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Influence of soil moisture level on the translocation of plumbum and cadmium in the grains of winter cereals

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Abstract. The agricultural economy of many countries of the world is dominated by grain crops, a large portion of which comprises wheat and barley. However, according to scientists from European and other countries, as a result of the climate change, grain crops suffer either an insufficient amount of precipitation or an excessive amount of it, which can affect the yield of crops and cause changes in the concentration of certain elements in them. Dangerous types of environmental pollution, in particular for grains, are caused by heavy metals, among which certain elements (Zn, Fe, Mn, Cu) are important for the development of plants. There are also such metals as Pb, Cd, etc., which at high concentration can lead to poisoning of the plant organism and cause a decrease in their quality and production in general. This paper is focused on the influence of soil moisture level, precipitation and irrigation (sprinkling) on the content and the coefficient of accumulation, as well as the hazard ratio of Pb and Cd for winter wheat and winter barley grains. We determined that against the background of 256.2 to 272.5 mm (precipitation, rainfall) soil moisture during the period from the end of tillering to the earing of the winter cereals, there were decreases by 31.3% and 11.8% in Pb and Cd accumulation coefficients in the Luran-variety barley and decreases by 39.3% and 22.5% in the Akratos-variety wheat, compared with 47.4 to 52.3 mm soil moisture (precipitation) during that period. Decrease in Pb and Cd accumulation coefficients in the cereal grain contributed to decrease in the concentrations of these toxicants in it. In particular, at 266.2 to 272.5 mm level of soil moisture during the indicated growing season of winter barley and winter wheat, the concentration of Pb in the grain from these cereals was 31.8% and 48.9% lower; while the concentration of Cd – was 11.1% and 21.4% lower, compared with 47.4 and 52.3 mm moisture level. At the same time, Pb was characterized by higher intensity of reduction in the grain of the winter cereals than Cd. The hazard ratio of Pb and Cd in the grain of the winter cereals also turned out to be lower when the level of soil moisture was 266–272.5 mm during the tillering-earing period, compared with the level between 47.4–52.3 mm. The prospects for further research are studies of changes in the mineral composition of the soil in the zone of the root system of cereals under excessive rainfall.

Keywords: soil; barley; wheat; precipitation; sprinkling; heavy metals; accumulation coefficient; hazard ratio.

Introduction

In many countries of the world, grain crops form the basis of agricultural production, primarily wheat, barley, corn, rice. Increasing the grain productivity is the priority of agronomists. Wheat and barley are used both for food and fodder, so they are in demand on the agricultural market.

It is known that grain crops contain a large amount of carbohydrates, which provide the human body with energy. Crops contain a high protein content, which is quickly absorbed by the human body and contains essential amino acids and other compounds that are useful for humans. Cereal grains also contain fat, fiber, ash, vitamins D, E, A, K, C, B, sodium, iodine, phosphorus, magnesium, zinc, selenium, iron, copper, calcium, bromine and others biologically active substances (Fatima et al., 2020; Loskutov et al., 2021).

Crops are characterized by a broad range of use, in particular, they are used in the food, pharmacological, cosmetic, alcohol, brewing spheres, as well as in the practical and folk medicine. Cereal crops are highly nutritious feeds in animal husbandry. The remains of straw of cereal crops are used as organic fertilizer and for organization of mushroom cultivation. Also, the remains of the vegetative mass of crops have found application in the energy industry. They are used as raw materials for the production of biofuel, which is of great environmental importance and has a high heat output (Burlaka et al., 2020).

Along with the increase in the demand for crops, the requirements for their quality and safety also increase, which to a certain extent depend on the ecological state of the environment where they are grown. As known, the current state of the environment in some territories is unfavourable for the production of high-quality plant raw materials, including cereals, due to the accumulation of various toxicants in them (Khilko, 2017; Tkachuk et al., 2020).

Heavy metals are among a number of toxicants that need to be controlled in plant raw materials. The sources of heavy metals entering the environment are rocks, air emissions from ferrous metallurgy enterprises, motor vehicles, liquid and solid municipal waste, organic and mineral fertilizers (Hutsol, 2020). The intensive use of chemicals in crop production creates a growing load of heavy metals on agricultural soils, leading to the translocation of these toxicants into grain products, which reduces their quality and safety (Razanov & Tkachuk, 2017; Razanov & Tkachuk, 2018).

Local and regional climatic conditions are the main factor determining the productivity of agricultural crops. Crop production is affected by extreme climatic conditions such as heat, drought or excessive rainfall (Hussain et al., 2018; Nicholson et al., 2018; Fatima et al., 2020; Zahra et al., 2023).

Recently, there was observed uneven rainfall (low or quite high amount) in some regions. In 2011, 240.8 mm (coefficient of local moisture – 1.67) fell during the germination-ripening period of cereals (Owen et al., 2021; Christidis et al., 2022; Novak et al., 2022).

It has been determined that the level of soil moisture to one degree or another affects the intensity of assimilation of mineral substances by plants (de San Celedonio et al., 2018). Under such conditions, there is a need to study the accumulation of heavy metals in grain crops under different soil moisture levels for prognostication of crop contamination.

The objective of the research was to study the influence of high soil moisture rates on the accumulation of Pb and Cd in grain of the winter cereals.

Materials and methods

The study of the influence of soil moisture on the accumulation of heavy metals in the grain of winter crops was conducted in the conditions of the Forest-Steppe of the Right Bank of Ukraine (48º59′20″ N 28º26′30″ E).

This region is situated in an area with unstable humidity, mostly low, and only in some cases abnormally high. The climate is temperate continental with long and warm summers and short, moderately cold winters. The influence of soil moisture level was studied according to the research scheme (Table 1). The following winter cereals were chosen for the research: winter wheat of the Akratos variety and winter barley of the Luran variety.

The monitoring of the level of soil moisture was carried out from the beginning of the budding phase to the ripening phase. We used sprinkling to cause additional soil moisture during the cultivation of winter wheat and winter barley in the period from the end of the beginning of the maturation phase to the earing phase. The amount of moisture due to precipitation and sprinkling in that period amounted to 256.2 mm in 2021 and 272.5 mm in 2022, while due to precipitation it was only 47.4 and 52.3 mm in 2021 and 2022, respectively.

Table 1
Scheme of research of the influence of soil-moisture level on the accumulation of heavy metals in the grain of the winter cereals

Crops	Features of soil moistening	Years of research	Soil moisture level, mm	Indicators of the intensity of accumulation of heavy metals in cereal grains	
Barley, Luran variety	precipitation	2020–2021	47.4	Concentration: Pb, Cd	Coefficient of accumulation and hazard ratio of Pb, Cd
		2021–2022	52.3		
	precipitation and sprinkling	2020–2021	256.2		
		2021–2022	272.5		
Winter wheat, Akratos variety	precipitation	2020–2021	47.4		
		2021–2022	52.3		
	precipitation and sprinkling	2020–2021	256.2		
		2021–2022	272.5		

To determine the concentrations of heavy metals (Pb, Cd), the soil was sampled using the envelope method, with a probe at 22–24 cm depth. The grain was selected manually separately from each local sampling plot.

The contents of Pb and Cd heavy metals in the grain crops were determined by the atomic absorption method.

The accumulation coefficient (AC) was determined by the formula:

$$AC = \frac{\text{Content of heavy metals in grain crops}}{\text{Content of heavy metals in soil}}$$

The hazard ratio (HR) was determined by the formula:

$$HR = \frac{\text{Content of heavy metals in grain crops}}{\text{Rate of heavy metals}}$$

In the study, we used winter wheat (Akratos) and winter barley (Luran).

All the data were analyzed using Statistica 8.0 (StatSoft Inc., USA). The results in the tables are shown as x ± SE (mean ± standard error). The differences between values were considered significant at $P < 0.05$.

Results

The results of studies on the intensity of soil contamination by mobile forms of heavy metals revealed no excesses of MPC for Pb, Cd. The concentration of Pb and Cd was 4.5 and 10.9 times lower than the maximum concentration value (MCV) in 2021 and 2022 and 4.47 and 11.3 times lower in 2021, respectively (Fig. 1).

The study of the intensity of contamination of winter cereals by heavy metals (Table 2) showed that against the background of 256.2–272.5 mm precipitation during the period from the end of the tillering phase to the earing phase, the concentration of Pb and Cd was 31.8% and 11.1% lower in the Luran winter barley, and 48.9% and 21.4% lower in the Akratos winter wheat, respectively, compared with 47.4 to 52.3 mm soil moistening.

Lead was characterized by higher intensity of reduction in the grain crops than Cd. In the conditions of 256.2–272.5 mm soil moistening during the tillering-earing period, the intensity of Pb reduction in grain of the winter barley was 20.7% higher, and 27.5% higher in the winter wheat, compared with Cd. When characterizing the coefficient of accumulation of heavy metals (Table 3), it should be noted that at 266.2 to 272.5 mm soil moisture, this indicator was lower by 31.3% for Pb, and by 11.8% for Cd in the grain of winter barley, while it was lower by 39.3% and 22.5%, respectively, in the grain of winter wheat, compared with 47.4 to 51.3 mm soil moisture.

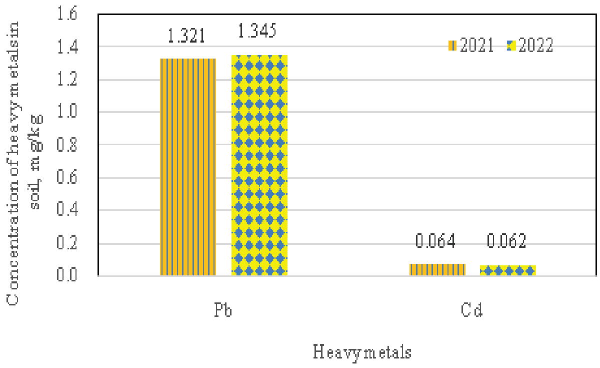

Fig. 1. Intensity of soil contamination by heavy metals (mg/kg) in the conditions of the Forest-Steppe of the Right Bank

The hazard ratio in the grain crops (Table 4) was lower for Pb and Cd at 266.2–272.5 mm level of soil moisture, compared with the moisture level of 47.4–51.3 mm.

In particular, the hazard ratio was 24.4% and 10.1% lower in the winter barley, and 39.0% and 21.4% lower in the winter wheat, respectively, compared with 47.4 to 52.3 mm moisture.

Discussion

Sufficient soil moisture is known to significantly affect the intensity of assimilation of nutrients by the root system of plants, including trace elements, which positively affects the yield of agricultural crops (Netis & Onufran, 2012).

However, when the moisture is above the norm, nutrients are leached from the upper soil horizons, and sometimes from the entire fertile soil layer (Netis, 2008; Lozovitsky, 2014). During irrigation in the conditions of low soil moisture, a high level of sodium enters the soil, thus increasing its alkalinity. At the same time, it should be noted that lowering the pH of the soil environment to a more neutral, as well as alkaline level, also promotes reduction of the movement of heavy metals into plants and their products (Razanov et al., 2015; Razanov et al., 2022).

Table 2
Concentration of heavy metals (mg/kg) in the grain crops grown at different levels of soil moisture (x ± SE, n = 12)

Crops	Features of soil moistening	Years of research	Heavy metals			
			Pb	on average over the years	Cd	on average over the years
Winter barley (Luran)	precipitation	2021	0.871 ± 0.004	0.912 ± 0.007	0.079 ± 0.004	0.091 ± 0.004
		2022	0.952 ± 0.004		0.101 ± 0.003	
	precipitation and sprinkling	2021	0.603 ± 0.006	0.622 ± 0.006	0.084 ± 0.002	0.082 ± 0.001
		2022	0.645 ± 0.008		0.076 ± 0.008	
Winter wheat (Akratos)	precipitation	2021	0.411 ± 0.007	0.462 ± 0.008	0.068 ± 0.003	0.072 ± 0.002
		2022	0.412 ± 0.001		0.072 ± 0.005	
	precipitation and sprinkling	2021	0.273 ± 0.005	0.253 ± 0.008	0.053 ± 0.002	0.055 ± 0.002
		2022	0.238 ± 0.003		0.057 ± 0.008	

Table 3
Coefficient of accumulation of the heavy metals in the grain crops grown at different levels of soil moisture

Crops	Features of soil moistening	Years of research	Heavy metals			
			Pb	on average over the years	Cd	on average over the years
Winter barley (Luran)	precipitation	2021	0.653	0.678	1.232	1.435
		2022	0.701		1.631	
	precipitation and sprinkling	2021	0.452	0.465	1.311	1.267
		2022	0.473		1.221	
Winter wheat (Akratos)	precipitation	2021	0.315	30.521	1.061	1.114
		2022	0.302		1.161	
	precipitation and sprinkling	2021	0.203	18.525	0.821	0.864
		2022	0.175		0.911	

Table 4
Hazard ratio of the heavy metals in the grain crops grown at different levels of soil moisture

Crops	Features of soil moistening	Years of research	Heavy metals			
			Pb	on average over the years	Cd	on average over the years
Winter barley (Luran)	precipitation	2021	0.840	0.824	0.794	0.892
		2022	0.801		1.022	
	precipitation and sprinkling	2021	0.607	0.624	0.845	0.804
		2022	0.647		0.767	
Winter wheat (Akratos)	precipitation	2021	0.827	0.824	0.685	0.707
		2022	0.828		0.728	
	precipitation and sprinkling	2021	0.544	0.504	0.533	0.553
		2022	0.464		0.579	

The beneficial effect of moisture is observed in case of optimal moisture, i.e. precipitation in such an amount as is necessary for plants (Goncharov & Pototsky, 1991; Ushkarenko, 1994; Lozovitsky, 2010). Precipitation-caused abnormally high levels of soil moisture recorded in 2011 and 2021 and this was accompanied by decrease in yield due to the leaching of nutrients from the root zone of plants, which disrupted their nutrition (Gudzenko & Vasylkivsky, 2016).

Under such conditions, it became necessary to study the influence of high levels of moisture on the intensity of accumulation of Pb and Cd in cereal grains in presence of a potential technogenic impact of heavy metals on agricultural land. According to the results of our research, against the background of 256.2–272.5 mm precipitation during the period from the end of the tillering vegetation phase to the earing vegetation phase, Pb decreased by 31.3% in the grain of winter barley and 39.3% in the grain of winter wheat and Cd decreased by 11.8% in the grain of winter barley and 22.5% in the grain of winter wheat. That is, excessive soil moisture has a certain effect on the movement of Pb and Cd into grain crops, i.e. reduction of these toxicants in grain.

Conclusions

As a result of the conducted research, we determined that the concentration of Pb in grain was lower by 31.8% and 48.9% and that of Cd by 11.1% and 21.4% in the winter barley and winter wheat against the background of soil moisture equaling 266.2–272.5 mm during the period from the end of the tillering phase to the beginning of the ripening phase, compared with the natural level of moisture (precipitation) equaling 47.4–52.3 mm. At the same time, lower accumulation coefficients of Pb and Cd in the winter barley and winter wheat grains were noted in the period from the end of the tillering phase to the beginning of the ripening phase when the soil moisture level was 266.2–272.5 mm, compared with 47.4–52.3 mm moisture level.

The prospect of further research consists in studying changes in the mineral composition of the soil in the zone of the root system of grain crops under excessive rainfall.

The authors declare no conflicting interests.

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