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The Influence of the Gray Forest Soil Moisture Level on the Accumulation of Pb, Cd, Zn, Cu in Spring Barley Grain

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ABSTRACT

Among a number of climate-related factors, moisture has the greatest impact on crop productivity. In recent years, certain changes have been observed under conditions of the Forest-Steppe of Ukraine with regard to precipitation – from low to in some cases – abnormally high, which requires the study of their impact on the yield and safety of cereal grain for its forecasted production. The article examined the effect of a high level of soil moisture (256.2–272.5 mm) and a low level (47.4–52.3 mm) during the growing season (germination→earing) of spring barley grain on the accumulation of heavy metals in it and its productivity under the conditions of gray forest soils of the Right Bank Forest Steppe of Ukraine. Spring barley varieties Helios and Caesar were selected for the research. A decrease in the accumulation coefficient at a high level of soil moisture (256.6–272.5 mm) in spring barley grain Pb from 8.3% to 11.3%, Cd – from 35.0% to 35.5%, Zn was established – by 15% and Cu – from 11.2% to 16.6% compared to the low level of soil moisture (47.1 mm – 53.3 mm). At the same time, it was found that with a high level of soil moisture, there is a decrease in the yield of Helios and Caesar spring barley by 18.0% and 14.1%, respectively.

Keywords: soil, heavy metals, Pb, Cd, Zn, Cu, spring barley, accumulation coefficient, concentration, precipitation, artificial moistening, growing season, germination, earing.

INTRODUCTION

At almost all historical stages of the development of society, cereal grains have been an important type of food resource for the population. They constitute one of the main export products, which provide significant inflows of foreign exchange funds, and are the basis of cash receipts and profits in agricultural enterprises. With proper storage, grain practically does not lose its qualities, so it is suitable for creating state reserves for the production of food and feed [Lotysh, 2018].

Today, Ukraine has alternative directions for the development of grain production in the technologies of growing grain crops, which have opened up new opportunities for modeling grain production systems and effective use of soil resources [Chukhlib, 2020].

Along with the importance of grain production, the requirements for its quality have increased, which depends on the ecological state of grain production. However, as a result of technogenic activity of the population in some territories, certain problems arise in the production of high-quality grain, in particular, the detection of increased content of various toxicants, including heavy metals, in plant products [Zhou and Zheng, 2022; Razanov et al., 2022]. Penetrating into plants, heavy metals can negatively affect metabolic processes, which leads to a decrease in yield and the threat of contamination of its products

[Tkachuk et al., 2016; Wang et al., 2017]. The main danger of heavy metals lies in their property of inclusion in the circulation and accumulation in agricultural products, including cereal grains, in particular, barley, which can lead to their entry into living organisms [Razanov et al., 2020; Voitovska et al., 2021]. It has been established that copper, cadmium, mercury and lead can be carcinogenic, embryotoxic, teratogenic, etc. effects [Fu Z and Xi S, 2020]. It is also known that the intake of heavy metals into the body for a long period of time negatively affects its hematopoietic organs, and also increases the formation of free radicals, which leads to lipid oxidation. The entry of heavy metals into the human body can contribute to an increase in morbidity and a reduction in life expectancy [Rehman et al., 2018; Balali-Mood et al., 2021].

It is known that the formation of the crop yield is connected with a complex of abiotic factors, among which natural and climatic conditions occupy an important place [Maidanovych, 2020; Zahra et al., 2023]. A necessary condition for the effective development of grain production is the scientific substantiation of the rational placement of grain crops, taking into account the climatic conditions that have changed significantly over the past decades [Bönecke et al., 2020; Pinke et al., 2022]. It is also necessary to note the occurrence of adverse weather phenomena, in particular, long periods without precipitation, low amounts of precipitation, as well as abnormally high rates of precipitation in very short periods. Thus, in some territories of Ukraine, record precipitation was observed, amounting to 268 mm in just one month, compared to low precipitation, which amounted to only 32-35 mm [Semerhei-Chumachenko et al., 2020; Goncharova et al., 2021].

It has been studied that barley is a rather demanding crop in terms of moisture supply [Panfilova et al., 2020]. A constant supply of water is optimal for it, and insufficient supply of moisture to barley during the milky maturity of grain can be the cause of a decrease in its yield. Also, an excess of moisture can lead to insufficient supply of oxygen to the roots, as a result of which the process of grain formation is reduced [Gudzenko and Vasylkivsky, 2016]. That is, violation of the moisture supply of barley reduces the grain yield to one degree or another. At the same time, the influence of this factor on the safety of barley grain, in particular, the accumulation of toxicants (heavy metals) in it, has not been sufficiently studied.

Under such conditions, there is a need for the studied intensity of accumulation of heavy metals in the soil – plant – barley grain system for the predicted control of the concentration of these toxicants in it.

The purpose of the research was to study the intensity of accumulation of heavy metals (Pb, Cd, Zn, Cu) in cereal grains (spring barley) under the influence of high moisture of the gray forest soil under the conditions of the Right Bank Forest Steppe.

MATERIALS AND METHODS

The research on the influence of excessive soil moisture on the translocation of heavy metals in spring barley grain was conducted under the conditions of gray forest soils of the Right Bank Forest Steppe of Ukraine.

The study region belongs to the area with unstable moisture and has periodic droughts. The climate is temperate continental with long and warm summers as well as short, moderately cold winters. The duration of the growing season of agricultural plants is about 200–205 days. Spring barley varieties Helios and Caesar were used in the research.

Helios is a six-row spring barley variety, medium-ripening, designed for intensive growing technologies. The variety is characterized by high productivity and resistance to lodging, it is characterized by high resistance to diseases and shedding, in addition, it responds well to fertilizers.

Spring barley of the Caesar variety belongs to the medium-growing, intensive variety type, with average resistance to lodging and shedding, requires fertile soils. It has a double-rowed ear and is well bushed. The direction of use of the variety is grain, brewing.

Artificial irrigation during the growing of spring barley was carried out during the growing season (germination → earing) in 2021 and 2022. In each variant, 4 repetitions were used. The study of the influence of the level of soil moisture was carried out according to the research scheme (Table 1).

Hydrothermal coefficient (HTC) was determined by the formula that reflects both temperature factor and precipitation during the certain period (germination→earing): $HTC = \Sigma R \times 10 / \Sigma t_{act>10}$, where ΣR and Σt – accordingly sum of precipitations and temperatures for the same

Table 1. Scheme of research

Variety	Features of hydration	Crop sowing period		Soil moisture level, mm				Indicators of the intensity of accumulation of heavy metals in spring barley grains	
		2021	2022	2021	HTC	2022	HTC		
Helios	Precipitation	8.04	5.04	52.3	0.87	47.4	0.72	Concentration Pb, Cd, Zn, Cu	Coefficient of accumulation Pb, Cd, Zn, Cu
	Precipitation + artificial irrigation	8.04	5.04	256.2	3.14	272.5	2.96		
Caesar	Precipitation	8.04	5.04	52.3	0.87	47.4	0.72		
	Precipitation + artificial irrigation	8.04	5.04	256.2	3.14	272.5	2.96		

period, when the temperature has not been lower than 10 C, 10 – coefficient (if HTC < 0.4 – very severe drought, HTC from 0.4 to 0.5 – severe drought, HTC from 0.6 to 0.7 – moderate drought, HTC from 0.8 to 0.9 – mild drought, HTC from 1.0 to 1.5 – quite wet, HTC > 1.5 – excessively wet) [Selyaninov, 1937].

The selection of soil samples to determine the concentration of heavy metals (Pb, Cd, Zn, Cu) in it was carried out by using the envelope method. The soil was sampled with a probe at a depth of 24 cm of soil plowing. The selection of spring barley grain Helios and Caesar was carried out by means of a hand probe from each batch separately. Determination of heavy metals in spring barley grain was carried out by using the atomic absorption method [GOST, 2010].

The accumulation coefficient (C_{acc}) was determined by the formula:

$$(C_{acc}) = \frac{\text{The content of heavy metals in cereal grains}}{\text{The content of heavy metals in the soil}} \quad (1)$$

RESULTS AND DISCUSSION

The research results (Fig. 1) showed that there were no excesses of heavy metals in the soil, in particular, Pb, Cd, Zn and Cu.

Thus, the concentration of heavy metals in the soil compared to the MPC (Pb – 6.0 mg/kg, Cd – 0.7 mg/kg, Zn – 23.0 mg/kg, Cu – 3.0 mg/kg) was lower in 2021, Pb was 4.47 times, Cd – 2.25 times, Zn – 35.9 times, and Cu – 9.6 times, while in 2022 these same indicators were 4.7 times, 2.25, 35.9 and 4.09 times.

According to the research results, a certain influence of high soil moisture during the period of germination → earing (256.2–272.5 mm) compared to precipitation (47.4–52.3 mm) on the concentration of heavy metals in cereal grains was revealed (Table 2).

Thus, in spring barley of the Helios variety, with high soil moisture in 2021, the concentration of Pb was lower by 15.0%, Cd by 50%, Zn by 13.0%, and Cu by 13.4% compared to low moisture. In barley grain of the same variety grown in 2022, the Pb, Cd, Zn, and Cu concentrations were also

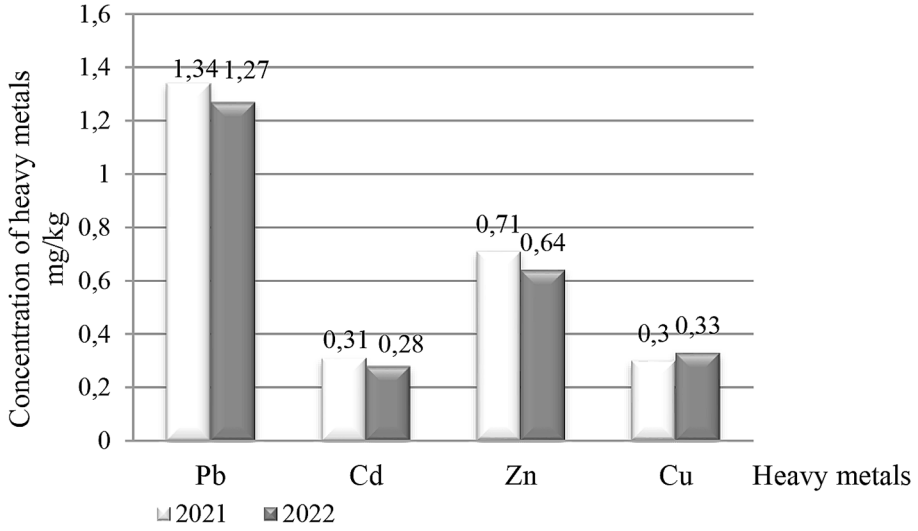

Figure 1. Intensity of soil contamination by heavy metals, mg/kg

Table 2. Concentration of heavy metals in spring barley grain, mg/kg

Variety	Features of hydration	Years of research	Heavy metals							
			Pb		Cd		Zn		Cu	
			MPC	Actual	MPC	Actual	MPC	Actual	MPC	Actual
Helios	Precipitation	2021	0.5	0.46	0.1	0.09	50	24.11	10	5.72
		2022	0.5	0.47	0.1	0.08	50	27.96	10	5.56
	Precipitation and artificial irrigation	2021	0.5	0.40	0.1	0.06	50	21.32	10	5.04
		2022	0.5	0.47	0.1	0.05	50	26.26	10	4.65
Caesar	Precipitation	2021	0.5	0.54	0.1	0.08	50	26.74	10	5.79
		2022	0.5	0.50	0.1	0.07	50	25.80	10	5.50
	Precipitation and artificial irrigation	2021	0.5	0.49	0.1	0.04	50	23.17	10	5.08
		2022	0.5	0.41	0.1	0.05	50	21.33	10	4.87

4.2%, 60%, 6.4%, and 19.5% lower, respectively, under high moisture compared to low moisture.

In the spring barley grains of the Caesar variety under high soil moisture, compared to low moisture in 2021, the concentration of Pb, Cd, Zn, and Cu was higher by 10.2%, 77%, 6.2%, and 14.0%, while in in 2022 – by 13.6%, 40%, 20.96% and 12.9%.

Also, when characterizing the accumulation of heavy metals in spring barley grain depending on the variety, it is necessary to note the differences found between them. In particular, spring barley of the Helios variety under normal soil moisture (precipitation) had a higher concentration of Cu and Cd by 19.4% and 12.5% in 2021 and 1.0% and 12.5% in 2022 compared to the Caesar variety. The concentration of Pb and Zn in the Helios barley grain under normal soil moisture in 2021 was lower by 33% and 9.8%. In 2022, the concentration of Pb in barley grains of the Helios variety was lower by 2%, and Zn, on the contrary, was higher by 7.7% compared to the Caesar variety.

In the spring barley grain of the Helios variety under high soil moisture (rainfall + irrigation), the concentration of Pb, Cd, Zn, and Cu was lower than the barley grain of the Caesar variety in 2021 by 18.3%, 15.3%, and 0.8%, and Cd, on the contrary, is higher by 33.3%.

In 2022, the concentration of Pb and Zn in the spring barley grain of the Helios variety under additional high soil moisture was higher by 6.8% and 23.3%, and Cu was lower by 4.5%. However, this difference did not cause excesses of MPC of these elements in the grain, and no clear patterns were found in the accumulation of heavy metals in the grain of spring cereals depending on the variety under artificial soil moistening.

According to the results of the research, it was also established that the coefficient of accumulation of Pb, Cd, Zn and Cu was lower at high soil moisture compared to low soil moisture (Table 3).

Thus, with high soil moisture in 2021, the coefficient of accumulation of Pb, Cd, Zn, and Cu in the Helios barley grains was lower by 14.7%, 34.4%, 11.7%, and 11.5%, respectively, compared to low moisture. In 2022, the hazard ratio of Pb, Cd, Zn, and Cu in the Helios barley grain under high moisture was 2.6%, 35.7%, 5.9%, and 18.4% lower, respectively, compared to low moisture.

Table 3. Coefficient of accumulation of heavy metals in spring barley grain, mg/kg

Variety	Features of hydration	Years of research	Heavy metals			
			Pb	Cd	Zn	Cu
Helios	Precipitation	2021	0.34	0.29	34.0	19.0
		2022	0.38	0.28	43.6	16.8
	Precipitation and artificial irrigation	2021	0.29	0.19	30.0	16.8
		2022	0.37	0.18	41.0	13.7
Caesar	Precipitation	2021	0.40	0.26	37.6	19.1
		2022	0.39	0.25	40.3	16.6
	Precipitation and artificial irrigation	2021	0.36	0.15	32.6	16.9
		2022	0.34	0.18	33.3	14.7

The coefficient of accumulation of Pb, Cd, Zn and Cu in barley grains of the Caesar variety in 2021 and 2022 with high soil moisture was lower by 10% and 12.8%, 42.3% and 28.0%, 13.3% and 17.3%, 11.5% and 11.4% compared to low hydration.

It should also be noted that the coefficient of accumulation of heavy metals in spring barley grains also varied depending on the variety. Thus, in the grains of spring barley of the Helios variety, grown in 2021 at a low level of soil moisture, the accumulation coefficient of Pb was lower by 15.0%, Zn by 9.5%, Cu by 0.3%, and Cd, on the contrary, higher by 15% compared to similar products of barley of the Caesar variety. In the grains of spring barley of the Helios variety, grown in 2022 under low soil moisture, the accumulation coefficient of Pb was lower by 2.5%, and Cd, Zn, and Cu were higher by 12%, 8.1%, and 1.2%, respectively, compared to the Caesar variety. At a high level of soil moisture, the coefficient of accumulation of Pb, Zn, and Cu in the spring barley grain of the Helios variety in 2021 was lower by 19.4%, 7.9%, and 0.6%, respectively, and Cd was higher by 26.6% compared to the Caesar variety. In 2022, the Helios spring barley grain at a high level of soil moisture had a Pb and Zn accumulation coefficient higher than the Caesar spring barley grain by 8.8% and 23.1, respectively, and Cu, on the contrary, was lower by 6.8%. The coefficient of accumulation of Cd in the grain of spring barley of the Helios and Caesar varieties was at the same level.

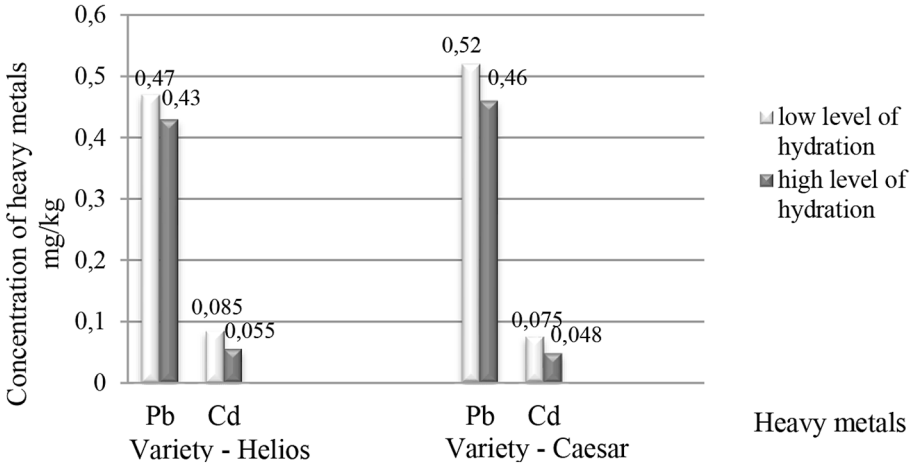

Figure 2. Average concentration of Pb and Cd in spring barley grain during the research period (2021–2022), mg/kg

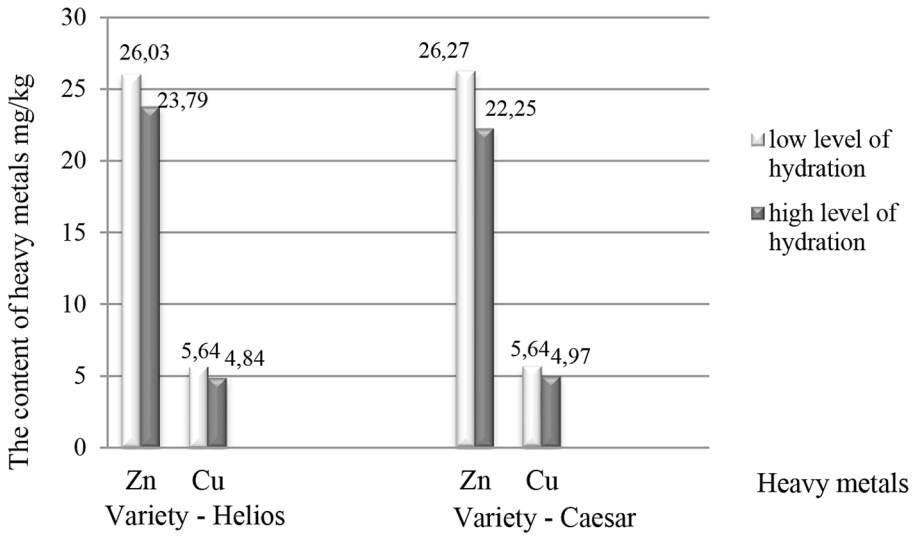

Figure 3. Average concentration of Zn and Cu in spring barley grain during the research period (2021–2022), mg/kg

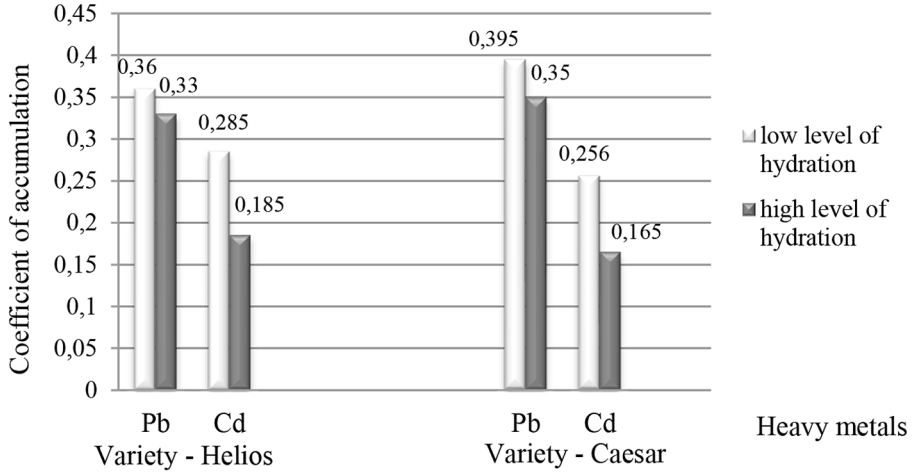

Figure 4. Average accumulation rate of Pb and Cd in spring barley grain during the research period (2021–2022), mg/kg

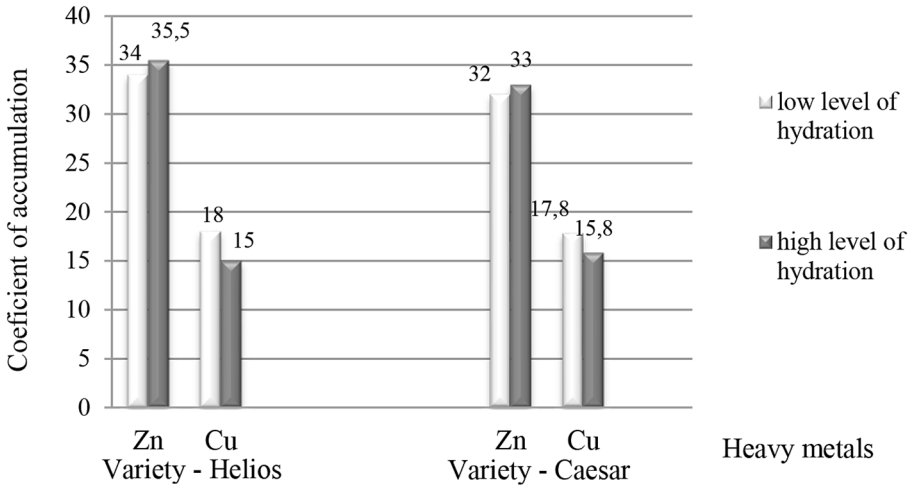

Figure 5. The coefficient of accumulation of Zn and Cu in spring barley grains on average during the research period (2021–2022), mg/kg

On average, over two years of research, with high soil moisture, the total rate of which was 266 mm together with precipitation during the month of June, a lower concentration of Pb, Cd, Zn, and Cu was found in the spring barley grains of the Helios and Caesar varieties compared to low precipitation levels, the amount of which during this period it averaged 49.8 mm (Fig. 2, Fig. 3).

The coefficient of accumulation of Pb, Cd, Zn, and Cu in spring barley grain (Fig. 4, Fig. 5) at a high level of moisture on average in 2021 and 2022 was lower, respectively, in the Helios variety by 8.3%, 35.0%, and 16.6% compared to the variant with low humidity.

In spring barley grains of the Caesar variety, the accumulation coefficient under artificial moisture was lower for Pb by 11.3%, Zn by

Table 4. Yield of spring barley depending on the level of moisture (2021–2022), t/ha

Variety	Soil moisture level, mm		Yield, t/ha		
	2021	2022	2021	2022	On average over the years of the study
Helios	52.3	47.4	3.1	3.0	3.05
	256.2	272.5	2.6	2.4	2.5
Caesar	52.3	47.4	3.7	3.4	3.55
	256.2	272.5	3.2	2.9	3.05

15.3%, and Cu by 11.2% compared to the option of low soil moisture.

During the research, the influence of soil moisture on the yield of spring barley Helios and Caesar was also revealed (Table 4).

In particular, with an average rainfall of 264 mm (2021–2022) in the germination→earing period, the yield of spring barley of the Helios and Caesar varieties was lower by 18.0% and 14.1%, respectively, compared to the average rainfall of 49.8 mm for this period

That is, at a high level of wetting of gray forest soils (precipitation, irrigation), a decrease in the accumulation of Pb, Cd, Zn, and Cu in spring barley grains was observed, regardless of the variety.

CONCLUSIONS

According to the research results, a lower coefficient of accumulation of Pb, Cd, Zn and Cu in spring barley grains was established at a high level of soil moisture in the period of germination → earing compared to a low level of moisture. In the grain of the Helios variety, the coefficient of accumulation of Pb, Cd, and Cu was lower for the high level of moisture in the two years of the study by an average of 8.3%, 35%, and 16.6% compared to the option of low soil moisture. In the spring barley grains of the Caesar variety, the accumulation coefficient at a high level of soil moisture decreased for Pb by 11.3%, Zn – by 15.1%, Cd – by 35.5%, and Cu – by 11.2% compared to the option of low soil moistening. The decrease in the coefficient of accumulation of heavy metals contributed to a certain decrease in the concentration of these elements in the spring barley grains of the Helios and Caesar varieties. Along with this, at a high level of soil moisture, there was a decrease in the yield of spring barley of the Helios variety by 18.0%, and of the Caesar variety by 14.1%, compared to a low level of soil moisture in the growing season of germination → earing.

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