

## INFLUENCE OF CLIMATE AND ANTHROPOGENIC FACTORS ON THE HEAVY METALS CONTENT IN SPRING BARLEY GRAIN GROWN IN THE EASTERN PART OF NORTHERN STEPPE OF UKRAINE

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**Topicality.** *In the conditions of ever-increasing technogenic pressure on the environment, the study of the influence of In the context of the growing anthropogenic load on the environment, studying the influence of abiotic factors on the translocation of heavy metals in the soil-plant system is of great practical importance for the agricultural sector. In the south-eastern industrial region, the environmental safety of crop production largely depends on the heavy metal accumulation in plants and their translocation depends on both soil properties and climatic factors. Purpose.* To investigate the effect of agroclimatic conditions in the eastern part of the Northern Steppe of Ukraine on the content of heavy metal mobile forms in soil and their translocation into spring barley grain. **Materials and methods.** Research was conducted in the field crop rotation of the Donetsk State Agricultural Research Station of NAAS on the Stepovyk variety in 2018–2022 with using field, laboratory, mathematical and statistical methods. **Results.** The highest increase in the acid-soluble zinc content was observed under increasing soil moisture. Under dry conditions in 2020, the acid-soluble zinc content was 45.3 mg/kg, while under excessive moisture conditions in 2022 it increased by 8.5 mg/kg or 18.8 %. The content of all studied heavy metals in spring barley grain did not exceed the maximum permissible concentration (MPC) with increasing soil moisture. The content of the studied heavy metals in spring barley grain under increasing soil moisture did not exceed the maximum permissible concentration (MPC). With increasing moisture availability, there was a tendency to increased copper content (by 8.2–9.9 %). The zinc accumulation in spring barley grain increased from 24.2 mg/kg to 28.9 mg/kg, or by 19.4% in the excessively wet year of 2022 compared to the dry year of 2020. The cadmium content increased by 0.02 mg/kg and reached of 40 %. **Conclusions.** Hydrometeorological conditions affect the content of heavy metals mobile forms in the soil and their translocation into spring barley grain, which necessitates the implementation of methods to reduce the environmental risks of heavy metal contamination of plant products under conditions of excessive wetting and real anthropogenic load.

**Key words:** *spring barley, agroclimatic conditions, soil, grain, content of heavy metals*

**Introduction.** In recent decades, the issue of food security has become increasingly relevant. Alongside the expansion of agricultural production, the quality of food and food ingredients has become an acute issue. In the EU countries, there are a large number of existing quality regulations and standards, general and legal acts aimed at ensuring the quality and safety of food products. The method for obtaining high-quality agricultural pro-

ducts is being widely implemented, the principles of which are based on the transition from quality control of the final product to predicting possible negative impacts and avoiding them at the stage of its production [1].

Achieving compliance of grain with modern quality and safety standards requires research into the mechanism of product formation in technogenic regions, determining the degree of risk due to environmental pollution.

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Analysis of literature and patent sources shows that the production of high-quality and safe agricultural products and raw materials requires considering the ecological state of the agricultural sector and the implementation of modern environmentally friendly agricultural technologies [2, 3].

Previous studies have shown that the environmental safety of crop production in the south-eastern industrial region largely depends on pollutant accumulation in plants, among which the most common are heavy metals. Heavy metals (HM) can contaminate soil, change its agrochemical, microbiological, and ecological properties, migrate and contaminate surface and ground water, and plants [4]. As is well known, the forms of heavy metals in soil and their translocation depend on many factors, such as chemical properties, complexation ability, concentration in soil solution, pH, absorption capacity, humus content, particle size distribution [5–7].

Heavy metals can inhibit the plant growth and development, suppress important metabolic processes, which further reduces the productivity and quality of agricultural products [8, 9].

The formation of grain quality indicators of cereal crops is largely influenced by the genotype of the variety, agrotechnical practices and meteorological conditions during grain filling [10–13].

Quality and safety standards for crop production are to some extent determined by the heavy metal content in agricultural products [14, 15].

The crucial meteorological parameters include ambient temperature and amount of precipitation, which determine the moisture content in the soil. Changes in temperature and moisture conditions have a significant impact on the state of humus, the microbiological activity of the soil, which determines acidity, redox potential and other characteristics. Soil temperature and moisture content are also factors influencing the mobility of heavy metals, which is especially important in the context of climate change. The study of the influence of climatic factors on the bioavailability of toxic elements to plants, especially in technologically stressed regions, is gaining relevance. Therefore, in the context of the growing anthropogenic pressure on the environment, the study of the influence of abiotic factors on the translocation of heavy metals in

the soil – plant system plays a major practical role in the agricultural sector.

The research aims to investigate the influence of agroclimatic conditions on the content of mobile forms of heavy metals in soil and their translocation into spring barley grain in the eastern part of the Northern Steppe of Ukraine.

**Materials and Methods.** Donetsk region has a temperate continental climate with hot, dry summers and relatively cold winters with unstable snow cover. Winters are cool and summers are hot. The average temperature in January is  $-4...-6$  °C, in July is  $+23...+24$  °C. Annual precipitation is 375–556 mm.

In Donetsk region, the average annual temperature has risen by  $0.8$  °C over the past 15 years. The distribution of temperatures throughout the year shows that the winter period has become much warmer, with average monthly temperatures rising by  $1-2.5$  °C. In recent years, the negative impact of dry weather conditions has been increasing in the region. In recent years, temperatures in the region have raised by  $+2.5...+3.0$  °C compared to long-term data [16].

Analysis of hydrometeorological conditions in recent years (data from the Donetsk Regional Centre for Meteorology) showed that during the spring barley growing season, air temperature often exceeds the long-term average by  $0.5-3.1$  °C (Table 1). A temperature drop of up to  $1.9$  °C from the long-term average is very rare. The amount of precipitation was generally lower than the long-term average by  $11.0-54.9$  mm.

Among these years, the driest were 2018, with the hydrothermal coefficient ranging from  $0.2-0.7$ , and 2020, especially April and June, with a HTC of  $0.15-0.20$ , which characterises drought of varying levels. At the same time, 2019 was the most favourable year in spring, but the severe June drought did not allow for good grain filling.

The year 2021 was contrasting in terms of soil moisture availability, with the average HTC being  $1.74$ , meaning that the growing conditions for plants were excessively humid, especially in June. At the same time, the HTC varied in a fairly wide range from  $0.7$  to  $2.8$ .

The year 2022 was unstable in terms of temperature and moisture supply. April and May were characterised by excessive precipitation, but the temperature regime was below the

**Table 1. Meteorological conditions of the spring-summer growing season**

Year	Month	Air temperature, °C		Precipitations, mm		HTC	Moistening conditions *
		average	± to long-term data	average	± to long-term data		
2018	April	12.3	+2.8	26.0	-17.2	0.7	medium drought
	May	18.7	+3.1	8.7	-33.1	0.2	very severe drought
	June	21.8	+2.4	40.2	-26.5	0.6	average drought
2019	April	10.9	+1.4	54.2	-11.0	2.1	excessively humid
	May	18.2	+2.6	41.7	-0.1	0.6	average drought
	June	22.5	+3.1	25.0	-41.7	0.4	severe drought
2020	April	8.2	+0.5	5.8	-37.4	0.15	very severe drought
	May	13.7	-1.9	95.0	+53.2	2.2	excessively humid
	June	22.5	+3.1	11.8	-54.9	0.2	very severe drought
2021	April	9.3	-0.2	32.0	-4.6	1.72	excessively humid
	May	16.4	+0.8	34.3	-7.5	0.7	mild drought
	June	20.2	+0.8	168.9	+102.2	2.8	excessively humid
2022	April	8.4	-1.1	65.2	+22.0	4.0	excessively humid
	May	14.9	-0.7	66.7	+24.9	1.4	sufficiently humid
	June	21.8	+2.4	10.5	-56.2	0.2	very severe drought

\* Gradation of conditions by Chirkov [17].

long-term average, which affected the growing season. In early June, an intensive increase in average daily temperature was observed that led to severe drought and reduced the HTC to 0.2.

The research was conducted in the field crop rotation of the Donetsk State Agricultural Science Station of NAAS in 2018–2022. The soil is heavy loamy ordinary chernozem. The humus content is 4.9 %, the pH is weakly alkaline, close to neutral, the content of total nitrogen is 0.22, and phosphorus is 0.14 %.

The sown area of the plot is 88.2 m<sup>2</sup>, the registration area is 62.7 m<sup>2</sup>, the threefold repetition, and the plots have a systematic arrangement.

The farms of the region use commonly accepted tillage and spring barley (*Hordeum vulgare*) cultivation technology of Stepovyk variety, which includes pre-sowing introduction of mineral fertilisers at a dose of N<sub>30</sub>P<sub>30</sub>K<sub>30</sub>, seed treatment with Vitavax 200 FF, spraying of crops with a tank mixture of Granstar herbicide, Falcon fungicide and Connect insecticide in the tillering stage.

Before harvesting, soil and plant samples were selected for analytical measurements of heavy metal content.

Sampling of soil was carried out from the topsoil (0–20 cm) in accordance with DSTU 4287:2004. Preparation of the soil for analysis was carried out according to standard methods. The content of acid-soluble and mo-

bile forms of copper (Cu), zinc (Zn), lead (Pb) and cadmium (Cd) was studied in the soil. For the extraction of mobile forms of HM, an acetate-ammonium buffer solution (CH<sub>3</sub>COOH<sub>4</sub>) with pH 4.8 according to DSTU 4770.1-9: 2007 was used. For the extraction of acid-soluble forms, a 1 N HCl solution was used. The content of cadmium, lead, copper and zinc in plant samples was determined according to DSTU EN 14082:2019. The content of chemical elements in soil samples and barley grain was determined with the analytical method of atomic absorption spectrophotometry using the KAS-120.1 in the electrothermal atomisation mode. All measurements were performed in threefold repetition. The grain quality was assessed by the heavy metal content using generally accepted MPCs. The maximum permissible concentration (MPC) of lead in barley grain is 0.5 mg/kg, cadmium – 0.1, zinc – 50.0 and copper – 10.0 mg/kg. Statistical processing of the results was carried out according to the method of B. A. Dospekhov [18].

**Results.** The results of determining the content of different forms of heavy metals in the soil in years with different levels of moisture supply are shown in Table 2.

Soil moisture affects the nature and extent of changes in the content of various forms of metals depending on the chemical properties of the element. For zinc, the largest increase in the content of the acid-soluble form was ob-

**Table 2. Content of different forms of heavy metals in the arable layer of soil**

Year	Average content of element compounds, mg/kg								Soil moisture content, mm
	Acid-soluble				Mobile				
	Cu	Zn	Pb	Cd	Cu	Zn	Pb	Cd	
2018	6.9	45.9	6.77	0.47	0.69	3.20	1.79	0.19	14
2019	6.8	47.5	6.93	0.51	0.64	3.57	1.87	0.21	14
2020	7.0	45.3	6.88	0.46	0.65	3.19	1.81	0.19	6
2021	6.0	53.6	7.09	0.54	0.79	3.70	2.0	0.24	38
2022	7.3	53.8	7.12	0.54	0.80	3.75	2.1	0.24	8
LSD <sub>05 mg/kg</sub>	1.5	5.0	0.4	0.09	0.07	0.31	0.11	0.02	

served at increased soil moisture content. In dry conditions (2020), the content of acid-soluble zinc was 45.3 mg/kg, while in 2022, despite the drought in June, it increased by 8.5 mg/kg or 18.8 %.

The content of mobile forms of all elements under the study grew with increasing soil moisture. However, this increase varied by degree. In the driest year of 2020, the content of mobile cadmium increased by 0.05 mg/kg compared to the wet year of 2022. The content of mobile forms, which are most accessible to plants, increased for zinc, lead and copper by 0.56 mg/kg, 0.29 mg/kg and 0.15 mg/kg, re-

spectively. The largest increase was observed for cadmium.

The content of toxic elements in spring barley (*Hordéum vulgáre*) grain harvested in the most contrasting years in terms of meteorological indicators was compared to study the influence of agroclimatic conditions on the biogenic accumulation of heavy metals in plants. For comparison, the years 2018 and 2020 (drought) and 2022 (excessive moistening) were chosen. April and May 2020 were characterised by a very severe drought, with the lowest soil moisture content (6 mm) at the end of June (Table 3).

The increased moisture availability led to

**Table 3. Heavy metal content in spring barley grain**

Year, moistening conditions	Elements content, mg/kg			
	Cu (MPC=10.0)	Zn (MPC=50.0)	Pb (MPC=0.5)	Cd (MPC=0.1)
2018, drought	4.55	24.5	0.29	0.05
2020, drought	4.62	24.2	0.24	0.05
2022, excessively humid	5.00	28.9	0.33	0.07
LSD <sub>05 mg/kg</sub>	0.50	3.7	0.07	0.01

an increase in copper content (by 8.2–9.9 %). In the excessively wet year of 2022, the zinc accumulation in spring barley grain increased from 24.2 mg/kg to 28.9 mg/kg, or by 19.4 % compared to the dry year of 2020. Under these conditions, the lead content increased by 0.09 mg/kg (37.5 %). The content of cadmium (element of the first hazard class) also increased by 0.02 mg/kg (40 %). Although all the studied heavy metals in spring barley grain with increasing moisture content were less than the maximum permissible concentration (MPC), it should be noted that an increase in moisture availability leads to an increased environmental risk of contamination of spring barley grain with heavy metals.

Growth in heavy metal contamination of plant products is associated not only with an

increase in the content of mobile forms of elements in the soil, but also with the risk of foliar contamination of plants with heavy metals, as thermal power plant emissions contain a large amount of acidic sulphur and nitrogen oxides. In particular, emissions of Kurakhivska TPP, in the affected area of which the experimental plots were located, annually release 84038.3 tonnes of SO<sub>2</sub> and 96247 tonnes of NO<sub>2</sub> [16]. Excessive precipitation produces corresponding acids, which leads to an increased content of soluble compounds of heavy metals in the soil and atmospheric aerosols. Soluble heavy metals are transported through atmospheric aerosols to the leaves and through cuticles into the plants.

Thus, changes in hydrometeorological conditions affect the content of mobile forms of heavy metals in the soil and their translocation

into spring barley grain. Therefore, environmental risks of heavy metal contamination of plant products need to be reduced under conditions of real anthropogenic load.

**Conclusions.** It was found that changes in hydrometeorological conditions affect the content of mobile forms of heavy metals in the soil and their accumulation in spring barley grain.

The influence of soil moisture on the nature and degree of changes in the content of mobile metals depends on the chemical properties of the element. For zinc, the greatest increase in the content of the acid-soluble form was observed with increasing soil moisture content, namely by 8.5 mg/kg or 18.8 %.

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**Бондарева О. Б., Вінюков О. О., Коноваленко Л. І., Чугрій Г. А. Вплив кліматичних і антропогенних чинників на вміст важких металів у зерні ячменю ярого в умовах східної частини Північного Степу України.** *Зернові культури*. 2023. 7(2). 272–277.

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**Актуальність.** В умовах всезростаючого техногенного пресингу на навколишнє середовище велике практичне значення для АПК має вивчення впливу абіотичних факторів на транслокацію важких металів в системі ґрунт – рослина. В південно-східному промисловому регіоні екологічна безпека рослинницької продукції значною мірою залежить від нагромадження в рослинах важких металів, транслокація яких значною мірою залежить як від властивостей ґрунту, так і кліматичних чинників. **Мета.** Дослідити вплив агрокліматичних умов на вміст рухомих форм важких металів у ґрунті та їх транслокацію в зерно ячменю ярого в умовах східної частини Північного Степу України.

**Матеріали і методи.** Дослідження були проведені у 2018–2022 рр. у польовій сівозміні Донецької ДСДС НААН на сорті ячменю ярого Степовик. Методи дослідження: польовий, лабораторний, математично-статистичний. **Результати.** Для цинку відмічене найбільше зростання вмісту кислоторозчинної форми при збільшенні вологості ґрунту. В посушливих умовах (2020 р.) вміст кислоторозчинного цинку склав 45,3 мг/кг, в умовах надмірного зволоження 2022 р. він зріс на 8,5 мг/кг, або на 18,8 %. Вміст усіх досліджених важких металів в зерні ячменю ярого при зростанні вологості ґрунту не перевищував гранично допустиму концентрацію (ГДК). При збільшенні вологозабезпеченості спостерігалась тенденція щодо збільшення вмісту міді (на 8,2–9,9 %). Накопичення цинку в зерні ячменю ярого збільшилось з 24,2 мг/кг до 28,9 мг/кг або на 19,4 % в надмірно вологий 2022 р. проти показника в посушливий 2020 р. Вміст свинцю за цих умов зріс на 0,09 мг/кг або 37,5 %. Вміст кадмію зріс на 0,02 мг/кг, що становить 40 %. **Висновки.** Зміни гідрометеорологічних умов впливають на вміст рухомих форм важких металів у ґрунті і на їх транслокацію в зерно ячменю ярого. Це викликає необхідність в умовах надмірного зволоження та реального техногенного навантаження застосовувати заходи щодо зменшення екологічних ризиків забруднення рослинної продукції важкими металами.

**Ключові слова:** ячмінь ярий, агрокліматичні умови, ґрунт, зерно, вміст важких металів