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Yield, chemical composition and the level of accumulation of heavy metals in the vegetative mass and seeds of milk thistle *(Silybum marianum L.)* in different types of organic fertilizer

Razanov S.F., Razanova A.M., Àmons S.E. and Gutsol G.V.

Vinnytsia National Agrarian University, 3, Soniachna Str., Vinnytsia, Ukraine, 21008

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ABSTRACT

The article presents the results of research on the influence of organic fertilization of gray forest soils on the level of lead, cadmium, zinc and copper in sheet mass and seeds of milk thistle. When fertilizing with humus, the concentration of lead, cadmium, zinc and copper in the mass of the leaves of the milk thistle increased by 5.1%, 18.2%, 53.1% and 20.4%, respectively. When fertilizing with a sugar beet lime sludge compost, the concentration of lead, cadmium, zinc and copper in the leaf mass of the milk thistle increased by 25.9%, 13.6%, 10.2% and 10.5%, respectively. In the cultivation of milk thistle after green manure and leguminous perennial grasses, the concentration of lead decreased by 8.6% and 2.4 times, respectively, and of cadmium by 9.1% and 2.6 times. The concentration of zinc with the use of green manure (mustard) remained on the background of the control variant, while with the predecessor of alfalfa sowing it was 9.0 times lower. The concentration of copper in the leaf mass of milk thistle when grown after green manure was 1.05 times higher, and after the four-year predecessor of alfalfa – 6.1 times lower compared to the control. The results of the research also showed that the concentration of heavy metals in the leaves of milk thistle exceeded the MPC in all variants, except for the use of a four-year predecessor of alfalfa. Characterizing the concentration of heavy metals in the seeds of milk thistle it should be noted that this figure ranged from 0.5 mg kg^{-1} to 4.1 mg kg^{-1}, cadmium – from 0.08 mg kg^{-1} to 0.68 mg kg^{-1}, zinc – from 27 mg $kg^{-1}$to 98 mg $kg^{-1}$and copper – from 7.5 mg kg^{-1} to 19.2 mg kg^{-1}. Comparing compliance of the concentration heavy metals with the maximum permissible levels (MPC) in the seeds of milk thistle, it should be noted that when used as fertilizer humus, sugar beet lime sludge compost and green manure, this figure was higher than the established norm, while growing this crop after four years, lower.

Key words : *Milk thistle, Lead, Cadmium, Zinc, Copper, Humus, Sugar beet lime sludge compost, Green manure, Organic fertilizer.*

Introduction

Activities of the population lead to an increase in the entry of various harmful substances into the environment, in particular, heavy metals. At the same time these toxicants, being in the exchange form, move on trophic chains from soil to vegetation, reducing quality of production and making it dangerous (Wang *et al.*, 2009; Zwolak *et al.*, 2019). The most powerful sources of environmental pollution by heavy metals are mining, metallurgy, machine building, chemical, transport, agro-industrial, housing and communal services, and otherscomplexes (Uzarowicz, 2011; Lemanowicz *et al.*, 2019;

HosseinArfaeinia *et al*., 2019). Thus, after mining in mines, mine effluents and water contain a number of pollutants, among which the most dangerous are heavy metals (Uzarowicz, 2011). A large number of hazardous heavy metals enter the environment mainly from wastewater due to the agricultural, chemical and transport industries in general (Zamani *et al*., 2012). In crop production, mineral fertilizers are a powerful source of heavy metals in the environment (Zwolak *et al*., 2019). The largest number of them is contained in phosphorus fertilizers (Lemanowicz *et al*., 2015), a relatively small amount of heavy metals enters the soil with nitrogen and potassium fertilizers.

Significantly increased the man-made impact on the environment of growth in recent years significant number of vehicles (Lough *et al*., 2005), as well as the number of various facilities that provide it, in particular, transport companies: gas stations, garages, service stations, parking, which are also a source of pollution by various environmental toxicants. Soils, water, air, as well as vegetation near highways, where more than 20% of gaseous emissions are deposited as a result of pollution, become objects of pollution from the operation of vehicles. The intensity of soil pollution from emissions from mobile sources depends on the number of vehicles, as a rule, in urban areas it is higher, and outside – lower (Al-Taani *et al*., 2019). Quite a noticeable man-caused load of vehicles was found on the soils of the roadside, which is accompanied by their contamination with heavy metals (Lough *et al*., 2005; Schauer *et al*., 2006). At the same time, the predominant share of emissions from transport is concentrated on the soil surface and in the form of mobile forms is included in trophic chains, accumulating in the phytomass of plants, leading to physiological disorders.

Heavy metals that enter plants through food chains (Zwolak *et al*., 2019) from the soil, and from there into the body of animals and humans, are the cause of serious diseases (Shaheen *et al*., 2016). This increases the incidence of the population, reduces life expectancy, and reduces the quantity and quality of crops of agricultural plants and animal products. Heavy metals that accumulate in the soil in excess, can change the biological properties of soil, namely to reduce the total number of microorganisms, narrow their species composition, change the structure of microbiocenoses, reduce the intensity of major microbiological processes and activity of soil enzymes (Wong *et al.*, 2008). Quite heavy contamination with heavy metals leads to changes and more conservative characteristics of the soil, such as humus, structure, pH and others. The result of this process is a partial and sometimes complete loss of soil fertility. Heavy metals are a significant source of contamination of medicinal plants, along with a wide variety of man-made pollutants, such as radionuclides, pesticides, nitrates, salts, acids, pathogens (Riah *et al*., 2014). They have the ability to accumulate in significant quantities in soils, which can lead to a deterioration in their quality and reduce the productivity of plants grown on them and the deterioration of their ecological quality (Wang *et al*., 2003). In the context of medicinal plants, they cause toxicity of medicinal raw materials, in the treatment of which there will be no benefit to the patient, but harm (Kishan *et al*., 2014; Malinowska *et al.,* 2017).

Heavy metals include chemical elements with an atomic mass greater than 40 and a density greater than 5 g cm^{-3}, which have the properties of metals (HazratAli *et al.,* 2018). The very concept of "heavy metals" is conditional, because this group includes copper, zinc and other elements that have a positive biological value for plants, they are called trace elements, but when accumulated above the limit, they can be toxic and activate or, conversely, block biochemical processes in living organisms (Adriano, 2013). The study of the adaptation of certain species of medicinal plants growing near potential sources of heavy metals provides an opportunity to determine the level of transport through the soil to medicinal plants of heavy metals and the level of their biological resistance to contamination. Due to this, it is possible to establish the feasibility of using such medicinal plants to increase or correlate the body's resistance to the effects of negative environmental factors. After all, the use of medicinal plants collected in areas with high content of heavy metals can endanger human health, adversely affecting the work of internal organs and physiological processes of organisms (Järup, 2003; Mahmood *et al*., 2014; Malinowska *et al*., 2017). Because from heavy raw materials heavy metals are converted into drugs and then enter the human body (Hu *et al*., 2017). Therefore, the problem of ecological purity of medicinal plants and the analysis of the impact of heavy metals on the quality of plant raw materials becomes especially relevant. In the process of life, medicinal plants, along with macronutrients, use trace elements, such as Zn, Cu, Co, and others. They are part of many biologically active compounds – proteins, enzymes, hormones, etc. It is established that the effect of metals on medicinal plants depends on the composition of the soil, the nature of the chemical element, as well as on the ionic or other combined form that can be extracted from the soil by the plant (Zhou *et al*., 2016). Toxic effects of metals on medicinal plants may be associated with a violation of the inherent relationship between plants and nutrients. The intake of excess heavy metals in medicinal plants disturbs the balance in the supply of micro- and macronutrients. Antagonism can exist both between individual heavy metals and between macronutrients (calcium, magnesium, potassium). At the maximum contamination with copper in medicinal plants the content of calcium and magnesium considerably decreases. It is known that medicinal plants absorb some metals in different ways, for example, lead, even at high concentrations in the soil, is in poorly soluble compounds and therefore its level in the plant will be lower (Fin•gar *et al.,* 2006). Zinc – strongly accumulates in medicinal plants and is contained in them; copper and cadmium – accumulate poorly and are strongly retained; lead – poorly accumulates and is poorly retained in plants (Malinowska *et al*., 2017).

Heavy metals entering the atmosphere and into the soil actively affect medicinal plants (Caldasa *et al*., 2004). In turn, soil contaminated with heavy metals becomes a secondary source of contamination of medicinal plants (Chishti *et al.,* 2011). Heavy metal pollution of medicinal plants and their accumulation by biotic components of ecosystems is influenced by two main factors – natural and anthropogenic, a clear predominance of anthropogenic sources of pollution has been observed in recent decades (Maurizio *et al*., 2018). The negative consequence of anthropogenic environmental change is a significant increase in the levels of heavy metals in its components, in particular, in soils and medicinal plants, among which lead, cadmium, copper and zinc are recognized as one of the most dangerous pollutants (Caldasa *et al*., 2004; Razanov *et al*., 2018; Razanov *et al*., 2020). Soil pollution Pb, Cd, Cu, Zn is irreversible, so their receipt, even in small quantities to medicinal plants for a long time leads to accumulation in the soil and migration in the system "soil – medicinal plant – medicinal raw materials – human body" (Zwolak *et al*., 2019).

Cadmium is not among the physiologically necessary trace elements for medicinal plants, but it is quite actively absorbed by plants (Kubier *et al*., 2019; Pan *et al*., 2010). Cadmium is a scattered element of the earth's crust and forms almost no minerals of its own. The metal itself is not toxic, but its soluble compounds are extremely dangerous, as toxicity is not inferior to mercury and arsenic (Caldasa *et al*., 2004). The cadmium that got into the soil is in a state accessible to medicinal plants, which has a negative environmental significance (Pan *et al*., 2010). The mobile form of cadmium causes a relatively high migration capacity of this element in the landscape and leads to increased contamination of the flow of substances coming from the soil into medicinal plants. Cadmium accumulation in medicinal plants is more intense in the early stages of the growing season, as medicinal plants are able to absorb this element through the leaf surface, while lead, which enters plants through the root system, is more intense in September, when root development reaches a maximum (Khatamipour *et al*., 2011). Lead like cadmium does not belong to the group of physiologically necessary trace elements for medicinal plants. But according to the degree of danger to living organisms, it is classified as the first (highest) class of danger (Sharma and Dubey, 2005). Therefore, an important indicator of the level of soil contamination is the level of phytomass contamination of plants. Elevated concentrations of heavy metals in plants, in particular those with medicinal properties are due to the fact that these species grow within residential areas, where the level of soil contamination is an order of magnitude higher than within natural ecosystems (Xie *et al*., 2019).

As part of medicinal plants, milk thistle *(Silybum marianum* L.) occupies one of the leading places because it has a 2000-year history of use in the treatment of various diseases. The fruits of the plant contain a mixture of flavonolignans, known collectively as silymarin. These components have a therapeutic effect in many liver diseases (anti-inflammatory, immunomodulatory, antioxidant, regenerative properties), as well as a positive clinical effect in patients with fatty liver disease, viral and toxic hepatitis, mushroom poisoning and others diseases (Abenavoli *et al*., 2018; Razanov *et al*., 2020; Adetunji *et al*., 2021). The main part of the research is devoted to the peculiarities of migration and accumulation of heavy metals in crops, while medicinal plants, in particular the well-known milk thistle, need more attention from scientists. Therefore, our study is relevant. The purpose of the articleis to study the intensity of accumulation of heavy metals in the leaf mass and seeds of milk thistle when growing it after green manure (mustard), the precursor of alfalfa, fertilization with humus and sugar beet lime sludge compost.

Materials and Methods

Field studies were conducted during 2018-2020. The research scheme included five variants of the experiment in four replications. The first variant of research included cultivation of milk thistle *(Silybum marianum* L.) after the predecessor of winter wheat (control). The second variant of research included the cultivation of milk thistle with humus fertilization (20 t ha^{-1}) after the predecessor of winter wheat. The third variant of research included the cultivation of milk thistle with fertilization by sugar beet lime sludge compost (6 t ha^{-1}) after the predecessor of winter wheat. The fourth variant of research covered the cultivation of milk thistle with green manure (mustard) after the predecessor of winter wheat. The fifth variant of research was aimed at growing milk thistle after a four-year predecessor of alfalfa.

Research on this topic was conducted in the Vinnytsia region on gray forest soils. Vinnytsia region belongs to the agrarian region of Ukraine with intensive agriculture. It is characterized by a high level of plowing of soils, which reach 90%. The basis of the agro-industrial complex of Vinnytsia region consists of agricultural enterprises, farms and personal peasant enterprises. Agricultural lands of Vinnytsia region amount to 2012 thousand hectares, of which 1730.5 thousand hectares are arable land, 48 thousand hectares are perennial plantations, 48.8 thousand hectares are hayfields and 183.9 thousand hectares are pastures. The main crops in this region are winter wheat, corn, sunflower and winter rape. Vinnytsia region is also a powerful producer of horticultural products, the area under which is growing from year to year. Recently, the list of crops is expanding due to the introduction of crop rotations of medicinal herbs, in particular, milk thistle, Echinacea purpurea and others.

Results and Discussion

The use of organic fertilizers in crop production is an important measure in increasing production and improving its quality. However, the use of organic fertilizers also contributes to soil contamination with heavy metals, which can accumulate in plants several tens of times higher than the soil. It is known that with such organic fertilizers as humus and sugar beet lime sludge compost with each kilogram in the soil falls 3.3 mg and 28 mg of lead respectively, 0.2 mg and 0.18 mg – cadmium, 12.1 mg and 22 mg zinc and 19.8 mg and 6.3 mg – copper.

Given that milk thistle is a plant with a high intensity of accumulation of these metals, we studied the effect of different organic fertilizers on the yield, chemical composition and intensity of accumulation of lead, cadmium, zinc and copper in the leaf mass and seeds of this crop. The results of studies on the seed productivity of milk thistle and the chemical composition of the seeds (Table 1) showed some differences that depend on the type of soil fertilizer.

The mass seeds of milk thistle increased by fertilization humus –8.7%, sugar beet lime sludge compost – 4.3%, green manure – 6.2% and 4-year predecessor – 7.5%, while yields increased by 20%, 6.6%,

Table 1. Productivity of milk thistle and chemical composition of seed culture

A variant of the experiment	Features of fertilizer	Mass of seeds from one plant, g	Crop capacity seeds, t ha^{-1}	Protein,%	Fat,%	Fiber,%
1	Without fertilizer	1.6	0.45	25.6	28.3	26.2
2	Humus, 20 t ha^{-1}	1.74	0.54	26.5	29.7	25.3
3	Sugar beet lime sludge compost, 6 t ha^{-1}	1.67	0.48	25.9	29.0	25.8
4	Green manure (mustard)	1.7	0.52	26.6	29.4	25.4
5	4-year-old predecessor (alfalfa sowing)	1.72	0.54	26.4	29.6	25.5

15.5% and 20%, respectively, compared with the option without fertilizer. The protein content of milk thistle seeds was 1.036 times higher than manure fertilization, 1.012 times higher than sugar beet lime sludge compost, 1.039 times higher than green manure cultivation and 1.032 times higher than the four-year predecessor of alfalfa sowing, while the percentage of fat increased 1.050 times, 1.025, 1.039 and 1.046 times, respectively. The amount of fiber in the seeds of milk thistle decreased by fertilization with humus, sugar beet lime sludge compost, green manure and after the four-year predecessor of alfalfa sown by 1.036 times, 1.016, 1.032 and 1.029 times, respectively.

Analysis of research results shown in Table 2, showed that when a fertilizer is humus, the concentration of lead, cadmium, zinc and copper in the mass of the leaves of the dairy termination increased by 5.1%, 18.2%, 53.1% and 20.4%, respectively. When fertilizing with a sugar beet lime sludge compost, the concentration of lead, cadmium, zinc and copper in the leaf mass of the milk thistle increased by 25.9%, 13.6%, 10.2% and 10.5%, respectively.

In the cultivation of milk thistle after green manure and leguminous perennial grasses, the concentration of lead decreased by 8.6% and 2.4 times, respectively, and of cadmium by 9.1% and 2.6 times. The concentration of zinc with the use of green manure (mustard) remained on the background of the control variant, while with the predecessor of alfalfa sowing it was 9.0 times lower. The concentration of copper in the leaf mass of milk thistle when grown after green manure was 1.05 times higher, and after the four-year predecessor of alfalfa – 6.1 times lower compared to the control. The results of the research also showed that the concentration of heavy metals in the leaves of milk thistle exceeded the MPC in all variants, except for the use of a four-year predecessor of alfalfa. In particular, in the control variant, the concentration of lead, cadmium, zinc and copper was 1.62, 1.1, 4.9 times and 2.8 times higher than the MPC, respectively. When fertilized with humus, the concentration of lead, cadmium, zinc and copper in the leaf mass of milk thistle was 1.94, 1.3, 7.5 times and 3.42 higher than the MPC. During sugar beet lime sludge compost fertilization, the concentration in the leaf mass of lead, cadmium, zinc and copper was 2.04, 1.28, 5.4 times and 3.14 times higher than the MPC, respectively.In the cultivation of milk thistle after green manure fertilization, the concentration of lead in the leaf mass was 1.48 times higher than the MPC, zinc – 4.9 times and copper – 3.0 times. When milk thistle growing after four years of predecessor (alfalfa) in its leaf mass, the concentration of lead, cadmium, zinc and copper was lower than the MPC by 1.47, 2.38, 1.85 and 2.17 times, respectively. The lowest concentration of heavy metals was observed in the leaf mass of milk thistle during its cultivation after the four-year predecessor of alfalfa. In the leaf mass of milk thistle when grown after alfalfa sowing compared to similar raw materials grown for fertilization with humus, sugar beet lime sludge compost and green manure, the concentration of lead was lower by 2.85, 3.0 and 2.2 times, cadmium – 3.1, 3.0 and 2.4, zinc – 13.8, 10 and 9.1 times, copper – 7.4, 6.8 and 6.5.

The coefficient of accumulation heavy metals in the leaf mass of milk thistle (Table 3) showed that this indicator ranged from 2.8 to 3.9 for lead, from 10 to 11.6 for cadmium, from 1.13 to 5.3 for zinc and

Table 2. Concentration of heavy metals in the leaf mass of milk thistle, mg kg^{-1} in absolutely dry matter, (n = 4, (m ± m)

A variant of the experiment	Features of fertilizer	Heavy metals							
		Pb		Cd		Zn		Cu	
		Actual concentration	MPC	Actual concentration	MPC	Actual concentration	MPC	Actual concentration	MPC
1	Without fertilizer	8.1±0.12	5.0	1.1±0.04	1.0	49±2.1	10	14.2±0.80	5.0
2	Humus,20 t ha^{-1}	9.7±0.08	5.0	1.3±0.03	1.0	75±2.4	10	17.1±0.73	5.0
3	Sugar beet lime sludge compost,6 t ha^{-1}	10.2±0.07	5.0	1.28±0.01	1.0	54±1.2	10	15.7±0.61	5.0
4	Green manure (mustard)	7.4±0.14	5.0	1.0±0.07	1.0	49±1.8	10	15.0±0.54	5.0
5	4-year-oldpredecessor (alfalfa sowing)	3.4±0.12	5.0	0.42±0.01	1.0	5.4±1.3	10	2.3±0.09	5.0

from 2.87 to 6.2 for copper.

The lowest coefficient of accumulation of lead, cadmium, zinc and copper in the leaf mass of milk thistle (Table 3) was observed for its cultivation after the four-year predecessor of alfalfa, while the highest when fertilizing sugar beet lime sludge compost.

Analysis of the risk factor heavy metals in the leaf mass of milk thistle (Table 4) showed that this figure ranged from 0.68 to 2.04 for lead, from 0.42 to 1.3 for cadmium, from 0.54 to 5.4 for zinc and from 0.46 to 3.42 for copper. The lowest risk factors for lead, cadmium, zinc and copper were found in the leaf mass of milk thistle when grown after its four-year predecessor alfalfa. The highest risk factor for lead in the leaf mass of milk thistle was for fertilization sugar beet lime sludge compost, cadmium, zinc and copper – for the introduction of humus. Thus, the concentration of lead in the leaf mass of milk thistle when fed its sugar beet lime sludge compost, humus, green manure was 2.85 times, 3.0 times and 2.17 times higher compared to similar raw materials when grown after a four-year predecessor of alfalfa. The risk factor for cadmium in the leaf mass of milk thistle when fertilized with humus, sugar beet lime sludge compost and green manure was 3.1 times, 3.0 times and 2.38 times higher, respectively, compared to similar raw materials obtained after the four-year predecessor of alfalfa. The risk factor for zinc and copper in the leaf mass of milk thistle was 13.8 and 7.4 times higher, respectively, when fertilized with humus, 10 and 6.8 with sugar beet lime sludge compost, and 9.0, 6.5 times higher with green manure compared to similar raw materials grown after four-year predecessor of alfalfa.

Characterizing the concentration of heavy metals in the seeds of milk thistle (Table 5) it should be noted that this figure ranged from 0.5 mg kg^{-1} to 4.1 mg kg^{-1}, cadmium – from 0.08 mg kg^{-1} to 0.68 mg kg^{-1}, zinc – from 27 mg kg^{-1} to 98 mg kg^{-1} and copper – from 7.5 mg kg^{-1} to 19.2 mg kg^{-1}.

The lowest concentration of lead, cadmium, zinc and copper was observed in the seeds of milk thistle when grown after its four-year predecessor alfalfa. The highest concentration of lead and cadmium was observed in the seeds of milk thistle for feeding its sugar beet lime sludge compost, and zinc and copper – for the use of humus. In particular, the concentration of lead, cadmium, zinc and copper in the seeds of milk thistle when fertilized with humus was higher by 6.8, 4.6, 2.8 and 2.5 times, sugar beet lime sludge compost – 8.2, 8.5, 3.0 and 2.4 times and green manure – 2.6, 4.6, 2.7 times and 2.1 times compared to similar raw materials obtained during the four-year predecessor of alfalfa. The concentration of lead, cadmium, zinc and copper in the seeds of milk thistle for fertilization with humus was higher compared to similar raw materials obtained without

Table 3. The accumulation coefficient of heavy metals in leaf mass of milk thistle

A variant of the experiment		Features of fertilizer		Heavy metals	
		Pb	Cd	Zn	Cu
1	Without fertilizer	3.1	11	4.8	5.9
2	Humus,20 t ha^{-1}	3.6	10.8	5.3	6.1
3	Sugar beet lime sludge compost, 6 t ha^{-1}	3.9	11.6	4.9	6.2
4	Green manure (mustard)	2.8	10	4.9	6.2
5	4-year-old predecessor (alfalfa sowing)	2.8	10.5	1.13	2.87

Table 4. Hazard ratio of heavy metals in the leaf mass milk thistle spotted

A variant of the experiment		Features of fertilizer		Heavy metals	
		Pb	Cd	Zn	Cu
1	Without fertilizer	1.62	1.1	4.9	2.84
2	Humus,20 t ha^{-1}	1.94	1.3	7.5	3.42
3	Sugar beet lime sludge compost, 6 t ha^{-1}	2.04	1.28	5.4	3.14
4	Green manure (mustard)	1.48	1.0	4.9	3.0
5	4-year-old predecessor (alfalfa sowing)	0.68	0.42	0.54	0.46

fertilization, respectively, 1.1, 1.08, 1.25 times and 1.03 times. When feeding milk thistle with sugar beet lime sludge compost, the concentration of lead, cadmium, zinc and copper in the seeds was 1.3, 1.83, 1.04 and 1.03 times higher than the control. In the cultivation of milk thistle after green manure, the concentration of lead and cadmium was at the level of control, in particular, 3.1 mg kg^{-1} and 0.37 mg kg^{-1}, and zinc and copper were slightly lower, respectively 1.04 and 1.09. In the variant, when growing milk thistle after the four-year predecessor of alfalfa, the concentration of cadmium, zinc and copper in the seeds was lower by 4.6, 2.8 and 2.3, respectively, compared to the control.

Comparing compliance of the concentration heavy metals with the maximum permissible levels (MPC) in the seeds of milk thistle, it should be noted that when used as fertilizer humus, sugar beet lime sludge compost and green manure, this figure was higher than the established norm, while growing this crop after four years, lower. Thus, the concentration of lead, cadmium, zinc and copper in milk thistle seeds was 6.8, 4.0, 1.96 and 1.92 higher than the maximum concentration limit for fertilization with humus, 8.2, 6.8, 1.62 and 1.81 higher than sugar beet lime sludge compost, green manure – 6.2 times, 0 times, 1.5 times and 1.6 times. When growing milk thistle after a four-year predecessor of alfalfa, the concentration of cadmium, zinc and copper was lower than the MPC by 1.25, 1.8 and 1.33, respectively, the concentration of lead was at the level of the MPC.

Analysis of the coefficient of accumulation in the seeds of milk thistle (Table 6) showed that this indicator ranged from 0.41 to 1.4 for lead, from 2.0 to 6.8 for cadmium, from 5.6 to 9.8 for zinc and from 6.6 to 9.3 for copper. The lowest coefficient of accumulation in the seeds of milk thistle spotted lead, cadmium, zinc and copper was observed when growing it after a four-year predecessor of alfalfa, and copper – when growing this crop after green manure. In addition, it should be noted that the accumulation coefficient of lead, cadmium and zinc was higher, respectively, for fertilization by humus 1.08, 1.08 and 1.25, sugar beet lime sludge compost – 1.16, 1.83 and 1.03 compared to similar raw materials obtained without fertilization. When growing milk thistle after green manure, the accumulation coefficient in the seeds of lead and cadmium was at the level of control, and zinc and copper – lower, respectively, 1.04 and 1.1. When growing milk thistle after the four-year predecessor of alfalfa, the accumulation coefficient of lead, cadmium and zinc in the seeds was lower by 2.9, 1.85 and 1.04, respectively,

Table 5. The content of heavy metals in the seeds of milk thistle, mg kg^{-1} in absolutely dry matter, (n = 4, (m ± m))

A variant of the experiment		Features of fertilizer				Heavy metals			
		Pb		Cd		Zn		Cu	
		Actual concentration	MPC	Actual concentration	MPC	Actual concentration	MPC	Actual concentration	MPC
1	Without fertilizer	3.1±0.4	0.5	0.37±0.031	0.1	78±4.1	50	17.5±0.23	10
2	Humus, 20 t ha^{-1}	3.4±0.09	0.5	0.4±0.011	0.1	98±1.3	50	19.2±0.31	10
3	Sugar beet lime sludge compost, 6 t ha^{-1}	4.1±0.43	0.5	0.68±0.014	0.1	81±7.4	50	18.1±0.27	10
4	Green manure (mustard)	3.1±0.23	0.5	0.37±0.013	0.1	75±2.1	50	16.0±0.31	10
5	4-year-old predecessor (alfalfa sowing)	0.5±0.27	0.5	0.08±0.007	0.1	27±3.4	50	7.5±0.27	10

Table 6. The coefficient of accumulation of heavy metals in the seeds of milk thistle

A variant of the experiment		Features of fertilizer		Heavy metals	
		Pb	Cd	Zn	Cu
1	Without fertilizer	1.2	3.7	7.8	7.3
2	Humus,20 t ha^{-1}	1.3	4.0	9.8	6.8
3	Sugar beet lime sludge compost, 6 t ha^{-1}	1.4	6.8	8.1	7.2
4	Green manure (mustard)	1.2	3.7	7.5	6.6
5	4-year-old predecessor (alfalfa sowing)	0.41	2.0	5.6	9.3

Table 7. The risk factor of heavy metals in the seeds of milk thistle

A variant of the experiment		Features of fertilizer		Heavy metals	
		Pb	Cd	Zn	Cu
1	Without fertilizer	6.2	3.7	1.56	1.75
2	Humus,20 t ha^{-1}	6.8	4.0	1.96	1.92
3	Sugar beet lime sludge compost, 6 t ha^{-1}	8.2	6.8	1.62	1.81
4	Green manure (mustard)	6.2	3.7	1.5	1.60
5	4-year-old predecessor (alfalfa sowing)	1.0	0.8	0.54	0.75

and copper was 1.27 times higher.

Analyzing the risk factor of heavy metals in the seeds of milk thistle (Table 7), it should be noted that this figure ranged from lead to 1.0 to 8.2, cadmium – from 0.8 to 6.8, zinc – from 0.54 to 1.56 and copper – from 0.75 to 1.75. The lowest risk factor for heavy metals was in the seeds of milk thistle when grown after its four-year predecessor alfalfa.At the same time, it should be noted that the risk ratio of lead, cadmium, zinc and copper in the seeds of milk thistle was 1.09, 1.08, 1.25 and 1.09 higher than its fertilization with humus, and 1.32, 1.83, 1.05 higher than sugar beet lime sludge compost and 1.04 times compared to control. When green manure was used, the hazard ratio of lead and cadmium was at the same level as the control, and that of zinc and copper was 1.04 times and 1.09 times lower. The risk ratio of lead, cadmium, zinc and copper in the seeds of milk thistle for its cultivation after the four-year predecessor of alfalfa was lower 6.2, 4.6, 2.8 and 2.3, respectively, compared to the control.

Conclusion

As a result of research, it was found that the cultivation of milk thistle in modern agricultural lands has a high level of accumulation in the leaf mass and seeds of lead, cadmium, zinc and copper, which requires constant monitoring of the content of these toxicants in this culture.

Studies have shown that fertilizing milk thistle with organic fertilizers increases yields, seed weight, protein and fat content, while increasing the accumulation of lead, cadmium, zinc and copper in its leaf mass and seeds, especially with the use of humus and sugar beet lime sludge compost relatively less than the use of green manure. Whereas in the cultivation of milk thistle after four years of alfalfa sowing without the use of fertilizing this crop during this period makes it possible to clean the soil of heavy metals due to phytoremediation and reduce the concentration of lead, cadmium, zinc and copper in the leaf mass and seeds below the maximum allowable.

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