ECOLOGY, BIOTECHNOLOGY, AGRICULTURE AND FORESTRY

IN THE 21ST CENTURY

PROBLEMS AND SOLUTIONS

EDITED BY
S. STANKEVYCH, O. MANDYCH

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The monograph is a collection of the results of scientists' achievements obtained directly in real conditions. The authors are recognized specialists in their fields, as well as young scientists and graduate students of Ukraine. The studies are conceptually grouped in sections: biotechnology, ecology, agriculture, forestry, sustainable development of the economy and the principles of effective agribusiness. The monograph will be of interest to specialists in biotechnology, ecology, breeding, plant protection, agrochemistry, soil science, forestry, agribusiness, etc., researchers, teachers, graduate students and students of specialized specialties of higher educational institutions, as well as everyone who is interested in sustainable development in the agricultural sphere and Green Deal Implementation strategies.

Keywords: sustainable development, modern technologies, agricultural production, biotechnology, ecology, plant protection, forestry, agribusiness.

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THE CONTENT OF HEAVY METALS IN THE ECOSYSTEMS OF NATURAL MEADOWS OF THE VINYNAT REGION

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Abstract. In accordance with the principles of sustainable development, one of the most urgent tasks of today 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 characterised by low cost compared to cultivated lands. However, in some areas, natural fodder lands undergo a strong anthropogenic load in the context of technogenesis, which leads to soil contamination with various toxicants, in particular, heavy metals such as Pb, Cd, Zn and Cu. The main sources of pollution of natural forage 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entering their bodies, which threatens the production of safe and high-quality products, and contaminated soils may be withdrawn from agricultural use.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 aim of the study was to determine the levels of accumulation of Pb, Cd, Zn and Cu in the ecosystems of natural forage lands under different anthropogenic load in the conditions of Eastern Podillia in Vinnytsia region. The intensity of accumulation of Pb, Cd, Zn and Cu by plants of absolute drylands, normal drylands and drylands of excessive moisture in the lowland dry meadows of Vinnytsia region under conditions of different technogenic load was assessed. The excess of heavy metals in the phytomass of cadmium alone was found to be 1.01 times higher in the areas of excessive moisture adjacent to the railway; - the tendency of the phytomass of excessively moist lands to higher accumulation of heavy metals, which can exceed the MPC by 1.18 times for lead and 1.1 times for cadmium (compared to meadow ecosystems of absolute and normal lands) and acquire the category of technogenically contaminated lands, was revealed. Prediction of the intensity of Pb, Cd, Zn and Cu intake into plants of natural fodder lands under conditions of anthropogenic load was improved based on the study of their accumulation coefficients. As a result of theoretical analysis and field and laboratory experiments, the intensity of Pb, Cd, Zn and Cu accumulation in phytocoenoses of dry lowland meadows of natural fodder lands under different anthropogenic pollution was studied.

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

Introduction

On the territory of Vinnytsia region, the most attractive fodder lands and phytomass for domestic and wild herbivores are dry lowland meadows. They are classified [3] as absolute dry meadows, normal dry meadows, and dry meadows of excessive moisture. Absolute drylands are characterised by the lowest productivity, while normal drylands and drylands with excessive moisture are relatively more productive [5]. The productivity of different types of meadows depends on soil fertility, the level of soil moisture, the botanical composition of the flora and anthropogenic impact [8, 9].

The meadow type of vegetation is distributed throughout the Vinnytsia region in small areas. Most of the meadows are located in the valleys of the Dniester, Southern Bug, Riv, Murafa, and Sob rivers. These herbaceous phytocoenoses account for about 10% of the land area. They occupy more moist soils than steppes.

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 [7]. In ancient times, the areas that are now occupied by meadows were mostly covered by forests or swamps. With the growth of population and the development of livestock, 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, the botanical composition and projective cover of dominant species change rapidly, requiring constant human intervention to maintain their high productivity [2].

An analysis of the dynamics of plant diversity shows that as of 2012, more than 100 species of adventive plants were growing in Vinnytsia region. About 20 species of the adventive flora are in the process of expansion, including: small-flowered galinsoga, common robinia, annual stenactis, Canadian witch hazel, fragrant witch hazel, ash maple, curved shield, eastern itch, Siberian geranium, nontrembling witch hazel, Sakhalin buckwheat, small-flowered break grass, spotted hemlock, white bindweed, Canadian goldenrod, etc.

Adventive plant species are divided into 3 groups according to the way they penetrate phytocoenoses: acolutophytes - species accidentally introduced as a result of vegetation transformation, ergasiophygophytes - plants that have become wild, and xenophytes - accidentally introduced as a result of human activity.

A significant part of the adventive component is made up of noxious and quarantine weeds. Among the adventitious plants, there are poisonous ones, the most dangerous being spotted hemlock, non-trebulous hemlock, white and dioecious treadmill, American laconos, Syrian cottonweed, etc. Another group of plants are producers of allergens that cause persistent and difficult-to-treat pollenosis in humans. The most famous of these is ragweed, which causes autumn hay fever and asthma exacerbations.

In the absence of grazing or mowing, meadow areas are quickly overgrown with trees and shrubs, which are represented by steppe cherry, medium-sized tawny, steppe plum and mixed shrubs.

According to the phytotypological classification adopted in Ukraine, meadows are divided according to their location on relief elements, similarity of environmental conditions for plant growth, composition of grass stands and crops, and the economic condition of the land. According to this classification, the grassland vegetation of the region includes: steppe and meadow areas on the slopes of gullies, lowland meadows, lowland bogs, floodplain meadows of medium and large rivers, and floodplain meadows of small rivers and gullies. According to this classification, plant communities are named by their dominant species (bromegrasses, bluegrasses, feather grasses, etc.) or by their groups (legumes and cereals, cereals and forbs, etc.).

Analysis of recent research and publications

The legume group of phytocoenoses of natural fodder lands includes 79 species, which is 5.7 %. Sedge and sytnik vegetation includes 95 species (6.9 %). This vegetation is characterised by low fodder quality. The herbage of natural fodder lands includes 39 highly digestible species, which is 2.8%. Poisonous plants also grow among natural fodder meadows, their number reaching 83 species (4.9%) and 59 (4.2%) of harmful species that negatively affect economic value. Natural forage lands include 61 species of vitamin-bearing plants, 53 species of plants containing tannins and 42 species containing essential oils [1].

On the basis of their own research, Yakubenko B.E. and others [44], taking into account the shortcomings of the previous classification of vegetation of natural fodder lands, proposed a more objective model that includes three classes of plant biodiversity formation, in particular tall ryegrass, stoloko bezostoyant and bentgrass.

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.

The analysis of the geobotanical survey of natural fodder lands of the Forest-Steppe of Ukraine showed that they are in an unsatisfactory condition due to high anthropogenic load and need to be restored [6]. The cenotic structure of the studied lands includes mainly cereal crops and cereal-grasses, less often cereal-sedge, sedge-grasses, herbs, and even less cereal-legumes and mono-dominant legumes, so in some areas they need radical restoration. A promising area for the restoration of natural fodder lands is the optimisation of biotechnology in grassland production, which is based on the use of low-cost energy-saving technologies [7].

Energy-saving technologies consist in the selection of individual species and grass mixtures, the use of fertilisers, 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 by heavy metals are the following complexes: mining, metallurgical, machine-building, chemical, transport, agro-industrial, housing and communal, etc. [8]. It is known that mine wastewater and post-mining water in mines contain a number of pollutants, among which heavy metals are the most dangerous. In steelmaking, only one tonne 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 fertilisers are a powerful source of heavy metals in the environment [11].

Research conditions and methods

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 load was carried out during 2018-2020 in the conditions of Eastern Podillia in Vinnytsia region. Experimental studies were conducted in three directions.

The first area of research included the study of the intensity of contamination of the phytomass of plants of natural fodder lands with heavy metals (Pb, Cd) and heavy metals - trace elements (Zn, Cu) in the conditions of dry lowland meadows in Vinnytsia region. For this purpose, soil and vegetation were sampled from each type of natural forage land (absolute drylands, normal drylands and excessive moisture) over a period of three years. Soil and vegetation were 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 second area of research covered the study of the intensity of heavy metal accumulation in the soils of natural forage lands under conditions of local pollution of absolute and normal dry soils and excessive moisture, located near district and regional roads, as well as around railway lines at a distance of 50-100 m in the Vinnytsia region. In these areas, soil and plants were examined for the intensity of heavy metal contamination for three years. 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 Gunka 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.

The third area of research was aimed at studying the intensity of heavy metal contamination of soils and vegetation of natural fodder meadows (normal drylands) under superficial and radical improvement in the conditions of the farm "Dzyaliv" in the village of Kamianohirka, Zhmerynka district, Vinnytsia region, and the farm "Volodymyr" in the village of Shershni, Tyvriv district, Vinnytsia region.

Research results

The current state of the flora of Vinnytsia region is characterised by a significant increase in the role of anthropogenic impact. In the course of synanthropisation, two main processes occur in parallel: on the 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.

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 reduced. Instead, diseases spread to natural phytocoenoses bordering the fields, and plants that are closely related to cultivated plants are affected by these diseases.

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.

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 state of species diversity of these areas, especially pastures and meadows used for livestock farms.

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).

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.

Table 1

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

Types of natural forage 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

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).

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.

The basic concept in ecology is the background content as the average content of chemical elements in natural bodies based on the results of the study of their natural variation (statistical parameters of distribution). The natural geochemical background is the average value of the natural variation in the content of chemical elements in environmental components, which was formed before the environment was subjected to anthropogenic pollution. Nowadays, anthropogenic emissions of chemical elements have occurred over vast areas. Therefore, the background content has changed everywhere and it is important to find out what it is in order to develop a strategy for environmentally friendly agriculture.

The results of the research (Table 2) showed that the concentration of heavy metals in the soils of absolute drylands on average in the studied areas ranged from 2.8 mg/kg to 3.0 mg/kg for lead and from 0.48 mg/kg to 0.5 mg/kg for cadmium.

Table 2

Content of mobile forms of heavy metals in the soils of natural fodder lands, mg/kg (average for 2018-2020 based on absolutely dry matter), (n=4, M±m)

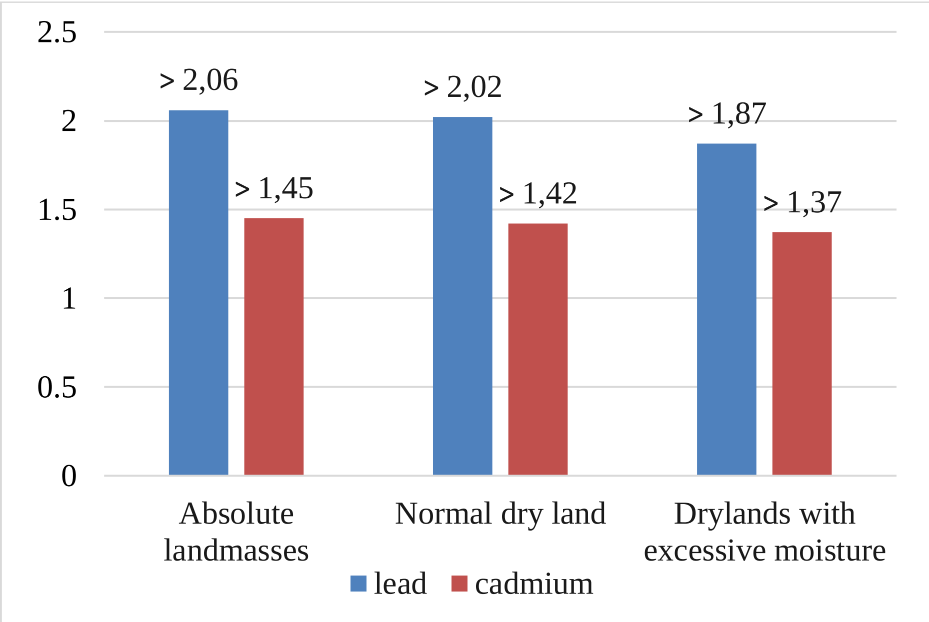
Research material	Lead	Cadmium
	Average	Average
Soils of absolute drylands	2,90±0,07**	0,48±0,03**
Soils of normal drylands	2,96±0,06**	0,49±0,05**
Soils of drylands with excessive moisture	3,20±0,02	0,51±0,047

The content of lead in the soils of absolute drylands was 2.06 times lower than the MPC, and cadmium by 1.45 times. In the soils of normal drylands in the study areas, the concentration of lead ranged from 2.8 mg/kg to 3.1 mg/kg, while cadmium ranged from 0.47 mg/kg to 0.51 mg/kg. The content of lead and cadmium in the soils of normal drylands was 2.02 times and 1.42 times lower than the GDR, respectively.

Under conditions of excessive moisture in the study areas, the content of lead in the soil ranged from 3.1 mg/kg to 3.3 mg/kg, and cadmium from 0.49 mg/kg to 0.53 mg/kg. The content of lead and cadmium in soils in these areas was 1.87 times and 1.37 times lower than the MPC, respectively.

The highest levels of lead and cadmium contamination (Fig. 1) were found in the soils of excessively moist soils, with relatively lower levels in normal soils and absolute dry soils. Thus, the concentration of lead and cadmium in the soils of excessive moisture drylands was 1.1 times and 0.6 times higher, respectively, and 1.08 times and 1.04 times higher, compared to absolute and normal drylands.

The concentration of zinc in the soils of absolute drylands (Table 3.3) ranged from 9.3 mg/kg to 14.2 mg/kg, and copper from 0.14 mg/kg to 0.17 mg/kg. On average, the content of zinc and copper in the soils of absolute drylands in the study areas was 2.0 times and 20 times lower than the MPC, respectively.



Notes. MPC for lead - 6.0 mg/kg, cadmium - 0.7 mg/kg

Fig. 1. Comparative assessment of heavy metal content in soil to the MPC, times

In the soils of normal drylands, the zinc content ranged from 10.5 mg/kg to 14.7 mg/kg, and the copper content from 0.18 mg/kg to 0.19 mg/kg. The zinc and copper content was 1.84 times and 16.6 times lower than the MAC, respectively. The content of heavy metals in the soils of excessively moist land ranged from 17.2 mg/kg to 20.1 mg/kg for zinc and from 0.19 mg/kg to 0.21 mg/kg for copper. The content of lead and cadmium in the soils was 1.25 times and 1.5 times lower than the MPC, respectively.

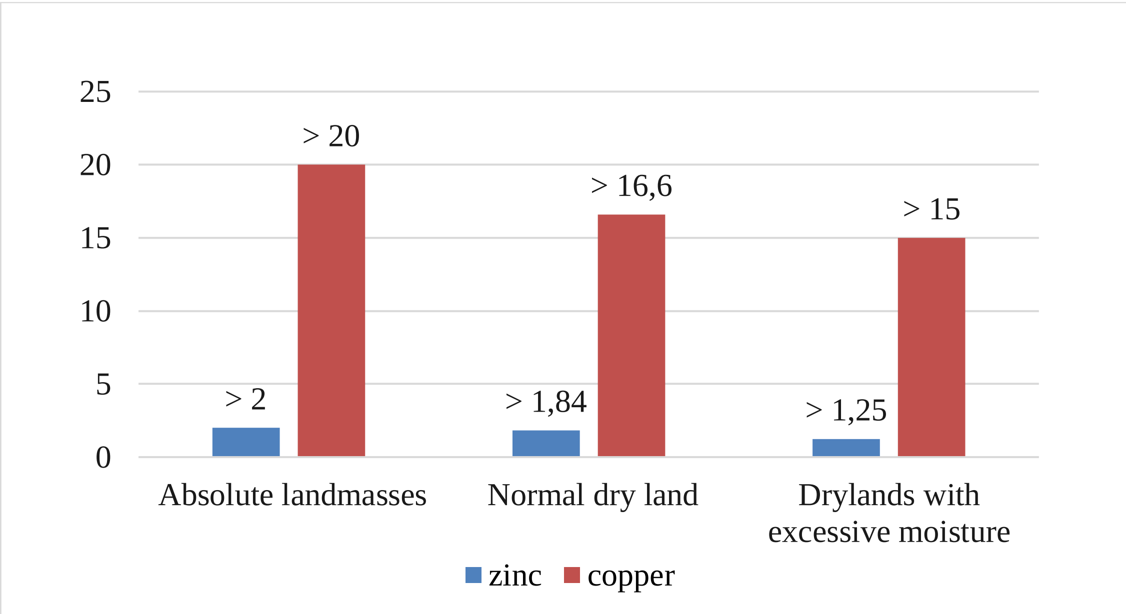
The highest levels of zinc and copper (Fig. 2) were observed in the soils of drylands with excessive moisture, and relatively lower levels in normal drylands and absolute drylands. Thus, the concentration of zinc and copper in the soils of drylands with excessive moisture was 1.6 times and

1.33 times and 1.46 times and 1.11 times lower than in absolute drylands and drylands with excessive moisture. In other words, the soils of drylands with excessive moisture had a high content of lead and cadmium, as well as zinc and copper.

Table 3

Content of mobile forms of heavy metals (trace elements) in the soils of natural fodder lands, mg/kg (average for 2018-2020 based on absolutely dry matter), (n=4, M±m)

Research material	Zinc	Copper
	Average	Average
Soils of absolute drylands	11,4±1,42***	0,15±0,07***
Soils of normal drylands	12,5±0,09**	0,18±0,03**
Soils of drylands with excessive moisture	18,3±1,22	0,20±0,04



Notes. MPC for zinc - 23 mg/kg, copper - 3.0 mg/kg

Fig. 2. Comparative assessment of the average content of heavy metals (trace elements) in soil (for 2018-2020) to the MPC, times

The lead hazard factor in the soils (Table 4) of natural fodder lands ranged from 0.48 to 0.53. The highest lead hazard coefficient of 0.53 was in the soils of excessive moisture drylands, and 1.08 and 1.1 times lower, respectively, in the soils of normal and absolute drylands.

The cadmium hazard factor in the soils of natural fodder lands ranged from 0.68 to 0.72. The highest lead hazard coefficient was observed in the soils of excessive moisture soils, and the lowest in 1.05 times and 1.3 times in the soils of normal drylands and absolute drylands, respectively.

Table 4

Hazard factor of mobile forms of heavy metals in soils of natural fodder lands on average for 2018-2020

Research material	lead			Cadmium		
	MPC	Actual concentration	Kneb	MPC	Actual concentration	Kneb
Soils of absolute drylands	6,0	2,9	0,48	0,7	0,48	0,68
Soils of normal drylands	6,0	2,96	0,49	0,7	0,48	0,79
Soils of drylands with excessive moisture	6,0	3,2	0,53	0,7	0,49	0,72

The zinc hazard factor in the soils (Table 5) of natural fodder lands ranged from 0.49 to 0.79. The highest zinc hazard factor was found in soils of excessive moisture, and relatively lower by 1.46 times and 1.61 times, respectively, in soils of normal and absolute drylands. The copper hazard coefficient in the soils of natural fodder lands in the studied areas ranged from 0.05 to 0.06. In the soils of excessive moisture and normal drylands, the copper hazard factor was 0.06. Whereas in the soils of absolute drylands, the copper hazard factor was 1.2 times lower.

Table 5

Hazard factor of mobile forms of heavy metals (trace elements) in soils of natural fodder lands on average for 2018-2020

Research material	Цинк			Мідь		
	MPC	Actual concentration	Kneb	MPC	Actual concentration	Kneb
Soils of absolute drylands	23	11,4	0,49	3,0	0,15	0,05
Soils of normal drylands	23	12,5	0,54	3,0	0,18	0,06
Soils of drylands with excessive moisture	23	18,3	0,79	3,0	0,20	0,06

The results of the research presented in Table 6 show that the content of lead in the herbs of absolute drylands ranged from 1.24 mg/kg to 1.32 mg/kg, and cadmium from 0.06 mg/kg to 0.071 mg/kg. In the herbs of normal drylands, the content of lead ranged from 0.87 mg/kg to 0.98 mg/kg, and cadmium from 0.047 mg/kg to 0.054 mg/kg.

The content of lead in the herbs of the drylands of excessive moisture ranged from 2.14 mg/kg to 2.31 mg/kg, and cadmium from 0.080 to 0.089 mg/kg. At the same time, it should be noted that the concentration of lead and cadmium in the herbage of excessive moisture drylands was 2.4 and 1.6 times higher, respectively, compared to the herbage of normal drylands and 1.7 and 1.3 times higher than in absolute drylands.

Table 6

Content of heavy metals in phytomass of natural fodder lands, mg/kg (average for 2018-2020)

Research material	lead				Cadmium			
	2018	2019	2020	Average	2018	2019	2020	Average
Herbs of the absolute drylands	1,24	1,32	1,27	1,27±0,03	0,064	0,060	0,071	0,065±0,007
Herbs of normal drylands	0,87	0,98	0,94	0,93±0,027	0,052	0,047	0,054	0,051±0,006
Herbs of drylands with excessive moisture	2,14	2,27	2,31	2,24±0,031	0,080	0,085	0,089	0,084±0,003

That is, the concentration of lead and cadmium was the highest in phytomass on dry lands with excessive moisture, but it did not exceed the MPC. On average, in the studied areas in 2018-2020, the concentration of lead in herbs was 3.93 times lower than the MPC, and cadmium 4.6 times lower in absolute drylands. On average, the content of lead and cadmium in the herbs of normal drylands in the studied territories was 5.3 times and 5.8 times lower than the MPC, respectively. Compared to the MPCs, the content of lead in the herbs of excessive moisture was 2.23 times lower and cadmium 3.5 times lower.

The concentration of zinc in the herbage of absolute drylands in the studied areas (Table 7) ranged from 7.2 mg/kg to 8.2 mg/kg, and copper from 1.7 to 1.9 mg/kg. In the vegetation of normal drylands, the concentration of zinc ranged from 6.2 mg/kg to 7.4 mg/kg, and copper from

1.7 mg/kg to 2.1 mg/kg. In the conditions of excessive moisture, the concentration of zinc ranged from 14.0 mg/kg to 15.0 mg/kg, and copper from 1.6 mg/kg to 1.8 mg/kg, which did not exceed the MPC. Thus, the highest concentration of zinc was observed in the herbs of excessive moisture drylands, and mussels in the herbs of absolute drylands.

At the same time, it should be noted that the zinc concentration in the herbage of excessive moisture drylands was 2.4 times higher compared to the herbage of normal drylands and 1.87 times higher compared to absolute drylands. The copper concentration in the herbage of excessive moisture drylands was 1.11 times lower compared to normal drylands and 1.05 times lower compared to absolute drylands.

Table 7

Content of heavy metals (trace elements) in the phytomass of natural fodder grassland, mg/kg (average for 2018-2020)

Research material	Zinc				Copper			
	Years of research			Average	Years of research			Average
	2018	2019	2020		2018	2019	2020	
Herbs of the absolute drylands	8,2	7,2	8,0	7,8± 0,07**	1,8	1,7	1,9	1,8± 0,077
Herbs of normal drylands	7,4	6,2	6,9	6,8± 0,088**	1,9	2,1	1,7	1,9± 0,039
Herbs of drylands with excessive moisture	14,0	14,8	15,0	14,6± 0,043	1,6	1,8	1,8	1,7± 0,042

Compared to the GDR, the content of zinc and copper in the vegetation (Fig. 4) of absolute drylands was on average 6.4 times and 16.6 times lower in the study areas, respectively.

The concentration of zinc and copper in the vegetation of normal drylands was on average 7.3 times and 15.7 times lower than the GDR in the study areas, respectively. Compared to the GDR, the concentration of zinc and copper in the vegetation of excessively moist land was 3.4 times and 17.6 times lower, respectively. The lead hazard coefficient in the herbage of natural fodder lands (Table 8) ranged from 0.18 to 0.44. The highest lead hazard coefficient was characterised by the herbage of excessive moisture, which was 0.44, while in the herbage of normal and absolute drylands this indicator was lower by 2.4 times and 1.76 times, respectively.

The cadmium hazard coefficient in the grass stand of natural fodder lands ranged from 0.17 to 0.28. The highest cadmium hazard coefficient was in the herbage of excessive moisture drylands, while this indicator was 1.64 times and 1.33 times lower in the herbage of normal and absolute drylands, respectively.

Table 8.

Metal hazard factor in the phytomass of natural fodder lands on average for 2018-2020.

Research material	Lead			Cadmium		
	MPC	Actual concentration	MPC	Kneb	Actual concentration	Kneb
Herbs of absolute drylands	5,0	1,27	0,25	0,3	0,065	0,21
Herbs of normal drylands	5,0	0,93	0,18	0,3	0,051	0,17
Herbs of drylands with excessive moisture	5,0	2,24	0,44	0,3	0,084	0,28

Table 9.

The hazard factor of heavy metals (trace elements) in the phytomass of natural fodder lands on average for 2018-2020.

Research material	Zinc			Copper		
	MPC	Actual concentration	Kneb	MPC	Actual concentration	Kneb
Herbs of absolute drylands	50	7,8	0,15	30	1,8	0,06
Herbs of normal drylands	50	6,8	0,13	30	1,9	0,06
Herbs of drylands with excessive moisture	50	14,6	0,29	30	1,7	0,05

The zinc hazard factor (Table 9) in the herbage of natural fodder lands in the studied areas ranged from 0.13 to 0.27. The highest zinc hazard factor was in the herbage of drylands with excessive moisture and was 0.29, which is 2.2 times and 1.9 times higher than in the herbage of normal and absolute drylands, respectively.

The copper hazard coefficient in the herbage of natural fodder lands in the studied areas ranged from 0.05 to 0.06. The highest copper hazard coefficient was in the herbage of absolute and normal drylands, which was 0.06, compared to 1.2 times lower in the herbage of excessive moisture drylands.

Characterising the coefficient of accumulation (Table 10), it was found that this indicator of lead in the herbage of natural fodder lands ranged from 0.31 to 0.7. The highest coefficient of lead accumulation was found in the herbs of drylands with excessive moisture, compared to 2.25 times less in normal drylands and 1.62 times less in absolute conditions.

Table 10.

Coefficient of heavy metal accumulation in phytomass of natural fodder lands on average for 2018-2020.

Research material	lead			Cadmium		
	Concentration in herbs	Concentration in soil	Kneb	Concentration in herbs	Concentration in soil	Kneb
Herbs of absolute drylands	1,27	2,9	0,43	0,065	0,48	0,13
Herbs of normal drylands	0,93	2,96	0,31	0,051	0,49	0,10
Herbs of drylands with excessive moisture	2,24	3,2	0,7	0,84	0,51	0,16

The coefficient of cadmium accumulation in the herbs of natural fodder lands ranged from 0.10 to 0.16. The highest coefficient of cadmium accumulation in vegetation was observed in the conditions of excessive moisture, which was 1.6 times lower and 1.23 times lower in the herbs of normal and absolute drylands.

One of the important indicators for assessing the transformation of heavy metals into vegetation is their accumulation coefficient (AC). The results of the study (Table 11) showed that the zinc accumulation factor in the grass stand of natural fodder lands ranged from 0.54 to 0.68. The highest coefficient of zinc accumulation in the herbage of drylands was in the phytomass of drylands with excessive moisture, compared to 1.46 times and 1.16 times lower in normal and absolute drylands, respectively.

The coefficient of copper accumulation in the herbage of natural fodder lands was in the range from 8.5 to 12.0. The highest coefficient of copper accumulation in the herbage of natural fodder lands was found in conditions of absolute dryness, relatively lower by 1.14 times and 1.41 times, respectively, on normal and excessive moisture soils.

Table 11.

The coefficient of accumulation of heavy metals (trace elements) in the phytomass of natural meadows on average for 2018-2020.

Research material	Цинк			Мідь		
	Concentration in herbs	Concentration in soil	Kneb	Concentration in herbs	Concentration in soil	Kneb
Herbs of absolute drylands	7,8	11,4	0,68	1,8	0,15	12
Herbs of normal drylands	6,8	12,5	0,54	1,9	0,18	10,5
Herbs of drylands with excessive moisture	8,6	18,3	0,45	1,7	0,20	8,5

That is, the intensity of pollution of the soils of absolute drylands, normal drylands and drylands of excessive moisture with lead, cadmium, zinc and copper does not exceed the MPCs, which are 6.0 mg/kg, 0.7 mg/kg, 23 mg/kg and 3.0 mg/kg, respectively. At the same time, it should be noted that the highest levels of lead, cadmium, zinc and copper were found in the soils of excessive moisture, and relatively lower levels in the soils of normal and absolute drylands. In the phytomass of lowland meadows, both in absolute and normal dry soils and in excessive moisture soils, no exceedances of the MPCs for lead, cadmium, zinc and copper were found. The content of lead, cadmium, zinc and copper in vegetation, their hazard and transition coefficient was highest in the conditions of excessive moisture, and relatively lower in the areas of absolute and normal dry soils.

Thus, the results of the study revealed that in the conditions of dry lowland meadows of Vinnytsia region, the safest and most suitable for providing herbivores with plant biodiversity are normal drylands, which are characterised by the most valuable fodder vegetation and lower pollution intensity compared to absolute drylands and drylands of excessive moisture. Due to the higher level of soil contamination, low efficiency of removal of these toxicants by phytoremediation, as plants of these meadows, compared to absolute drylands and drylands with excessive moisture, have low fodder value and are characterised by a higher water content, which enhances the process of chemical migration into plants.

It is known that road and rail transport is one of the most significant sources of local heavy metal pollution. When operating roads, heavy metals are released into the environment through the combustion of fuels and lubricants (petrol, gas, diesel), as well as the use of de-icing materials. In railway operations, heavy metals are released into the environment through the combustion of diesel fuel, as well as the combustion and spreading of coal, as well as ore and other bulk materials during their transportation.

It was found that the highest level of heavy metal pollution in the environment is observed in the roadside area, but in some cases these toxicants can move beyond this area as a result of snowmelt and precipitation. Heavy metals in the exchangeable form migrate from the soil to vegetation, which, when used as feedstock, can lead to excessive accumulation in livestock products, which further increases the risk of toxicants entering the human body.

Therefore, the territory of natural fodder lands and the safety of their vegetation in the zone of local pollution with heavy metals, taking into account the growing intake of these toxicants into the environment, should be constantly monitored for the intensity of their pollution and the translocation of these toxicants into plants.

The results of studies on the concentration of heavy metals in soils in the area of local pollution of natural fodder lands (Table 12) showed that the lead content in the territory of absolute drylands ranged from 3.3 mg/kg to 3.8 mg/kg, normal drylands from 3.8 mg/kg to 4.9 mg/kg and excessive moisture drylands from 4.2 mg/kg to 5.7 mg/kg.

In the studied areas adjacent to interregional roads under conditions of absolute dryness, the concentration of lead in soils was 1.11 times and 1.15 times higher than in the areas of interdistrict roads and railway communication.

In the soils of areas adjacent to interregional roads under normal dry conditions, lead concentrations were 1.16 times and 1.28 times higher than in areas of interregional roads and railways.

Table 12

The content of mobile forms of heavy metals in the soils of the zone of local anthropogenic load, mg/kg, on average for 2018-2020, based on absolutely dry matter), (n=4, M±m)

Dry lowland meadows	lead			Cadmium		
	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Territories adjacent to the railway connection
Absolute drylands	3,4 ± 0,31 ***	3,8 ± 0,27 **	3,3 ± 0,21 ***	0,52 ± 0,018 **	0,54 ± 0,023 **	0,58 ± 0,03**
Normal drylands	4,2± 0,24**	4,9 ±0,23**	3,8± 0,17	0,58± 0,033	0,6± 0,029	0,68± 0,032*
Dry soils with excessive moisture	5,1 ± 0,41	5,7 ± 0,32	4,2 ± 0,41	0,54 ± 0,032	0,67± 0,034	0,71± 0,041

Under conditions of excessive moisture, the concentration of lead in soils on interregional roads was 1.11 times higher than on interdistrict roads and 1.35 times higher than on railways.

The lead content in the soils of absolute and normal dry soils and excessive moisture soils under conditions of local pollution in the studied areas of Vinnytsia region did not exceed the MPC. However, in the soils of excessively moist soils, the lead concentration was close to the upper limit of the MPC.

The highest concentration of lead in the soils of the areas adjacent to inter-rayon roads was observed in excessively moist soils, and relatively lower by 1.2 times in normal soils and 1.5 times in absolute soils. In the areas adjacent to interregional roads, the concentration of lead in the soil of excessive moisture soils was 1.16 times and 1.5 times higher, respectively, compared to normal and absolute soils. In the areas adjacent to the railway connection, the concentration of lead in the soils of excessively moist soils was 1.1 times and 2.7 times higher than in normal and absolute soils, respectively.

The concentration of cadmium in the soils of absolute drylands, normal drylands and excessive moisture soils ranged from 0.52 mg/kg to 0.58 mg/kg, 0.58 mg/kg to 0.68 mg/kg and 0.64 mg/kg to 0.71 mg/kg, respectively.

In terms of absolute dry land, the concentration of cadmium in the areas adjacent to the railway was 1.11 times and 1.07 times higher than in the areas of inter-district and oblast roads, respectively.

In the soils of the territories adjacent to the railway in normal dry conditions, the concentration of cadmium was 1.17 times and 1.13 times higher than in the territories adjacent to the rayon and oblast roads, respectively.

On excessively moist lands, the concentration of cadmium in soils of the areas adjacent to railway connections was 1.1 times and 1.06 times higher than on district and regional roads, respectively. The highest concentration of cadmium in soils in the areas of localised contamination of railway areas was observed in the areas of excessive moisture, where the MPC was exceeded by 1.01 times.

In the areas adjacent to the district road network, in excessively moist soils, the concentration of cadmium was 1.1 times and 1.2 times higher than in normal and absolute soils, respectively.

In the soils of the territories adjacent to the regional roads under conditions of excessive moisture, the concentration of cadmium was 1.1 times and 1.2 times higher than in normal and absolute dry soils, respectively.

In the areas adjacent to the railway line under conditions of excessive moisture, the concentration of cadmium was 1.04 times and 1.2 times higher than in normal and absolute dry soils, respectively.

The concentration of heavy metals, in particular, zinc (Table 13) in the soils of absolute drylands in the area of local pollution ranged from 14.5 mg/kg to 19.2 mg/kg, in the conditions of normal drylands from 16.2 mg/kg to 19.9 mg/kg and in the conditions of excessive moisture from 18.3 mg/kg to 20 mg/kg.

At the same time, it should be noted that the highest concentration of zinc in the area of local pollution was observed in the soils of excessively moist soils.

Table 13.

Content of mobile forms of heavy metals in the soils of the zone of local anthropogenic load, mg/kg, on average for 2018-2020 (based on absolutely dry matter), (n=4, M±m)

Dry lowland meadows	Zinc			Copper		
	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	14,5± 3,2 **	17,2± 4,3*	19,2±3,4 *	2,82 ± 0,22	2,81±0,83 *	2,87±0,72 *
Normal drylands	16,2±4,1 *	18,7±3,2	19,9±4,7	2,84±0,22	2,82±0,073	2,83±0,84
Dry soils with excessive moisture	18,3± 4,7	18,9± 4,3	20,0± 4,5	2,99 ±0,82	2,91±0,033	2,92±0,27

In the soils of the territories adjacent to the district roads under conditions of excessive moisture, the zinc concentration was 1.5 times and 1.2 times higher than in absolute and normal dry soils, respectively.

In the areas adjacent to the railway, under conditions of absolute dryness, the concentration of zinc in soils was 1.11 times and 1.32 times higher than in the areas adjacent to regional and district roads.

In the soils of the areas adjacent to the railway under normal dry conditions, the zinc concentration was 1.22 times and 1.06 times higher than in the areas adjacent to inter-district and regional roads, respectively.

Under conditions of excessive moisture, the concentration of zinc in the soils of the railway areas was 1.09 times and 1.06 times higher than in the areas of the district and regional roads, respectively. The concentration of zinc in the soils of absolute drylands, normal drylands and excessively moist soils under conditions of local pollution did not exceed the MPC.

In the areas adjacent to the regional roads, the concentration of zinc in the soils of excessively moist soils was 1.27 times and 1.1 times higher than in absolute and normal soils, respectively.

The concentration of copper in the soils of absolute drylands in the area of local pollution ranged from 2.81 mg/kg to 2.87 mg/kg, in normal drylands from 2.82 mg/kg to 2.84 mg/kg, and in areas of excessive moisture from 2.91 mg/kg to 2.99 mg/kg.

In the areas adjacent to the railway, under conditions of absolute dryness, the concentration of copper in soils was 1.2 times and 1.2 times higher than in the areas adjacent to the district and regional roads, respectively.

Under normal dry land conditions, the concentration of copper in the soils of the territories adjacent to the localised pollution zone did not differ significantly. In the soils of the areas adjacent to inter-regional roads, under conditions of excessive moisture, the copper concentration was 1.3 times and 1.3 times higher, respectively, compared to the areas of inter-regional and railway roads. The concentration of copper in the soils of absolute drylands, normal drylands and excessive moisture soils in the conditions of local pollution of natural fodder lands did not exceed the MPC. At the same time, it should be noted that the highest concentration of copper was found in the soils of excessively moist soils. In the areas adjacent to the district roads, under conditions of excessive moisture, the concentration of copper in soils was 1.05 times and 1.06 times higher than in the areas of normal and absolute dry soils, respectively. The concentration of copper in the soils of the territories adjacent to interregional roads in conditions of excessive moisture was 1.05 times and 1.04 times higher than in normal and absolute dry soils, respectively. In the areas adjacent to the railway connection, the concentration of copper in the soils of excessively moist soils was 1.03 times and 1.01 times higher than in normal soils and absolute soils, respectively. The hazard coefficient for lead and cadmium in soils in the localised pollution zone (Table 14) under conditions of absolute dryness ranged from 0.55 to 0.63 and from 0.74 to 0.83, respectively. The highest hazard factor for lead was observed in the soils of areas adjacent to regional roads, and for cadmium in areas adjacent to railway lines.

The hazard coefficient for lead and cadmium in normal soils under conditions of localised pollution ranged from 0.63 to 0.81 and 0.85 to 0.97, respectively. The highest hazard coefficient for lead was in soils adjacent to regional roads, and for cadmium in areas adjacent to railway lines.

A similar trend was observed in the conditions of excessive moisture, with the highest levels of lead in the soils of areas close to regional roads and cadmium in the soils of areas adjacent to railways. However, the concentration of lead and cadmium in the soil was higher compared to normal and absolute dry land.

Table 14

Heavy metal hazard factor in the soils of the local technogenic load zone, mg/kg (average for 2018-2020)

Dry lowland meadows	lead			Cadmium		
	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0,56	0,63	0,55	0,74	0,77	0,82
Normal drylands	0,70	0,81	0,63	0,82	0,85	0,97
Dry soils with excessive moisture	0,85	0,95	0,70	0,91	0,95	1,01

The hazard coefficient for zinc and copper in absolute dryland soils (Table 15) in the localised pollution zone ranged from 0.63 to 0.83 and 0.27 to 0.29, respectively. The highest concentrations of zinc and copper were found in the soils adjacent to the railway line.

Under normal dryland conditions, the concentration of zinc and copper in soils ranged from 0.70 to 0.86 and from 0.27 to 0.28, respectively. The highest levels of zinc were observed in soils in the areas adjacent to railway lines, and copper in the areas adjacent to district roads.

The hazard coefficient for zinc and copper in the soils of excessively moist land under conditions of local pollution ranged from 0.79 to 0.87 and 0.30 to 0.33, respectively. The highest levels of zinc were detected in soils adjacent to railway lines, and copper in areas adjacent to district roads.

Given that plants are capable of accumulating high concentrations of heavy metals in their vegetative mass several times and sometimes several tens 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 16) 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 15

Hazard factor of heavy metals in soils of the local technogenic load zone, mg/kg (average for 2018-2020)

Dry lowland meadows	Zinc			Copper		
	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections
Absolute drylands	0,63	0,74	0,83	0,27	0,27	0,29
Normal drylands	0,70	0,81	0,86	0,28	0,27	0,27
Dry soils with excessive moisture	0,79	0,82	0,87	0,33	0,30	0,30

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 localised 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.

Table 16

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 inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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

In the vegetation of excessively moist land in the area of localised 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 rayon 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 localised 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 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 17) 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 localised contamination of natural fodder lands was characterised 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.

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.

Table 17

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 inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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

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 rayon and oblast 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 18) 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 18

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 inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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 characterised 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.

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 19

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 inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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 forage 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 20.

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 inter-regional roads	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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 rayon and oblast 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 21).

Table 21.

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 inter-regional	Areas adjacent to interregional motorways	Areas adjacent to railway connections	Territories adjacent to inter-regional 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 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.

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

1. The analysis of the intensity of pollution of dry lowland meadows with heavy metals in the studied areas of Vinnytsia region showed that the content of lead in the soil ranged from 2, 9 mg/kg to 3.2 mg/kg, cadmium from 0.48 mg/kg to 0.51 mg/kg, zinc from 11.4 mg/kg to 18.3 mg/kg and copper from 0.15 mg/kg to 0.20 mg/kg, which did not exceed the MPCs, which are 6.0 mg/kg, 23.7 mg/kg, and 0.7 mg/kg, 23 mg/kg and 3.0 mg/kg, respectively. The highest level of soil contamination with lead, cadmium, zinc and copper was observed in excessive moisture soils, and relatively

lower in normal and absolute dry soils.

2. The content of lead in the phytomass of dry meadows ranged from 0.93 mg/kg to 2.24 mg/kg; cadmium from 0.051 mg/kg to 0.084 mg/kg; zinc from 6.8 mg/kg to 14.6 mg/kg and copper from 1.7 mg/kg to 1.9 mg/kg, which was lower than the MPCs, which are 5.0 mg/kg, 0.3 mg/kg, 50 mg/kg and 30 mg/kg, respectively. The highest level of contamination was observed in plants of phytocoenoses in the territory of excessive moisture, while the level was relatively lower in conditions of normal and absolute dryness.

3. 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.

4. The results of the study showed that in the area of localised pollution of dry lowland meadows, the average soil content of lead, cadmium, zinc and copper was in the areas adjacent to roads: district roads - 4.23 mg/kg, 0.54 mg/kg, 16.3 mg/kg and 2.88 mg/kg; regional roads - 4.80 mg/kg, 060 mg/kg, 18.2 mg/kg and 2.84 mg/kg; railway roads - 3.76 mg/kg, 0.65 mg/kg, 19.7 mg/kg and 2.87 mg/kg. Exceedance of the MPCs in soils in the studied areas of local pollution of dry lowland meadows in Vinnytsia region was found only for cadmium by 1.01 times in the areas of excessive moisture adjacent to the railway.

5. In the areas of localised 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.

References

1. Bakhmat M., Padalko T., Krachan T., Tkach O., Pantsyreva H., Tkach L. Formation of the Yield of Matricaria recutita and Indicators of Food Value of Sychorium intybus by Technological Methods of Co-Cultivation in the Interrows of an Orchard. Journal of Ecological Engineering. 2023. Vol. 24 (8). P. 250-259. DOI: https://doi.org/10.12911/22998993/166553

2. Bondarenko V., Havrylianchik R., Ovcharuk O., Pantsyreva H., Krusheknyckiy V., Tkach O. and Niemec M. Features of the soybean photosynthetic productivity indicators formation depending on the foliar nutrition. Ecology, Environment and Conservation. Vol. 28. Issue 2022. P. 20-26. DOI: 10.53550/EEC.2022.v28i04s.004
3. Didur I., Chynchyk O., Pantsyreva H., Olifirovych S., Olifirovych V., Tkachuk O. Effect of fertilizers for Phaseolus vulgaris L. productivity in Western Forest-Steppe of Ukraine. Ukrainian Journal of Ecology. 2021. Vol. 11 (1). P. 419–424 DOI: 10.15421/2021_61
4. Didur I.M., Pantsyreva H.V., Telekalo N.V. Agroecological rationale of technological methods of growing legumes. The scientific heritage. 2020. Vol. 52. P. 3-12.
5. Didur I.M., Prokopchuk V.M., Pantsyreva H.V. Investigation of biomorphological and decorative characteristics of ornamental species of the genus Lupinus L. Ukrainian Journal of Ecology. 2019. Vol. 9(3). P. 287-290. DOI: 10.15421/2019_743
6. Environmental aspects of the land market functioning. Agriculture and forestry. 2019. №15. C. 203 - 213.
7. Hanna Pantsyreva, Kateryna Mazur. The state of the soil cover of Ukraine in the context of bio-organic technologies for growing agricultural crops. Agro-ecological potential of soil cover of Vinnytsia region: Scientific monograph. Riga, Latvia: «Baltija Publishing», 2023.124-147 p.
8. Honcharuk I., Matusyak M., Pantsyreva H., Kupchuk I., Prokopchuk V., Telekalo N. Peculiarities of reproduction of pinus Nigra arn. in Ukraine. Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering. 2022. Vol. 15 (64). № 1. P. 33-42. DOI: https://doi.org/10.31926/but.fwiafe.2022.15.64.1.3
9. Honcharuk I., Pantsyreva H., Mazur V., Didur I., Tkachuk O., Telekalo N. Integration of traditional and innovation processes of development of modern science. Collective monograph. Publishing House «Baltija Publishing», Riga, Latvia. 2020. P. 42-108.
10. Ivanyshyn O., Khomina V., Pantsyreva H. Influence of fertilization on the formation of grain productivity in different-maturing maize hybrids. Ukrainian Journal of Ecology. 2021. Vol. 11 (3). P. 262-269 DOI: 10.15421/2021_170 (Web of Science).
11. Kvitko GP, Tkachuk OP, Hetman N. Perennial legumes - the basis of natural intensification of fodder production and improvement of soil

fertility in the Forest-Steppe of Ukraine. Fodder and fodder production. Vinnytsia, 2012. Issue 73. C. 113 - 117.
12. Mazur K., Pantsyreva H., Prokopchuk V. Distance form of education in agricultural universities: features and problems. Colloquium-journal. 2021. Vol. 13(100). P. 29-32.
13. Mazur K., Pantsyreva H., Zatolochnyi O. The influence of globalization of society on international of higher education in Ukraine and Poland. The scientific heritage. 2020. Vol. 45. P. 71-75.
14. Mazur V., Didur I., Myalkovsky R., Pantsyreva H., Telekalo N., Tkach O. The Productivity of intensive pea varieties depending on the seeds treatment and foliar fertilizing under conditions of right-bank forest-steppe Ukraine. Ukrainian Journal of Ecology. 2019. Vol. 10 (1). P. 101-105. DOI: 10.15421/2020_16
15. Mazur V., Didur I., Tkachuk O., Pantsyreva H., Ovcharuk V. Agroecological stability of cultivars of sparsely distributed legumes in the context of climate change. Scientific Horizons. 2021. Vol. 1 (24). P. 54-60 DOI: https://doi.org/10.48077/scihor.24(1).2021.54-60
16. Mazur V., Pantsyreva H. Scientific aspects of technologies of growing, storage and processing of legumins. Collective monograph. Publishing House «Baltija Publishing», Riga, Latvia. 2021. P. 195-220.
17. Mazur V., Pantsyreva H., Mazur K., Myalkovsky R., Alekseev O. Agroecological prospects of using corn hybrids for biogas production. Agronomy Research. 2020. Vol. 18. P. 177-182. DOI: https://doi.org/10.15159/ar.20.016 Didur I., Bakhmat M., Chynchyk O., Pantsyreva H., Telekalo N., Tkachuk O. Substantiation of agroecological factors on soybean agrophytocenoses by analysis of variance of the Right-Bank Forest-Steppe in Ukraine. Ukrainian Journal of Ecology. 2020. Vol. 10 (5). P. 54-60. DOI: 10.15421/2020_206
18. Mazur V., Tkachuk O., Pantsyreva H., Demchuk O. Quality of pea seeds and agroecological condition of soil when using structured water. Scientific Horizons. 2021. Vol. 24 (7). P 53-60.
19. Mazur V., Tkachuk O., Pantsyreva H., Kupchuk I., Mordvaniuk M., Chynchyk O. Ecological suitability peas (Pisum Sativum) varieties to climate change in Ukraine. Agraarteadus. 2021. Vol. № 2 (32). P. 276-283 DOI: 10.15159/jas.21.26
20. Mazur V.A., Branitskyi Y.Y., Pantsyreva H.V. Bioenergy and economic efficiency technological methods growing of switchgrass. Ukrainian Journal of Ecology. 2020. Vol. 10 (2). P. 8-15. DOI:

10.15421/2020_56

21. Mazur V.A., Didur I.M., Pantsyreva H.V., Telecalo N.V. Energy-economic efficiency of growth of grain-crop cultures in the conditions of right-bank Forest-Steppe zone of Ukraine. Ukrainian Journal of Ecology. 2018. Vol. 8(4). P. 26-33.
22. Mazur V.A., Mazur K.V., Pantsyreva H.V. Influence of the technological aspects growing on quality composition of seed white lupine (Lupinus albus L.) in the Forest Steppe of Ukraine. Ukrainian Journal of Ecology. 2019. Vol. 9 (1). P. 66-71
23. Mazur V.A., Mazur K.V., Pantsyreva H.V., Alekseev O.O. Ecological and economic evaluation of varietal resources Lupinus albus L. in Ukraine. Ukrainian Journal of Ecology. 2018. Vol. 8. P. 148-153.
24. Mazur V.A., Myalkovsky R.O., Mazur K.V., Pantsyreva H.V., Alekseev O.O. Influence of the Photosynthetic Productivity and Seed Productivity of White Lupine Plants. Ukrainian Journal of Ecology. 2019. Vol. 9(4). P. 665-670. DOI: 10.15421/2019_807
25. Mazur V.A., Myalkovsky R.O., Pantsyreva H.V., Didur I.M., Mazur K.V., Alekseev O.O. Photosynthetic productivity of potato plants depending on the location of rows placement in agrophytocenosis. Ecology, Environment and Conservation. 2020. Vol. 26 (2). P. 536-545
26. Mazur V.A., Pantsyreva H.V., Mazur K.V., Didur I.M. Influence of the assimilation apparatus and productivity of white lupine plants. Agronomy Research. 2019. Vol. 17 (1). P. 206-219. (Scopus). http://dx.doi.org/10.15159/ar.19.024
27. Mazur V.A., Pantsyreva H.V., Mazur K.V., Monarkh V.V. Ecological and biological evaluation of varietal resources Paeonia L. in Ukraine. Acta Biologica Sibirica. 2019. Vol. 5 (1). P. 141-146. https://doi.org/10.14258/abs.v5.i1.5350
28. Mazur V.A., Vradii O.I. Monitoring of soil contamination with heavy metals at the research site in the Research and Development Group "Agronomic" of Vinnytsia National Agrarian University. Collection of scientific works of Vinnytsia National Agrarian University Agriculture and Forestry. 2019. №13. C. 17- 18
29. Monarkh V., Pantsyreva H. Stages of the Environmental Risk Assessment. Ukrainian Journal of Ecology. 2019. Vol. 9(4). P. 484-492. DOI: 10.15421/2019_779
30. Mudrak H.V., Vdovenko I.P. Analysis of scientific and methodological principles of assessing the suitability of lands of special raw material

zones for environmental requirements. Agriculture and forestry. 2017. № 6. С. 129 - 140

31. Myalkovsky R., Pantsyreva H. The use of digestate for the development of organic agricultural production. Agro-ecological potential of soil cover of Vinnytsia region: Scientific monograph. Riga, Latvia: «Baltija Publishing», 2023. 77-95 p.
32. Optimisation of natural fodder lands of the Forest-Steppe of Ukraine. Scientific Bulletin of NAU. 2005. Issue 87. С. 207 - 212.
33. Pantsyreva H., Alieksieiev O. Study of soil conservation technology and environmental stability of rural areas taking into account limited resources and climate change. Agro-ecological potential of soil cover of Vinnytsia region: Scientific monograph. Riga, Latvia: «Baltija Publishing», 2023. 96-123 p.
34. Pantsyreva H., Mazur K. Research of early rating soybean varieties on technology and agroecological resistance. Theoretical and practical aspects of the development of modern scientific research: Scientific monograph. Part 2. Riga, Latvia: Baltija Publishing, 2022. P. 84-108. DOI: https://doi.org/10.30525/978-9934-26-195-4-18
35. Pantsyreva H., Mazur K. The influence of bio-organic growing technology on the productivity of legumes. Colloquium-journal, 2021, Vol. 12(99). P. 25-31.
36. Pantsyreva H., Pelekh L., Hontaruk Y., Myalkovsky R. Agro-technological aspects of production of digest as fertilizer. Agricultural engineering 2023. Vol. 55. P. 19-29 DOI: https://doi.org/10.15544/ageng.2023.55.3
37. Pantsyreva H., Pelekh L., Hontaruk Y., Myalkovsky R. Agro-technological aspects of production of digest as fertilizer. Agricultural engineering 2023. Vol. 55. P. 19-29 DOI: https://doi.org/10.15544/ageng.2023.55.3
38. Pantsyreva H., Stroyanovskiy V., Mazur K., Chynchyk O., Myalkovsky R. The influence of bio-organic growing technology on the productivity of legumins. Ukrainian Journal of Ecology. 2021. Vol. 11 (3). P. 35-39 DOI: 10.15421/2021_139
39. Pantsyreva H., Vovk V., Bronnicova L., Zabarna T. Efficiency of the Use of Lawn Grasses for Biology and Soil Conservation of Agricultural Systems under the Conditions of the Ukraine's Podillia. Journal of Ecological Engineering. 2023. Vol. 24 (11). P. 249–256 https://doi.org/10.12911/22998993/171649
40. Pantsyreva H.V. Morphological and ecological-biological evaluation of

the decorative species of the genus Lupinus L. Ukrainian Journal of Ecology. Vol. 9(3), P. 74-77. DOI: 10.15421/2019_711

41. Pantsyreva H.V., Myalkovsky R.O., Yasinetska I.A., Prokopchuk V.M. Productivity and economical appraisal of growing raspberry according to substrate for mulching under the conditions of podilia area in Ukraine. Ukrainian Journal of Ecology. 2020. Vol. 10 (1). P 210-214. DOI: 10.15421/2020_33
42. Prokopchuk V., Pantsyreva H., Mazur K. Features of cultivation and use of species of the genus Iris L. in landscaping Podillya of Ukraine. Colloquium-journal, 2021, Vol. 12(99). P. 53-57.
43. Puyu V., Bakhmat M., Pantsyreva H., Khmelianchyshyn Y., Stepanchenko V., Bakhmat O. Social-and-Ecological Aspects of Forage Production Reform in Ukraine in the Early 21st Century. European Journal of Sustainable Development. 2021. Vol. 10 (1). P. 221-228 DOI: https://doi.org/10.14207/ejsd.2021.v10n1p221
44. Razanov S.F., Tkachuk O.P. Intensity of soil pollution during the cultivation of leguminous perennial grasses. Agricultural production of Polissya. Zhytomyr, 2017. Issue 10. C. 53-55.
45. Samokhval T.P. Fodder productivity and agroecological value of the eastern goat's fescue in the conditions of the Right-Bank Forest-Steppe of Ukraine. Bulletin of Agrarian Science. Kyiv, 2013. № 9. C. 114-117.
46. Titarenko O., Ibatullin I., Nedashkivskyi V., Nedashkivska N., Stepanchenko V. .Accumulation of zn and cu by cereal and leguminous vegetation under agrochemical improvement of natural fodder lands of the right bank forest steppe of Ukraine. International Journal of Ecosystems and Ecology Science (IJEES). 2022. Vol. 12 (4). 245-250
47. Titarenko O.M. Accumulation of heavy metals in the phytomass of natural fodder lands of Eastern Podillia: PhD thesis for the degree of Candidate of Agricultural Sciences: speciality 03.00.16 "Ecology". Titarenko O.M.. Lviv. 2021. 21 c
48. Titarenko O.M. Ecological and phytocoenotic assessment of natural fodder lands under conditions of technogenic load of the Right-Bank Forest-Steppe: a monograph. Vinnytsia: TOVORY, 2021. - 194 p.
49. Vdovenko S.A., Palamarchuk I.I., Pantsyreva H.V. and ets. Energy efficient growing of red beet in the conditions of central forest steppe of Ukraine. Ukrainian Journal of Ecology. 2018. Vol. 8. P. 34-40.
50. Vdovenko S.A., Pantsyreva H.V., Palamarchuk I.I., Lytvynuk H.V.

Symbiotic potential of snap beans (Phaseolus vulgaris L.) depending on biological products in agrocoenosis of the RightBank Forest-steppe of Ukraine. Ukrainian journal of Ecology. 2018. Vol. 8 (3). P. 270-274.

51. Vdovenko S.A., Procopchuk V.M., Palamarchuk I.I., Pantsyreva H.V. Effectiveness of the application of soil milling in the growing of the squash (Cucurbita pepo var. giraumontia) in the right-benk forest stepp of Ukraine. Ukrainian Journal of Ecology. 2018. Vol. 8 (4). P. 1-5
52. Yakubenko BE, Stetsenko VS, Melnychuk MD Structure and productivity of natural and anthropogenic phytocoenoses of the Forest-Steppe of Ukraine. Agrarian science and education. 2002. № 3-4. C. 9 -14.