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ENVIRONMENTAL RISKS IN IRRIGATED AGRICULTURE

Maryna ZAKHAROVA, Sviatoslav BALIUK, Lyudmila VOROTYNTSEVA

National Scientific Center "Institute for Soil Science and Agrochemistry Research named after O.N. Sokolovsky", 4 Chaikovska Street, Kharkiv, Ukraine

Corresponding author email: zakharova_maryna@ukr.net

Abstract

The influence of heavy metals content in irrigation waters and irrigated soils on the quality of plant products was studied. In samples of irrigation water, irrigated soil and vegetables (tomato), the content of Cu, Zn, Co, Ni, Pb, Cd, Fe, Mn was determined. The studies were carried out in regions with different levels of technogenic loading.
At a minimum technogenic loading, the heavy metals content in water and soil was estimated as background. The heavy metal contamination wasn't found in the water-soil-plant system. With local pollution, the Pb content in water and soil exceeds the background by 3-5 times, in vegetables it exceeds the Maximum allowable concentrations (MAC). With regional pollution (industrial zone, Donbas), the content of Cd, Co, Pb in water and soil exceeds the background by 3-12 times, the content of Cd, Pb exceeds the MAC in vegetables. At significant technogenic loading irrigation intensifies the hazard of pollutants to accumulate in vegetables and poses serious risks to public health and the environment. The control of heavy metals content in the water-soil-plant system is necessary for ecologically safe agriculture.

Key words*: heavy metals; irrigation; irrigation water; soils; vegetables.*

INTRODUCTION

Land resources of Ukraine are the most valuable national wealth. This is due to the prevalence of fertile chernozem soils in the country's soil cover. However, long-term ecologically unbalanced farming, imperfect management of protection and reproduction of land resources in Ukraine have led to significant degradation of the soil cover (Stashuk et al., 2009; Baliuk et al., 2015). Soil degradation, including soil pollution, has become threatening in the country.

At the same time, sustainable agriculture has an important role to play in achieving many of the 2030 Sustainable Development Goals (SDG) (Transforming our World, 2015). Climate change will put additional pressure on agricultural production systems as they strive to meet the food needs of a growing population (FAO, 2020). Climate change has already caused a seriously disrupting rainfall patterns, increasing the frequency of droughts and emergencies. Agriculture will face the effects of climate change much earlier than society as a whole. The consequence of global warming will most likely be an increase in the area of irrigated land. Under these conditions, irrigated agriculture has an important role to play on the path to sustainability.

However, in large areas of all continents, there is a high degree of degradation of ecosystems. More and more food security depends on soil and water quality. Meeting SDG 2, 3, 6, 13, 15 targets will only be possible if people have enough food to eat and if what they are eating is nutritious and affordable (FAO, IFAD, UNICEF, WFP and WHO, 2020).

Heavy metals (HM) are among the most aggressive harmful substances that enter agricultural landscapes from anthropogenic sources and can negatively affect the quality of plant products and human health. Currently, heavy metals of technogenic origin in significant quantities enter all components of agricultural landscapes (Kabata-Pendias, 2015; Semenov, 2019; Eugenio, 2020; Baliuk et al., 2017; Bambara et al., 2015; Lu et al., 2016; Malakar et al., 2019). It is HMs that has recently been considered indicators of anthropogenic pressure on soils and landscapes (Kabata-Pendias, 2015). In irrigated agriculture, the problem of HM accumulation is exacerbated, since irrigation waters act as an additional source of metals entering the soil and a factor in increasing their migration. Irrigated water with a high HM content contributes to the accumulation of these elements in soils and plants to dangerous concentrations, which can harm ecosystems and people.

At the same time, researchers are increasingly using the term “potentially toxic elements” in relation to HMs, since they are essential components of the chemical composition of soil, water and plants, and their toxicity manifests itself when the permissible concentrations are exceeded (Kabata-Pendias, 2015; Nematollahi, 2020; Raj, 2020). There are many elements among HM, the physiological role of which has been proven (Vazhenin, 1976; Kabata-Pendias, 2015; Baliuk et al., 2015). In trace amounts, they are vital for plants, animals and humans.

The concentration of these elements in soil, water, plants can be below optimal, which can cause "hidden hunger". Unfortunately, micronutrient malnutrition is currently widespread in both industrialized and developing countries of the world (Guidelines, 2006; Gödecke et al., 2018). Therefore, it is necessary to study the content of HMs from the point of view of their deficiency and the need to use them in the form of micronutrient fertilizers.

The content of HMs is characterized by significant spatio-temporal variation under the influence of global, regional and local pollution, which makes it necessary to constantly monitor their content in irrigation water, irrigated soils and agricultural plants.

Yield increases on irrigated agricultural land should be accompanied by monitoring of pollutants and soil, water and crop quality (Dragović et al., 2008; Baliuk et al., 2017; Bambara et al., 2015; Lu et al., 2016; Malakar et al., 2019).

Irrigated lands are located in all natural zones (Table 1) of Ukraine.

Table 1. Distribution of irrigated lands in Ukraine by natural areas (Stashuk et al., 2009)

Zone, subzone	Irrigated land (%) of total area of irrigation
Polissya	1.0
Forest Steppe	13.6
Step Northern	31.2
Step Southern	30.4
Steppe Dry	23.0
Carpathian mountain region	0.5
Mountain region of Crimea	0.3

In Forest-steppe and Steppe zones of Ukraine are disposed 98% irrigated lands. In Ukraine, irrigation covers various types of soils, but the main areas of irrigation are chernozems - more than 60% of the total area. Irrigated soils of Ukraine are located in regions with different levels of technogenic load. Therefore, it is necessary to study the content of HMs in irrigated soils, irrigation waters and plant products with regional, local pollution and without significant anthropogenic load. This will assess environmental risks in irrigated agriculture and determine if they can be used in an environmentally friendly manner.

The aim of the study was to determine the influence of the content of heavy metals (Cu, Zn, Co, Ni, Pb, Cd, Fe, Mn) in irrigation waters and irrigated soils on the quality of plant products in regions with different levels of technogenic load. Research objectives:

1) heavy metals content in irrigation water and water quality;
2) mobile forms of heavy metals content in irrigated soils and soil quality;
3) heavy metals content in vegetables (tomato) and tomatoes quality.

MATERIALS AND METHODS

Soil samples were selected on an irregular grid with GPS referencing, taking account of soil and lithological heterogeneity. Soil samples were taken on experimental sections from the boreholes. They were collected from the 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm depth. More than 20 samples from test tomato were collected immediately prior to harvest. Irrigation water samples were tested several times during the growing season. Mobile heavy metals in soils were determined by extraction with ammonium acetate solution at pH 4.8 for one hour using a 1:5 soil: extractant ratio. The heavy metal content of crops was determined by ashing at 550°C for 5 hours and dissolving the ash in 10 per cent HCl. Water samples were analyzed after drying and dissolving the precipitate in M HCl. In all cases, metals were determined by atomic absorption spectroscopy. Statistical processing of the results was performed using Statistica 10 and MapInfo 11.0.

Site 1 - Merefa stationar (Kharkiv district of Kharkiv region) is located in the southern part of the Left-Bank Forest-Steppe of Ukraine with a minimum technogenic loading. The studies were conducted in long-term stationary field experience with irrigation of Institute of Vegetable and Melons Growing NAAS. Soil is chernozem typical (Chernozems Chernic, WRB). Vegetables were grown on the site. Irrigation was carried out with using "suitable" waters Mzha River (national classification of the irrigation water quality). Duration of irrigation is 50 years. Mineralization of irrigation water during irrigation was 0.6-0.8 g/l. Irrigation norms in experiment were (depending on the crops grown and weather condition): 350-1350 m^3/ha. Groundwater depth was more than 11 m.

Site 2 - Kharkiv stationar (Kharkiv district of Kharkiv region) is located in the southern part of the Left-Bank Forest-Steppe of Ukraine, near a large industrial city, under local pollution. The studied sites are production areas with vegetable crop rotation. Soil is chernozem typical (Chernozems Chernic, WRB). Water is "limited suitable" for irrigation (due to the risk of HM soil pollution). The source of irrigation was a pond. Duration of irrigation is 20 years. Mineralization of irrigation water during irrigation was 1.1-1.2 g/l. Irrigation norms were (depending on the crops grown and weather condition): 450-1500 m^3/ha. Groundwater depth was more than 5 m.

Site 3 - Maryinka stationar (Maryinsky district of Donetsk region) is located within the northern part of the Left-Bank Steppe of Ukraine under regional pollution (industrial zone, Donbas).

The studied sites are production areas with vegetable crop rotation. Soil is ordinary chernozem (Chernozems Chernic, WRB). Water is unsuitable or limited suitable for irrigation due to the risk of HM soil pollution. The source of irrigation was the Kurakhovskoe water storages. Duration of irrigation is 50 years. Mineralization of irrigation water during irrigation was 2.9-3.1 g/l. The irrigation rate ranged 1500-3000 m^3/ha. Groundwater depth was more than 10 m.

Irrigation was carried out by sprinkling machines at all study sites.

RESULTS AND DISCUSSIONS

The quality of irrigation water is one of the main factors that determine the direction of soil processes and regimes, physical, physicochemical, biological properties of irrigated soil and its ecological and agromeliorative state. Irrigation water quality affects the quality of plants, both directly through the leaf surface, and indirectly through the soil. Therefore we characterize the quality of irrigation water first of all (Table 2).

Table 2. Content of heavy metals in irrigation water, mg/dm^3
(average ± standard deviation)

Site		Content of heavy metals in irrigation water, mg/dm^3							
		Zn	Cd	Ni	Co	Fe	Mn	Pb	Cu
Merefa stationar		0.016 ±0.004	0.002 ±0.0003	0.012 ±0.001	0.008 ±0.0003	0.053 ±0.007	0.011 ±0.003	0.016 ±0.003	0.004 ±0.001
Kharkiv stationar		0.025 ±0.005	0.003 ±0.001	0.025 ±0.008	0.025 ±0.008	0.098 ±0.049	0.038 ±0.012	0.062 ±0.011	0.009 ±0.003
Maryinka stationar		0.007 ±0.005	0.009 ±0.002	0.058 ±0.010	0.055 ±0.011	0.015 ±0.009	0.059 ±0.017	0.065 ±0.013	0.004 ±0.002
Assessment of water quality by									
Background Forest-steppe of Ukraine [1]		0.016	0.002	0.014	0.010	0.072	0.017	0.024	0.013
Background Steppe of Ukraine [1]		0.013	0.005	0.023	0.023	0.065	0.022	0.032	0.008
National classification of the irrigation water quality	Class 1 - Suitable	< 0.5	< 0.005	< 0.08	< 0.02	< 2.0	< 0.50	< 0.02	< 0.08
	Class 2 - Limited suitability	0.5-1.0	0.005-0,01	0.08-0.2	0.02-0.05	2.00-5.00	0.50-1.00	0,02-0.05	0.08-0.2
	Class 3 – Unsuitable	> 1.0	> 0.01	> 0.2	> 0.05	> 5.0	> 1.00	> 0.05	> 0.2

[1] Authors data

The irrigation water used at Merefa stationar is of high quality. The HM content in it does not exceed the background for the forest-steppe. Irrigation water is of good quality according to the National classification of the irrigation water quality, it is suitable for irrigation.
The irrigation water used at Kharkiv stationar is of poor quality due to the high content of Co and Pb. The content of Co in the irrigation water is 1.7-3.5 times higher than the background. Water is limited suitable for irrigation due to the content of this element. The Pb content in the irrigation water exceeds the background 2.1-3.0 times. The water is unsuitable for irrigation due to the content of this element, according to the national classification.
The irrigation water used in Maryinka stationar is of poor quality due to the high content of Cd, Co and Pb.
The content of Cd in the irrigation water exceeds the background by 1.4-2.0 times. Water is limited suitable for irrigation due to the content of this element. Co content in irrigation water exceeds the background by 1.9-2.9 times. The Pb content in the irrigation water exceeds the background 1.6-2.4 times. The water is unsuitable for irrigation in terms of Co and Pb content, according to the national classification.
The assessment of the HM content in the arable soil horizon (0-30 cm) was carried out (Table 3).

Table 3. Contents of heavy metals in the 0-30 cm layer of irrigated soils of Ukraine, mg/kg

Site		Contents of heavy metals in irrigated soils, mg/kg							
		Zn	Cd	Ni	Co	Fe	Mn	Pb	Cu
Merefa stationar	average	1.00	0.07	0.70	0.40	1.90	12.40	0.50	0.20
	min./ max.	0.75/ 1.20	0.05/ 0.10	0.30/ 1.20	0.20/ 0.70	1.00/ 2.50	10.0/ 16.0	0.20/ 1.10	0.10/ 0.60
Kharkiv stationar	average	2.13	0.14	1.15	0.32	2.61	6.19	2.25	0.90
	min./ max.	0.90/ 3.75	0.025/ 0.272	0.50/ 2.75	0.10/ 0.45	1.25/ 4.75	4.50/ 10.10	1.40/ 2.75	0.33/ 2.05
Maryinka stationar	average	0.71	0,95	1.35	2.70	6.35	9.30	6.25	0.95
	min./ max.	0.54/ 1.35	0.49/ 1.15	0.63/ 3.15	0.95/ 3.45	3.65/ 9.45	7.15/ 13.40	4.40/ 8.10	0.48/ 2.20
Background		1.00	0.10	1.00	0,50	2.00	43.00	0.50	0.50
Maximum allowable concentrations (MAC)		23.0	-	4.0	5,0	-	500	6.0	6.0
Level of plants microelements nutrition	lower	<5.0	-	-	<0.3	-	<20.0	-	<0.5
	normal	5.0-10.0	-	-	0.3- 0.7	-	20.0- 40.0	-	0.5- 1.0

The content of mobile HM forms in the 0-30 cm layer of Merefa stationar soils has been studied for 20 years. The average values of the content of mobile forms of most HMs in the studied soils (Zn, Cd, Ni, Co, Fe, Pb) are slightly lower or at the level of the background soils of Ukraine. The average value of the content of mobile Mn in Merefa stationar soils is 3.5 times lower than the background, and Cu - 2.5 times, which may be associated with their lower initial content.
In Merefa stationar soils, the concentration of HM mobile forms is significantly lower than the established MAC and the issue of the supply of plants with the necessary microelements becomes more acute. The studied soils were characterized by a low supply of plants with Zn and Mn mobile forms. Even the maximum content of these elements in soils is significantly lower than the optimum by 4.2 and 1.3 times, respectively. The average Cu content is also insufficient for plants. Plants are provided with Co at an average level. The concentrations of trace elements in the studied soils indicate their deficiency and the need for additional application in the form of micronutrient fertilizers. Thus, despite the fact that chernozems are considered to be soils of optimal chemical composition, they may contain insufficient amounts of mobile forms of microelements necessary for plants.
The content of HM mobile forms in the 0-30 cm layer of the Kharkiv stationar soils has been studied for 10 years. The excess of the maximum values of HM content over the minimum is 2.0-10.9 times. The average values

of mobile forms content (Zn, Cd, Ni, Fe, Pb, Cu) in the studied soils exceed the background content in the soils of Ukraine by 1.1-4.5 times. The average value of mobile Mn content in Kharkiv stationar soils is 6.9 times lower than the background value, and Co - 1.6 times.

In Kharkiv stationar soils, the concentration of HM mobile forms is lower than the established MAC, however, the rather high content of Pb in the soil is alarming (it exceeds the background by 2.8-5.5 times). The question of the provision of plants with necessary microelements remains an acute issue. The studied soils of Kharkiv stationar were characterized by a low supply of plants with Zn and Mn mobile forms. The maximum content of these elements in soils is 3.7 and 1.5 times lower than the optimum, respectively. The Zn and Mn concentrations in the studied soils indicate the need for their additional application in the form of micronutrient fertilizers. The average Cu and Co content is at a level sufficient for plants.

The content of mobile HM forms in the 0-30 cm layer of Maryinka stationar soils was studied for 12 years. The average values of the content of mobile Co, Ni, Fe, Cu forms in the studied soils exceed the background content in soils of Ukraine by 1.4-3.2 times, Cd and Pb content - by 9.5-12.5 times. The average value of mobile Mn content in soils of Maryinka stationar is 4.6 times lower than the background value, and 1.4 times for Zn.

In Maryinka stationar soils, the concentration of most HMs is below the established MAC, the Pb content exceeds the MAC and causes concern about the high content of Cd in the soil (MAC for this element has not been established). The concentration of these elements in soils creates a threat to obtain low-quality plant products.

The question of the provision of plants with necessary microelements remains. The studied soils of Maryinka stationar were characterized by a low supply of plants with Zn and Mn mobile forms. The maximum content of these elements in soils is 1.3 and 2.0 times lower than the optimum, respectively; additional introduction of these elements in the form of micronutrient fertilizers is necessary. The average Cu content is at a level sufficient for plants. The Co content significantly exceeds the optimal content of this element in soils.

The HM content in plants reflects the environmental conditions in which the plants were grown, an excess of HM MPC in the soil or in irrigation water can cause an increase in the HM content to the Maximum allowable concentrations in vegetables (Table 4).

Table 4. Content of heavy metals in tomatoes (raw vegetables), mg/kg

Site		Content of heavy metals, mg/kg							
		Zn	Cd	Ni	Co	Fe	Mn	Pb	Cu
Merefa stationar	average	1.75	0.015	0.06	0.11	2.3	0.19	0.27	0.14
	min./ max.	1.08/ 2.40	0.009/ 0.020	0.05/ 0.10	0.09/ 0.15	1.2/ 4.1	0.11/ 0.34	0.25/ 0.29	0.09/ 0.22
Kharkiv stationar	average	1.72	0.022	0.15	0.22	2.3	0.32	0.53	0.63
	min./ max.	1.62/ 1.77	0.025/ 0.030	0.10/ 0.18	0.20/ 0.30	1.8/ 4.5	0.18/ 0.42	0.24/ 0.65	0.34/ 0.86
Maryinka stationar	average	6.00	0.05	0.34	0.48	14.53	4.40	1.69	0.81
	min./ max.	4.53/ 7.20	0.03/ 0.06	0.16/ 0.54	0.28/ 0.72	8.37/ 16.19	2.86/ 5.71	0.95/ 2.13	0.41/ 1.05
Maximum allowable concentrations in vegetables (MAC in vegetables)		10.0	0.03	0.50	1.00	50.0	20.0	0.50	5.00

In Merefa stationar tomatoes, the TM content (even maximum values) does not exceed MAC in vegetables. Average Pb concentrations in Kharkiv stationar tomatoes were 1.1 times higher than MAC in vegetables. In some sampling periods, the maximum content of Pb and Cd in tomatoes was noted, which corresponded to MAC in vegetables (Cd) or exceeded them by 1.3 times (Pb). The average concentrations of Cd and Pb in Maryinka stationar tomatoes exceed MAC in vegetables by 1.6-3.4 times. The maximum values exceed MAC in vegetables by 2.0 and 4.3 times, respectively. The remaining elements content in tomatoes of Maryinka stationar significantly exceeds the levels of these elements in the tomatoes of other sites. This may be associated with a significant aerial intake of HM under conditions of significant technogenic load. Therefore, the conclusion about the need for additional application of micronutrient fertilizers does not seem to be relevant for this object.

We found that the objects of study differ significantly in the degree of anthropogenic impact on them:

- Merefa stationar is quite remote from large industrial centers, water suitable for irrigation is used, soils are not contaminated with HM. In these conditions, environmentally friendly, suitable for consumption tomatoes are grown;
- Kharkiv stationar is located in conditions of intense influence of local pollution, irrigation is carried out with waters that are not suitable for irrigation in terms of Pb content, in soils the Pb content exceeds the background by 2.8-5.5 times. Under these conditions, vegetable products do not meet the sanitary and hygienic requirements for the Pb content - the content exceeds MAC in vegetables. Marked individual cases of Cd contamination of tomatoes;
- Maryinka stationar is located in conditions of intense technogenic pollution, irrigation is carried out with waters that are not suitable for irrigation in terms of Co and Pb content, in soils the Pb content exceeds MAC, the Cd content exceeds the background by 5.0-11.5 times. Under these conditions, vegetable products do not meet the sanitary and hygienic requirements for the content of Pb and Cd - the content exceeds MAC in vegetables.

One of the directions of detoxification of contaminated soils and a decrease in the intake of toxicants into plants is the introduction of ameliorants-adsorbents of organic and mineral nature into the soil, which bind metals into sedentary forms. The most promising and economically profitable is the use of local raw materials (industrial waste containing iron and calcium). A phyto-reclamation approach is also used to remove toxic compounds from soils.

CONCLUSIONS

As a result of the work, an assessment of environmental risks in irrigated agriculture in Ukraine under various technogenic loads was carried out on the example of the system "irrigation water-soil-plant".

In Merefa stationar, the content of Cu, Zn, Co, Ni, Pb, Cd, Fe, Mn in irrigation water is at the background level, it is not contaminated with these elements and is suitable for irrigation according to ecological criteria of National classification of the irrigation water quality. The mobile forms of HM content in the plow horizon of the irrigated soil are also at background level, significantly lower than the MAC. The concentrations of Zn, Cu and Mn in the studied soils indicate the need for additional application in the form of micronutrient fertilizers. Tomatoes that are grown under these conditions are good for consumption.

In Kharkiv stationar, the content of Cu, Zn, Ni, Cd, Fe, Mn in irrigation water is at the background level, it is not contaminated with these elements. The Co content in the irrigation water exceeds the background one by 1.7-3.5 times, the Pb content - by 2.1-3.0 times. The water is unsuitable for irrigation due to its Pb content due to ecological criteria. The mobile forms of Zn, Cd, Ni, Fe, Pb, Cu content in the arable horizon exceeds the background content by 1.1-4.5 times. The Mn and Co content in soils is lower than the background content. High maximum concentrations of Pb content in soil are dangerous; they exceed background concentrations by 5.5 times. Concentrations of Zn and Mn in soils indicate the need for additional micronutrient fertilization. Tomatoes grown under these conditions are unsuitable for consumption: the average Pb concentrations in tomatoes were 1.1 times higher than MAC in vegetables, and the maximum - 1.3 times.

In Maryinka stationar, the content of Zn, Fe and Cu in irrigation water is at the background level, it is not contaminated with these elements. The content of most elements in the irrigation water is much higher than the background. The water is unsuitable for irrigation due to the Co and Pb content; high concentrations of Cd are also dangerous. The content in the plow horizon of Co, Ni, Fe, Cu mobile forms exceeds the background content by 1.4-3.2 times, the Cd and Pb content by 9.5-12.5 times. The Mn and Co content in soils is lower than the background content. High maximum concentrations of Pb in soil are dangerous; they exceed background concentrations by 5.5 times. Concentrations of Zn and Mn in soils are lower than background,

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however, there is no need for additional application due to the significant aerial intake of these elements. Tomatoes grown under these conditions are not suitable for consumption: the average concentrations of Cd and Pb in tomatoes were 1.6-3.4 times higher than MAC in vegetables, and the maximum - 2.0-4.3 times.

The use of such products poses a threat to human health, therefore, crops resistant to the accumulation of toxicants should be grown on contaminated soils and vegetable crops should be excluded from the crop rotation, which belong to crops with a high ability to accumulate metals.

It has been established that HMs, which to the greatest extent pollute irrigation water and irrigated soils, can accumulate in agricultural products in quantities exceeding MAC in vegetables, which indicates the need for constant monitoring of the levels of HM in the interrelated links: irrigation water - irrigated soil - plants. It is necessary to take measures to reduce the intake of HMs in plants under local and regional pollution. It is necessary to develop an ecologically safe system of irrigated agriculture, including economically feasible measures to improve the quality of irrigation water, the use of soil-protective crop rotations, the introduction of highly profitable agricultural technologies, chemical soil reclamation and the reconstruction of reclamation systems.

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