv/ 100 g of soil	pH	
Norma	17,5	7,5	6,0	–	–	–	–
Field 1/70	11,1	12,8	6,2	1,26	2,74	5,2	2,9
Field 2/88	16,2	27,3	13,9	1,24	2,32	5,5	3,1
Field 3/40	5,6	21,8	10,0	1,21	3,11	5,1	3,3
Field 4/57	10,0	17,3	26,1	1,30	3,56	4,9	2,8

Analysing the concentration of heavy metals in soils (Table 2), it should be noted that in the samples of the selected soil, the concentration of lead was lower than the MPC by 1.01, 1.42, 1.22 and 1.17 times, respectively, cadmium was also lower than the MPC by 1.16, 1.4, 1.16 and 1.27 times, respectively, as well as zinc by 2.52, 2.05, 2.64 and 2.42 times, respectively, and copper concentration in the soils was higher than the MAC by 2.26, 1.6, 1.73 and 1.63 times, respectively.

At the same time, it was found that the concentration of lead in field 1 was 1.40, 1.20 and 1.15 times higher than the concentration of the same heavy metal in fields 2, 3 and 4, respectively. The concentration of cadmium in fields 1 and 3 was 1.2 times higher than in fields 2 and 4. The concentration of zinc in field 2 was 1.23, 1.28 and 1.17 times higher than in fields 1, 3 and 4, respectively. The concentration of copper in field 1 was 1.41, 1.30 and 1.38 times higher than in fields 2, 3 and 4.

Table 2

Concentration of heavy metals in soil, in the Research and Development Group "Agronomic" of Vinnytsia National Agrarian University, mg/kg

Heavy metals	**MAC**	**Field 1**	**Field 2**	**Field 3**	**Field 4**
Lead	6,0	5,9	4,2	4,9	5,1
Cadmium	0,7	0,6	0,5	0,6	0,55
Zinc	23	9,1	11,2	8,7	9,5
Copper	3,0	6,8	4,8	5,2	4,9

The honey-growing lands included honey plants of field and fodder crop rotations, honey plants of fruit, berry and vegetable crops, honey plants of forests and parks, protective strips and special honey plants.

The analysis of the state of contaminated soils of honey-growing lands in the studied territories indicates a variety of contamination with lead, cadmium, zinc and copper (Table 3).

In particular, the concentration of heavy metals in the soils of agricultural honey plants was higher than in the soils of forest park plantations. Thus, lead was 2.10 times higher, cadmium 1.80 times higher, zinc 1.39 times higher, and copper 1.96 times higher, respectively. The concentration of copper in the soil of field and fodder crop rotations was 1.18 times higher than the MPC, while the concentration of lead, cadmium and zinc, on the contrary, was lower – 2.38 times, 3.18 times and 3.83 times, respectively.

The concentration of heavy metals in the soils of forest plantations was below the MPC. In particular, lead by 5.0 times, cadmium by 5.83 times, zinc by 5.34 times and copper by 1.32 times, respectively. These data indicate intensive contamination of agricultural land with heavy metals due to the use of mineral and organic fertilisers that contain these elements. At the same time, it should be noted that the intensity of soil contamination with heavy metals depended on the type of honey crops grown on them.

Table 3

Intensity of heavy metal contamination of honeybee soils, mg/kg

Heavy metals	**Concentration of heavy metals in soils**		
	field and fodder crop rotations	**forest and park plantations**	**MAC**
Lead	2,00–3,05* 2,52	1,00–1,40 1,20	6,00
Cadmium	0,15–0,30 0,22	0,08–0,15 0,12	0,70
Zinc	1,97–12,5 6,00	1,20–7,40 4,30	23,00
Copper	0,06–7,00 3,53	0,04–4,50 2,27	3,00

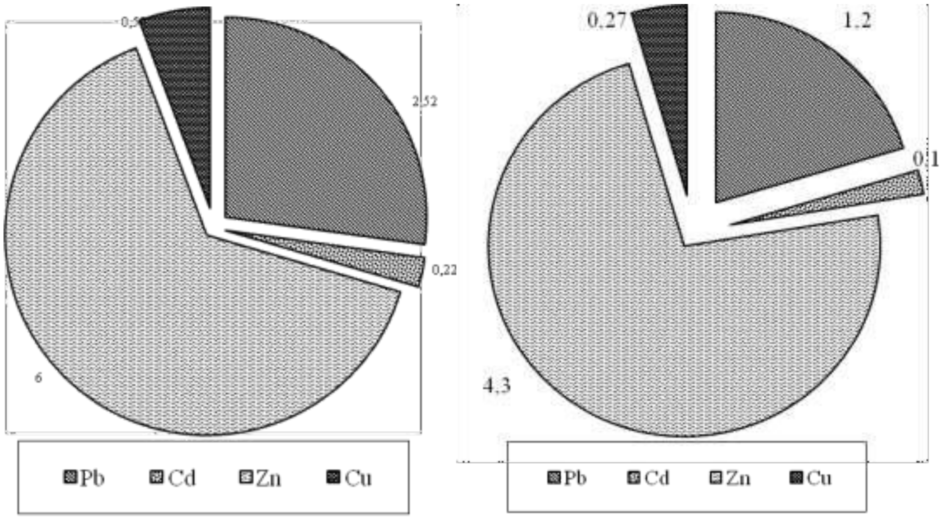
Note: * – numerator is the minimum and maximum concentration of heavy metals in soils, denominator is the average concentration of heavy metals in soils

Thus, the concentration of lead ranged from 1.2 to 2.52 mg/kg, cadmium from 0.12 to 0.22 mg/kg, zinc from 4.3 to 6.0 mg/kg and copper from 2.27 to 5.53 mg/kg. That is, the difference in concentrations for lead was 2.1 times, for cadmium – 1.83 times, for zinc – 1.4 times, and for copper – 2.44 times.

Based on the results of the research, a comparative characterisation of soil contamination with heavy metals in field and fodder crop rotations and forest parks was also carried out (Fig. 1).

The results obtained in Fig. 2, show that in the soil of field and fodder crop rotations, the largest share of heavy metals is zinc, whose concentration is 2.38 times higher than that of lead, 27.2 times higher than that of cadmium, and 11.32 times higher than that of copper.

A similar trend was observed in the soils of forest park honey plants. In particular, the concentration of zinc was 3.58 times higher than that of lead, 35.8 times higher than that of cadmium, and 15.9 times higher than that of copper. At the same time, it should be noted that the MPCs for zinc were also significantly higher than for other heavy metals.



soils of field and fodder crop rotations soils of forest park honey plants

Fig. 1. Comparative characteristics of soil pollution in field and fodder crop rotations and forest parks

Reducing the content of heavy metals in soils is a complex problem. It requires a comprehensive approach. Firstly, it is necessary to consider heavy metal antagonist elements, which will be used to remove this type of heavy metal from the soil by replacing it. This method is effective, but too expensive, as it requires the application of expensive chemicals in large quantities [7].

Therefore, a more promising way is not to remove heavy metals, but to convert them into inactive and low-active compounds. This can be achieved by increasing the capacity of the soil's absorbing complex by applying certain fertilisers, mainly organic, green manure, litter and microfertilisers.

Under conditions of intense anthropogenic impact, there is a high level of heavy metal intake into agroecosystems, in some cases exceeding permissible levels. This leads to a decrease in the quality of crop production, making it dangerous for the population [2; 5].

A number of measures have been developed to reduce the intensity of soil pollution with heavy metals, including the use of microfertilisers and other fertilisers instead of mineral fertilisers, which are a powerful source of heavy metals.

We have identified the impact of microfertiliser application to reduce the concentration of lead, cadmium, zinc and copper. The use of micronutrient fertilisers in modern fertilisation systems is the main way to solve the problem of micronutrient deficiencies and ensure the best return on investment.

The most valuable organic fertiliser for gardeners is chicken manure. The content of nutrients in it cannot be compared with manure or humus. Unlike other types of fertiliser, manure is a more effective and environmentally friendly fertiliser. Chicken manure is well absorbed by plants. It can be applied to almost all crops. Organic fertilisers are an almost indispensable component of ecological and organic production.

Humic and fulvic acids are the biological "centre" of humus. Therefore, to restore the humus layer and improve its fertility properties, the application of humates will be an effective and cost-efficient solution. Humates are biologically active substances that serve not only as organic fertilisers but also as biostimulants. These compounds improve the plant's absorption of nutrients and moisture, enhance the activity of soil microflora, and increase plant resistance to stressful conditions.

Green manures are plants that are temporarily grown on vacant soil areas to improve soil structure, enrich it with nitrogen and suppress weed growth. Usually grown in a separate period of time and then ploughed and mixed into the soil in an immature form, or shortly after flowering, green manure is associated with organic agriculture and is considered essential for systems with annual crops that are to be made sustainable. Traditionally, the practice of using green manure can be attributed to the cycle of fallow land in crop rotation, which is used to rest the land.

Seedlings can be legumes such as soya, laguta, annual clover, peas, as well as non-legumes such as millet, sorghum, buckwheat. Legumes are often used for their nitrogen-fixing capabilities, while non-legumes are used mainly to suppress weeds and increase biomass in the soil.

The coefficient of reduction in the intensity of soil pollution with heavy metals under agrochemical measures is shown in Table 4.

Table 4

Efficiency of reducing the concentration of heavy metals in the soil of agricultural land using agrochemical measures

Agrochemical measures	**Coefficient of reduction of soil pollution intensity by heavy metals under agrochemical measures, times**			
	lead	**cadmium**	**zinc**	**copper**
Use of organic fertilisers	0,9	0,4	0,7	0,7
Use of micronutrient fertilisers	2,3	2,1	0,7	0,8
Use of litter	3,2	2,7	0,8	0,7
Use of green manure	3,1	2,3	2,9	1,8

Thus, the highest rates of reduction of soil contamination intensity were found for lead and cadmium when using manure, zinc and copper when using green manure. The application of manure to the soil reduced the intensity coefficient of lead contamination by 2.3 times. The greatest impact on the reduction of cadmium in the soil was found with the use of manure, compared to organic fertilisers, microfertilisers and green manure. The studied coefficient was higher by 2.3, 0.6 and 0.4, respectively.

The introduction of organic and microfertilisers and manure into the soil had almost the same indicators of reducing the intensity of zinc contamination (0.7–0.8), and compared to it, the use of green manure reduced the zinc content the best – by 2.1–2.2.

The application of these fertilisers had a similar effect on the reduction of copper in the soil. The application of green manure reduced the copper content by 1.0–1.1 compared to other fertilisers.

The concentration of heavy metals in the soils of agricultural lands of honey plants when using manure, organic fertilisers, microfertilisers, green manure and green manure is shown in Table 5.

The soils of honey plant farmland are most contaminated with lead, followed by zinc, copper, and the least contaminated with cadmium.

Conclusions and proposals. Analysing the results it should be noted that the use of organic fertilisers reduced the intensity of soil pollution of agricultural honey plants by lead by 1.11 times, cadmium by 2.75 times, zinc and copper by 1.42 times compared to the same indicators on soils without fertilisers.

Table 5

Concentration of heavy metals in the soils of agricultural lands of honey plants, mg/kg

Agrochemical measures	**Heavy metals in soils, mg/kg**			
	lead	**cadmium**	**zinc**	**copper**
No fertiliser application	2,52	0,22	6,0	3,53
Use of organic fertilisers	2,26	0,08	4,2	2,47
Use of micronutrient fertilisers	1,09	0,02	4,2	2,82
Use of litter	0,79	0,08	4,8	2,47
Use of green manure	0,8	0,09	2,06	1,96

When microfertilisers were applied to the soil, the intensity of honey plant pollution decreased by 2.31 times for lead, 11 times for cadmium, 11 times for zinc – by 1.42 times and copper – by 1.25 times. It should also be noted that the intensity of soil contamination of agricultural honey plants decreased when manure was applied: lead – by 3.2 times, cadmium – by 2.75 times, zinc – by 1.25 times and copper – by 1.42 times.

The use of green manure resulted in a 3.15, 2.44, 2.9 and 1.8-fold reduction in the intensity of soil pollution of agricultural land with lead, cadmium, zinc and copper compared to the same indicators on soils without fertilisation. At the same time, it should be noted that the highest efficiency of lead reduction in the soil was achieved with the use of manure.

For example, when using manure, the efficiency of lead reduction was 2.8 times lower compared to organic fertilisers, 1.4 times lower for microfertilisers, and 1.03 times lower for green manure. When using microfertilisers, the effectiveness of cadmium reduction was 4 times lower compared to the use of organic fertilisers and manure, and the use of green manure was 4.5 times lower.

The effectiveness of zinc reduction in the soil with the use of green manure was 2.3 times lower compared to the use of manure, microfertilisers and organic fertilisers, and the effectiveness of copper reduction with the use of green manure was 1.2 times lower compared to the application of manure and organic fertilisers, and 1.4 times lower compared to the use of microfertilisers.

To reduce the intensity of soil pollution of agricultural honey plants, we propose to replace the use of mineral fertilisers with organic fertilisers, microfertilisers, manure and green manure.

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ДЕПРЕСІЯ ВИХІДНОГО МАТЕРІАЛУ ПШЕНИЦІ ОЗИМОЇ В ЗАЛЕЖНОСТІ ВІД СОРТУ ТА ТИПУ ЧИННИКА

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Застосування мутагенних чинників для генетичного поліпшення дозволяє в короткі терміни отримати суттєві позитивні зміни, але проблемою залишається наявність сильної депресії в першому поколінні. Метою дослідження було виявити наслідки дії мутагенів з високою ушкоджувальною здатністю на показники мутантної популяції в першому поколінні для встановлення оптимальних параметрів протоколу застосування для генетичного поліпшення пшениці озимої. Насіння двох сортів пшениці озимої Вежа та Ігриста обробляли водним розчином хімічних мутагенів азиду натрію у концентраціях 0,01 %, 0,025 %, 0,05 %, 0,1 % та етилметансульфонату (тут та далі ЕМС) у концентраціях 0,025 %, 0,05 %, 0,1 %. Для кожної обробки були використані 1000 зерен пшениці озимої. Експозиція дії мутагену становила 24 години. оцінювали схожість, виживання, фертильність, ознаки структури врожайності. Сорт Вежа виявився значно більш стійким до депресивних впливів у першому поколінні, ніж сорт Ігриста. В усіх випадках для усіх сортів фертильність статистично значимо знижувалася за дії усіх концентрацій та в порівнянні з контролем. Азид натрію виявляв свою дію набагато сильніше в аналогічних концентраціях, ніж ЕМС. Діапазон застосованих концентрацій досяг напівлетальних значень, Вплив генотипу був достовірним, як і підвищення концентрації. За результатами дискримінантного аналізу високомінливими були схожість, виживання, фертильність, вага зерна з головного колосу та з рослини, МТЗ, що достовірно відтворювали мутагенну депресію. Як мутаген азид натрію в дії призводить до суттєвого підвищення депресії в першому поколінні в порівнянні з етилметансульфонатом, а сорт Ігриста суттєво поступається за стійкість до обох чинників в порівнянні з сортом Вежа, що швидше за все обумовлено генетично. Різниця між сортами не завжди достовірна при дії нижчих доз та суттєво зростає при її підвищені. Застосування 0,1 % концентрації ЕМС та 0,05–0,1 % концентрацій азиду натрію суттєво підвищую пряму та віддалену загибель