ВІСНИК
ЛЬВІВСЬКОГО НАЦІОНАЛЬНОГО УНІВЕРСИТЕТУ ПРИРОДОКОРИСТУВАННЯ

ISSN 2786-6807 Засновано в 1997 р.

СЕРІЯ
АГРОНОМІЯ

№ 27 2023

Редакційний штат

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UDC 631.95/631.963.2

CONTENT OF HEAVY METALS IN THE PHYTOMASS OF THE NATURAL MEADOW ECOSYSTEMS OF VINNYTSIA REGION UNDER GENERAL BACKGROUND POLLUTION AND AS A RESULT OF ANTHROPOGENIC TRANSFORMATION OF LAND

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https://doi.org/10.31734/agronomy2023.27.032

Titarenko O. Content of heavy metals in the phytomass of the natural meadow ecosystems of Vinnytsia region under general background pollution and as a result of anthropogenic transformation of land

Meadows as plant ecosystems of the Forest-Steppe zone are secondary in origin. They were formed on the site of indigenous (primary) vegetation types – forest or marsh ecosystems – after being transformed by humans to meet the needs of agriculture or livestock. In ancient times, the areas that are now occupied by meadows were mostly covered by forests or swamps. With population growth and livestock development, these forests were cut down, swamps drained, and the land was used for agricultural production as pastures and hayfields. Meadows on the plains of former forest or marsh ecosystems are unstable dynamic phytocoenoses in different stages of succession. Therefore, dominant species' botanical composition and projective cover change rapidly, requiring constant human intervention to maintain their high productivity.

Following the principles of sustainable development, one of the most urgent tasks is to provide the population with a sufficient amount of high-quality and safe food of both plant and animal origin. It is known that the quality and safety of food products are directly dependent on the environmental conditions of food raw material production. Vegetation of natural fodder lands is an important element of livestock production, which is characterized by low cost compared to cultivated lands.

However, in some areas, natural fodder lands undergo a strong anthropogenic load in technogenesis, leading to soil contamination with various toxicants, particularly heavy metals such as Pb, Cd, Zn, and Cu. The main sources of pollution of natural fodder lands are industry, motor vehicles, chemicalisation of the crop production sector, and others. Under such conditions, the use of phytocoenoses as feedstock for both domestic and wild animals increases the risk of heavy metals entering their bodies, which threatens the production of safe and high-quality products, and contaminated soils may be withdrawn from agricultural use.

The study aimed to determine the levels of accumulation of Pb, Cd, Zn, and Cu in the ecosystems of natural fodderlands under different anthropogenic loads in the conditions of Eastern Podillia in Vinnytsia region.

Key words: natural meadows, phytomass, soil, lead, cadmium, zinc, copper, accumulation coefficient, hazard coefficient, fertilisers, soil cultivation.

Тітаренко О. Вміст важких металів у фітомасі природних лучних екосистем Вінницької області за загального фонового забруднення та в результаті антропогенної трансформації земель

Луки як рослинні екосистеми зони Лісостепу вторинні за своїм походженням. Вони сформовані на місці корінних (первинних) типів рослинності – лісових чи болотних екосистем – після перетворення їх людиною під потреби землеробства чи тваринництва. У давні часи площі, які тепер зайняті луками, були переважно вкриті лісами чи болотами. Зі зростанням кількості населення та розвитком тваринництва ці ліси були вирубані, болота осушені, а землі залучені до аграрного виробництва як пасовища та сіножаті. Луки на рівнинних територіях колишніх лісових чи болотних екосистем є нестійкими динамічними фітоценозами в різних стадіях сукцесій. Тому ботанічний склад і проєктивне покриття домінантних видів швидко змінюються, тож потребують постійного втручання людини для підтримання їхньої високої продуктивності.

Дотримуючись принципів сталого розвитку, одним із найактуальніших завдань є забезпечення населення достатньою кількістю якісних і безпечних продуктів харчування як рослинного, так і тваринного походження. Відомо, що якість і безпечність харчових продуктів безпосередньо залежать від екологічних умов виробництва харчової сировини. Рослинність природних кормових угідь – важливий елемент виробництва продукції тваринництва, яка характерна низькою вартістю порівняно з орними угіддями.

Однак природні кормові угіддя в умовах техногенезу зазнають на деяких територіях сильного антропогенного навантаження, що призводить до забруднення ґрунтів різними токсикантами, зокрема важкими металами, такими як Pb, Cd, Zn та Cu [4]. Основними джерелами забруднення природних кормових угідь є промисловість, автотранспорт, хімізація галузі рослинництва тощо. Використання за таких умов фітоценозів як кормової сировини як для свійських, так і для диких тварин, підвищує ризик надходження в їхні організми важких металів, що ставить під загрозу одержання безпечної і якісної їх продукції, а забруднені ґрунти можуть бути виведені із сільськогосподарського користування.

Визначено рівні накопичення Pb, Cd, Zn, Cu в екосистемах природних кормових угідь за різного антропогенного навантаження в умовах Східного Поділля на території Вінницької області.

Ключові слова: природні луки, фітомаса, ґрунт, свинець, кадмій, цинк, мідь, коефіцієнт накопичення, коефіцієнт шкідливості, добрива, обробіток ґрунту.

Problem Formulation. Practice shows that the ecological conditions of natural fodderlands are deteriorating from year to year, including due to their pollution with toxicants. It is known that every year more than 6 million tons of harmful substances containing heavy metals are released into the environment, and the amount of these metals in ecosystem components is growing rapidly. Heavy metals entering the soils of natural fodder lands are included in a small cycle of substances, which increases the risk of their ingress into feed raw materials [2].

At the same time, the intensity of heavy metal accumulation in phytomass under conditions of different sources of anthropogenic load on natural fodder lands of Vinnytsia region has not been studied sufficiently. Therefore, there is a need for a detailed study of the intensity of heavy metal contamination of phytocoenoses of natural fodder lands under different directions of anthropogenic load. The priority of such tasks is caused by the social factor, namely the reduction of man-made impact on the population by preventing the transformation of pollution toxins in plant feedstock.

Analysis of Recent Research and Publications. Natural fodderlands include 61 species of vitamin-bearing plants, 53 species of plants containing tannins, and 42 species containing essential oils [1]. Taking into account the shortcomings of the previous classification of the vegetation of natural fodder lands and based on their research, Yakubenko B. E. and others [4] proposed a more objective model that includes three classes of plant biodiversity formation, in particular tall ryegrass, stoloko bezostoyant, and bentgrass [7].

The first formation includes five associations, including tall ryegrass fine bentgrass, tall ryegrass meadow fescue, vyokoraygras meadow bluegrass, tall ryegrass pure and tall ryegrass lying alfalfa.

Energy-saving technologies consist of the selection of individual species and grass mixtures, the use of fertilizers, modes of use of natural fodder lands and the establishment of their impact on the composition, structure, and productivity of grass stands, and the forecasting of their development [5].

The growing anthropogenic activity of the population leads to an increase in the flow of various harmful substances into the environment, in particular, heavy metals, which, being in the exchangeable form, move through trophic chains from soil to vegetation, reducing the quality and safety of food raw materials [3; 9].

Powerful sources of environmental pollution with heavy metals are the following complexes: mining, metallurgical, machine-building, chemical, transport, agro-industrial, housing communal, etc. [8]. It is known that mine wastewater and post-mining water in mines contain several pollutants, among which heavy metals are the most dangerous. In steelmaking, only one ton of steel is smelted and up to 40 kg of particulate matter is released into the atmosphere, including Mn, Cu, Zn, Cd, and Pb compounds [2].

A significant amount of heavy metals is also released into the environment by chemical production, in particular, with wastewater containing cadmium, lead, and zinc compounds. The fastest-growing sources of environmental pollution today are motor vehicles, agricultural production, and industrial waste [7; 10]. In agricultural production, especially in crop production, mineral fertilizers are a powerful source of heavy metals in the environment [11].

Objectives Setting. Scientific and economic research to study the intensity of Pb, Cd Zn, and Cu accumulation by phytocoenoses of dry lowland meadows of natural fodder lands under different technogenic loads was carried out during 2018–2020 in the conditions of Eastern Podillia in Vinnytsia region. Experimental studies were conducted in three directions [10].

The first area of research included the study of the intensity of contamination of the phytomass of plants of natural fodderlands with heavy metals (Pb, Cd) and heavy metals – trace elements (Zn, Cu) in the conditions of dry lowland meadows in Vinnytsia region. Vegetation was sampled simultaneously when the grass reached a height of 10–12 cm, i.e. suitable for grazing by animals. From each type of natural fodder land, similar cereal and legume vegetation was selected at a distance of 1.5–2 km from mobile and stationary sources of pollution.

The study of local contamination of the phytomass of grass stands was carried out in the conditions of the international motorways M-12 Khmelnytskyi – Vinnytsia – Odesa – Vinnytsia-Odesa (in the vicinity of Zarvantsi and Hunka villages), M-21 Vinnytsia-Zhytomyr (in the vicinity of Kordelivka village) and local – Vinnytsia-Zhmerynka (in the vicinity of Riv village), Vinnytsia-Tyvriv (in the vicinity of Vasylivka village). Natural fodder lands in the area of influence of the railway connection were studied in the vicinity of Hnivan and Zhmerynka [7].

Presenting Main Material. The current state of the flora of Vinnytsia region is characterized by a significant increase in the role of anthropogenic impact. In the course of synanthropisation, two main processes occur in parallel: on one hand, the extinction and suppression of natural elements of the flora, and on the other hand, its enrichment with adventive species and the formation of new types of plant communities with their participation. The number of invasive species with a high invasive capacity is 49, which is 2.8 % of the total number [10].

It has been established that chemicalisation of the crop production industry has a high impact on plants of natural fodder lands, in particular the use of herbicides, which have a significant impact on the formation of yield and quality of agrocenoses. In addition, the damage to plants by pathogens is significantly reduced and their spread to the fields is hindered. Instead, diseases spread to natural phytocoenoses bordering the fields, and plants that are closely related to cultivated plants are affected by these diseases [8].

It was found that the species that suffer the most are those that are of significant value both genetically and economically. The use of herbicides on other crops has a similar effect – it reduces the spread of weeds, pathogens, and pests on crops, but significantly increases their number in natural phytocoenoses [6].

The spread of diseases to natural phytocoenoses and the presence of a significant number of segetal ruderal vegetation in the communities leads to a deterioration in the conditions of species diversity of these areas, especially pastures and meadows used for livestock farms [11].

The analysis of the phytocoenoses of absolute drylands in the study area (Table 1) shows that the grasses here are represented by sheep fescue (Festuca ovina), meadow fescue (Festuca pratensis), common bentgrass (Agrostis capillaris), creeping wheatgrass (Elytrigia repens), thyme (Thymus), and whitebush (Nardus) [6].

Table 1

Species composition of dominant plants of different types of natural fodder meadows in the studied areas

Types of natural fodder meadows	Botanical families of meadow plants			
	Cereals	Legumes	Sedges	Herbs
Absolute landmasses	Sheep's fescue, meadow fescue, creeping wheatgrass, common bentgrass	Creeping clover, horned larkspur	-	Yarrow, myrtle, plantain, dandelion
Normal dry land	Pasture ryegrass, meadow timothy, horned bentgrass, collective bentgrass, wheatgrass	Pink clover, horned larkspur, creeping clover, meadow clover, meadow pea, white sweet clover	-	Yarrow, dandelion
Drylands with excessive moisture	Turfgrass, slender bluegrass	Meadow clover	Slender sedge	Meadow whitewash

Small amounts of creeping clover (Trifolium repens), meadow peas (Písum pratensis), yarrow (Achillea millefolium), mimosa (Setaria), plantain (Plantago), dandelion (Leontodon), and horned lily (Lotus corniculatus) are found in small quantities [9].

Under normal dryland conditions, the plant diversity includes pasture ryegrass (Lolium perenne), meadow timothy (Phleum pratense), horned larkspur (Lotus corniculatus), pink clover (Trifolium hybridum), meadow clover (Trifolium pratense), yarrow (Achillea millefolium), meadow pea (Písum pratensis), common bentgrass (Dactylis glomerata), white sweet clover (Melilotus albus), wheatgrass (Elymus repens), dandelion (Lentodon) [2].

Vegetation of drylands with excessive moisture is represented mainly by sedge (Carex), and relatively less by soddy bentgrass (Deschampsia cespitosa), and meadow whitebush (Nardus pratense), slender bluegrass (Tamarix gracilis Willd), meadow clover (Trifolium pratense), and awnless bromegrass (Bromus inermis).

Vegetation in the lowlands of natural lowland meadows is constantly affected by both natural and climatic conditions and anthropogenic impact, which reduces the stability of their coenoses. Therefore, the conservation of phytocoenoses under such conditions requires a competent approach based on an in-depth analysis of the ongoing monitoring of their agroecological condition [8].

Given that plants are capable of accumulating high concentrations of heavy metals in their vegetative mass several times and sometimes several dozens of times higher than in the soil, there is a need to monitor the contamination of vegetation of natural fodder lands in the area of local anthropogenic load, where there is a risk of contamination of phytocoenoses above permissible levels.

The results of the study (Table 2) showed that the concentration of lead and cadmium in vegetation in absolute dryland conditions ranged from 3.2 mg/kg to 4.1 mg/kg and from 0.13 mg/kg to 0.2 mg/kg, respectively.

Table 2

Heavy metals content in phytomass under conditions of local anthropogenic load, mg/kg, on average for 2018–2020 per absolutely dry matter, (n=4, M±m)

Dry lowland meadows	Lead			Cadmium		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	3.2±0.74**	4.1±0.63	3.7±0.5**	0.13±0.06***	0.16±0.02***	0.2±0.04***
Normal drylands	4.4±0.52*	5.2±0.53	4.4±0.71*	0.16±0.05**	0.19±0.04**	0.28±0.03*
Dry soils with excessive moisture	4.7±0.44	5.9±0.47	4.8±0.38	0.20±0.03	0.22±0.041	0.33±0.032

The highest levels of lead were found in the phytomass of areas adjacent to regional roads, and cadmium in areas adjacent to railway lines. For example, the concentration of lead in the vegetation of absolute drylands under conditions of local pollution in the areas adjacent to interregional roads was 1.28 times and 1.1 times higher than in the areas adjacent to district and railway roads, respectively. The concentration of cadmium in the vegetation of absolute drylands under conditions of local pollution in the areas adjacent to the railway was 1.53 times and 1.25 times higher than in the areas adjacent to the district and regional roads, respectively.

Under normal land conditions of localized pollution, the concentration of lead in vegetation ranged from 4.4 mg/kg to 5.2 mg/kg, and cadmium from 0.16 mg/kg to 0.28 mg/kg. The concentration of lead in the vegetation of the areas adjacent to the regional roads under normal dry conditions was 1.18 times and 1.18 times higher than in the areas adjacent to the district and railway roads, respectively. The concentration of cadmium in vegetation in areas adjacent to interregional roads was 1.75 times and 1.47 times higher than in areas adjacent to district and railway roads, respectively.

In the vegetation of excessively moist land in the area of localized contamination, lead concentrations ranged from 4.7 mg/kg to 5.9 mg/kg, and cadmium from 0.20 mg/kg to 0.33 mg/kg. Lead concentrations were also highest in vegetation adjacent to roads, and cadmium concentrations were highest in areas adjacent to railways. In particular, the concentration of lead in the vegetation of areas of excessive moisture adjacent to regional roads was 1.25 times and 1.22 times higher than in the vegetation of district and railway areas, respectively. The concentration of cadmium in the vegetation of the areas adjacent to the railway was 1.65 times and 1.5 times higher than that of the areas of district and regional roads, respectively. At the same time, it should be noted that the MAC for lead in vegetation adjacent to interregional roads in normal dry conditions was exceeded by 1.04 times and in excessively wet conditions by 1.18 times. The results of the study show that under conditions of localized pollution of natural fodder lands, the highest levels of lead and cadmium were observed in the herbs of excessively moist soils. Thus, in the vegetation of the areas adjacent to district roads, the concentration of lead was 1.06 times and 1.46 times higher compared to normal and absolute drylands, respectively.

In the areas adjacent to the regional roads, the concentration of lead in herbs was 1.43 times and 1.13 times higher than in absolute and normal dry land, respectively. The concentration of lead in the herbs of the areas adjacent to the railway connection was 1.29 times and 1.09 times higher than in the absolute and normal drylands, respectively.

The concentration of cadmium in the herbage of the areas adjacent to the district roads was 1.53 times and 1.25 times higher than in the absolute and normal drylands, respectively. In the areas adjacent to interregional roads, the concentration of cadmium in herbs was 1.37 times and 1.15 times higher than in absolute and normal drylands, respectively. The concentration of cadmium in the vegetation of the territories adjacent to the railway connection was 1.65 times and 1.17 times higher than in absolute and normal drylands, respectively.

The results of the research (Table 3) on the intensity of phytocoenosis contamination with heavy metals (trace elements) in the area of local contamination of natural fodder lands showed that under conditions of absolute dryness, the concentration of zinc ranged from 8.2 mg/kg to 14.5 mg/kg, while copper ranged from 2.1 mg/kg to 3.0 mg/kg.

Under normal dryland conditions, zinc concentrations in vegetation ranged from 9.1 mg/kg to 17.5 mg/kg, and copper from 2.9 mg/kg to 3.2 mg/kg. The concentration of zinc and copper in the vegetation of excessively moist land ranged from 13.2 mg/kg to 19.3 mg/kg and 2.9 mg/kg to 3.8 mg/kg, respectively.

The highest level of zinc and copper contamination in the area of localized contamination of natural fodder lands was characterized by the vegetation of the areas adjacent to the railway. In particular, the concentration of zinc and copper in the vegetation of the areas adjacent to the railway connection in absolute dry land conditions was higher than in the areas adjacent to inter-district and regional roads by 1.76 times and 1.54 times, and 1.42 times and 1.11 times, respectively.

Table 3

Heavy metals content in phytomass of the area of local anthropogenic load, mg/kg, on average for 2018–2020 per absolutely dry matter, (n=4, M±m)

Dry lowland meadows	Zinc			Copper		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	8.2±5.2***	9.4±5.0***	14.5±7.1***	2.1±0.71**	2.7±0.82*	3.0±0.87*
Normal drylands	9.1±4.2***	9.8±5.6***	17.5±7.0**	2.9±0.55	2.7±0.56*	3.2±0.5*
Dry soils with excessive moisture	13.2±3.2	14.7±5.3	19.3±5.5	2.9±0.41	2.9±0.63	3.8±0.7

In the vegetation under normal dry conditions, the concentration of zinc and copper in the areas adjacent to the railway was higher than in the areas of district and regional roads by 1.92 times and 1.78 times, and 1.1 times and 1.18 times, respectively.

Under conditions of excessive moisture in the areas adjacent to the railway, the concentration of zinc and copper was lower than in the areas of district and regional roads by 1.46 times and 1.31 times and 1.31 times and 1.31 times, respectively.

At the same time, it should be noted that the concentration of zinc and copper in the vegetation of natural fodder lands in the area of local pollution in the studied territories did not exceed the MPC.

At the same time, it was also found that the concentration of zinc and copper in the vegetation of excessively moist soils in the area of their local pollution was higher compared to absolute and normal soils. Thus, in the conditions of excessively moist soils in the areas adjacent to district roads, the concentration of zinc was 1.6 times and 1.45 times higher than in absolute and normal soils, respectively.

Copper concentration in the vegetation of excessive moisture drylands was at the same level as in normal drylands, while in absolute drylands it was 1.38 times lower.

In the vegetation of areas adjacent to regional roads, the concentration of zinc and copper in excessive moisture soils was 1.5 times and 1.56 times higher than in normal and absolute dry soils, and 1.07 times and 1.07 times higher, respectively.

In the areas adjacent to the railway lines, the concentration of zinc and copper in vegetation under conditions of excessive moisture compared to normal and absolute dry soils was 1.1 times and 1.3 times higher, respectively, and 1.2 times and 1.26 times higher.

The hazard coefficient of lead and cadmium in the herbs of absolute drylands under conditions of local pollution (Table 4) was, respectively, in the range from 0.64 to 0.82 and from 0.43 to 0.66. The highest hazard coefficient for lead in absolute, normal, and excessive moisture soils was found in the herbs of the territories adjacent to regional roads, and for cadmium – in the territories close to railway connections.

Under normal dryland conditions, the hazard coefficient for lead in herbs ranged from 0.88 to 1.04, and for cadmium from 0.53 to 0.93. In areas of excessive moisture, the hazard factor for lead in herbs ranged from 0.94 to 1.18, and for cadmium from 0.66 to 1.1.

Table 4

Hazard factor of heavy metals in phytomass of the zone of local anthropogenic load, mg/kg (average for 2018–2020)

Dry lowland meadows	Lead			Cadmium		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0.64	0.82	0.74	0.43	0.53	0.66
Normal drylands	0.88	1.04	0.88	0.53	0.63	0.93
Dry soils with excessive moisture	0.94	1.18	0.95	0.66	0.73	1.1

The highest hazard coefficient for lead and cadmium was characterized by the herbage of excessive moisture drylands, while the lower one was observed in normal and absolute drylands.

The analysis of the hazard factor of heavy metals in the vegetation of absolute drylands under conditions of local pollution showed that under conditions of normal drylands, the concentration of zinc ranged from 0.16 mg/kg to 0.29 mg/kg and copper from 0.07 mg/kg to 0.1 mg/kg.

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Under normal dryland conditions, the hazard factor for zinc and copper in vegetation ranged from 0.18 to 0.35 and 0.09 to 0.1, respectively. On the territory of excessive moisture, the concentration of zinc in vegetation ranged from 0.26 mg/kg and copper from 0.9 mg/kg to 0.12 mg/kg. The highest zinc hazard factor in the vegetation of absolute, normal, and excessively moist lands was observed in the areas adjacent to the railway

Table 5

Hazard factor of heavy metals in phytomass of the zone of local anthropogenic load, mg/kg (average for 2018–2020)

Dry lowland meadows	Zinc			Copper		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0.15	0.18	0.29	0.07	0.09	0.1
Normal drylands	0.18	0.19	0.35	0.09	0.09	0.1
Dry soils with excessive moisture	0.26	0.29	0.38	0.09	0.09	0.12

Among the different natural fodder lands, the highest zinc and copper hazard coefficient was observed in the herbage of excessive moisture, and a relatively lower one in normal and absolute drylands.

A certain trend in the accumulation of heavy metals in the herbs of natural fodder lands, in particular, depending on the source of local pollution and the type of dry land, was also observed in the coefficient of accumulation of lead, cadmium, zinc, and copper in phytomass.

Table 6

Coefficient of heavy metal accumulation in phytomass of the zone of local anthropogenic load, mg/kg (average for 2018–2020)

Dry lowland meadows	Lead			Cadmium		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0.94	1.07	1.12	0.25	0.29	0.34
Normal drylands	1.04	1.06	1.15	0.27	0.31	0.41
Dry soils with excessive moisture	0.92	1.03	1.14	0.31	0.32	0.46

In particular, the coefficient of accumulation of lead and cadmium in herbs in absolute dry land conditions in areas adjacent to railway communication was higher than in areas adjacent to district and regional roads by 1.19 times and 1.04 times, and 1.36 times and 1.17 times, respectively. Under normal dry land conditions, the coefficient of lead and cadmium accumulation in herbs in the areas adjacent to the railway was 1.1 times and 1.08 times and 1.5 times, and 1.32 times higher than in the areas adjacent to the district and region roads, respectively.

In the herbage of the areas adjacent to the railway, under conditions of excessive moisture, the coefficient of lead and cadmium accumulation was 1.23 and 1.1 times higher, respectively, and 1.48 and 1.43 times higher, compared to the areas adjacent to the district and regional roads.

Comparing the coefficient of accumulation of heavy metals in vegetation depending on the type of dry meadow in the area of local pollution, it should be noted that in areas close to district roads, this indicator of lead in the phytomass of normal dry meadows compared to absolute dry meadows and excessive moisture was 1.1 times and 1.13 times higher, respectively.

The coefficient of accumulation in the herbs of the territories adjacent to the regional road connection in the conditions of absolute dry soils was higher than in normal and excessively moist soils by 1.01 and 1.04 times, respectively. In the areas adjacent to the railway connection, the coefficient of lead accumulation in herbs of normal drylands was 1.03 times and 1.01 times higher than in absolute drylands and excessively moist soils, respectively.

The coefficient of cadmium accumulation in the vegetation of the areas adjacent to the district and regional roads, as well as railway communication, in the conditions of excessive moisture, was higher than in absolute and normal drylands by 1.24 times, and 1.15 times, 1.1 times and 1.03 times, and 1.35 times and 1.12 times, respectively.

The coefficient of zinc and copper accumulation in the vegetation of the areas adjacent to the railway in absolute dry conditions was higher than in the areas adjacent to the roads of district and regional connections by 1.34 times and 1.38 times, and 1.4 times and 1.08 times, respectively (Table 7).

The zinc and copper hazard coefficient in the vegetation of areas adjacent to railway transport under normal dry conditions was 1.57 times, 1.69 times, 1.1 times, and 1.2 times higher than in areas adjacent to district and regional roads.

The coefficient of accumulation of zinc and copper in the vegetation of excessive moisture in the areas adjacent to the railway was higher than in the areas adjacent to the district and regional roads by 1.33 times and 1.24 times, and 1.35 times, and 1.31 times, respectively.

The coefficient of zinc accumulation in plants of excessive moisture soils in the areas adjacent to district and regional roads and railways, compared to absolute and normal soils, was 1.28 times and 1.28 times higher, respectively; 1.42 times and 1.48 times; and 1.28 times and 1.09 times.

Table 7

Coefficient of heavy metal accumulation in phytomass of the zone of local anthropogenic load, mg/kg (average for 2018–2020)

Dry lowland meadows	Zinc			Copper		
	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to interregional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0.56	0.54	0.75	0.74	0.96	1.04
Normal drylands	0.56	0.52	0.88	1.02	0.95	1.13
Dry soils with excessive moisture	0.72	0.77	0.96	0.96	0.99	1.3

The coefficient of copper accumulation by plants in the areas adjacent to the district roads was 1.37 times higher in normal dry soils compared to absolute dry soils and 1.06 times higher compared to excessive moisture soils. In the vegetation of excessive moisture soils in the areas adjacent to regional roads, the copper accumulation coefficient was 1.03 times higher than in absolute dry soils and 1.04 times higher than in normal dry soils.

The coefficient of copper accumulation by plants in the areas adjacent to the district roads was 1.37 times higher on normally dry soils compared to absolutely dry soils and 1.06 times higher compared to excessively moist soils. In the vegetation of excessive moisture soils in the areas adjacent to the district roads, the copper accumulation coefficient was 1.03 times higher than in absolutely dry soils and 1.04 times higher than in normal dry soils.

The highest content of lead, cadmium, zinc, and copper in phytomass in the area of local pollution was in the conditions of excessive moisture. The content of lead in phytomass exceeded the MPC in normal soil conditions by 1.04 times and in excessive moisture by 1.18 times. Whereas the cadmium content in phytomass exceeded the MAC by 1.1 times only in the areas of excessive moisture adjacent to the railway connection.

Conclusions. The coefficient of accumulation of lead, cadmium, zinc, and copper in phytomass was in the range of 0.31–0.7, 0.10–0.16, 11.4–18.3, and 8.5–12, respectively. The highest coefficient of accumulation in phytomass of lead, cadmium, and zinc was observed in the conditions of excessive moisture, and copper in the territory of absolute drylands. In the areas of localized pollution of lowland dry meadows, the average content of lead, cadmium, zinc, and copper in the phytomass of natural fodder lands was respectively 4.1 mg/kg, 0.16 mg/kg, 10.1 mg/kg and 2.63 mg/kg; district roads – 4.1 mg/kg, 0.19 mg/kg, 11.3 mg/kg and 2.76 mg/kg; railway roads – 4.3 mg/kg, 0.27 mg/kg, 17.1 mg/kg and 3.3 mg/kg. Exceedance of the MPC for lead in phytomass was found in normal and excessively moist soils by 1.04 times and 1.18 times, respectively, and for cadmium – by 1.1 times only in excessively moist soils.

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Стаття надійшла 21.07.2023