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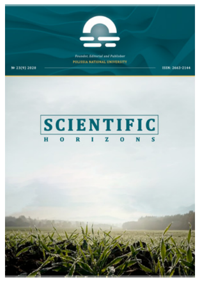

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Ecological safety of sunflower seeds in the conditions of agricultural intensification

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Abstract. Sunflower cultivation using intensive technologies, which manifests itself in the disruption of crop rotation, high rates of mineral fertilisers and pesticides, leads to an increased risk of products contaminated with heavy metals, nitrates, and pesticide residues. The purpose of this study was to identify the risks of toxic substances accumulation in the soil and sunflower seeds. In this study, the atomic absorption spectrophotometric method was used to determine the content of toxic substances in soil and sunflower seeds. The content of alkaline-hydrolysed nitrogen, mobile phosphorus, exchangeable potassium, the reaction of the soil solution pH, as

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well as the content of mobile forms of heavy metals: lead, cadmium, copper, zinc, mercury, cobalt, and molybdenum; boron, and radioactive caesium were determined in the soil after sunflower cultivation. The factual content of soil contaminants was compared with their maximum permissible concentrations. The study investigated the content of heavy metals, namely, lead, cadmium, copper, and zinc, as well as nitrates in sunflower seeds. Their content was compared with the values of maximum permissible concentrations. The coefficients of accumulation of the heavy metals under study by sunflower seeds were calculated. Thus, copper and zinc are most intensively absorbed from the soil and accumulate in sunflower seeds, while lead is the least absorbed. The findings suggest that since no excess of the permissible levels of heavy metals and nitrates in sunflower seeds was found, there is a higher probability of their increased accumulation in sunflower by-products: seed husks, stems, leaves, petioles, and roots. The study results can be used in organic sunflower cultivation

Keywords: heavy metals; nitrates; accumulation; cultivation; soil fertility

INTRODUCTION

The widespread use of sunflower oil in the food industry and its by-products, such as meal and fuselage, in animal feeding requires constant monitoring of the quality and environmental safety of the raw material, sunflower seeds. The absence of mandatory control over the environmental safety of sunflower seeds in Ukraine raises the risk of growing seeds with excessive use of mineral fertilisers and pesticides. And this, according to A. Zimaroieva *et al*. (2021), can cause the accumulation of heavy metals, pesticides, nitrates, and radionuclides in sunflower seeds, which can accumulate in vegetable fats and adversely affect human health and contaminate livestock products.

O. Andriienko *et al*. (2020) proved that the considerable demand for oilseeds in the world substantially affects the dynamics of their acreage. Among all oilseeds, sunflower is the most significant, with its oilseeds having favourable nutritional characteristics. The high selling price of sunflower seeds and their unpretentiousness to growing conditions are driving the growth of sunflower acreage. The economic attractiveness of sunflower cultivation leads to an oversaturation of crop rotations with this crop. V. Mazur *et al*. (2021) and S. Razanov *et al*. (2020) argue that, while it is scientifically sound to return sunflower crops to their previous location after 7 years, they are, in fact, grown in the same place much more often. This leads to a range of agro-ecological issues caused by the impaired resilience of such an agro-ecosystem to the effects of pests, diseases, weeds, and soil overdrying and nutrient depletion. Under such management conditions, the yield of this profitable crop is declining.

I. Didur *et al*. (2020) and A. Melnyk (2018) show that in case of violation of the terms of sunflower return to the previous place in the crop rotation and its cultivation after unfavourable predecessors, the soil is depleted of the main nutrients: alkaline hydrolysed nitrogen, mobile phosphorus, and exchangeable potassium. It also accelerates the acidification of the soil solution, destruction of the soil structure, and increases water erosion. M. Sadak *et al*. (2023) and I. Tkalich *et al*. (2018) note that under such conditions, the sustainability of the sunflower agroecosystem is also affected. Its crops are becoming increasingly infested with annual late weeds: white quinoa, common ragweed, and especially the quarantine specialised species – sunflower broomrape. Fungal diseases of sunflower, such as white and grey rot, phomopsis, etc., cause irreparable damage, which can lead to a 70% loss of yield.

According to S. Aloud *et al*. (2022) and I. Savchuk *et al*. (2021), maintaining and increasing sunflower seed production under such conditions is possible with the improvement of cultivation techniques, the main of which are increasing rates of mineral fertilisers and increasing the frequency of pesticide application, primarily for the control of weeds, diseases, and pests. Studies by L. Romanchuk *et al*. (2019), D. Knoell andT. Wyatt (2021) have shown that with increasing rates of mineral fertilisation, the fertility and agro-ecological condition of the soil changes, which can affect the quality and environmental safety of the grown seeds. The risk of accumulation of heavy metals, especially lead, cadmium, copper, zinc, and mercury, nitrates and radionuclides in the soil and sunflower seeds is growing.

According to M. Ahmed *et al*. (2021), J. Han *et al*. (2022), the scientifically sound rates of mineral fertiliser application for sunflower crops are $N_{60}P_{60}K_{60}$. However, if the period for returning its crops to the previous place of cultivation is shortened, the factual fertiliser rates can increase by 1.5-2 times. Under such conditions, the volume of low-grade mineral fertilisers produced using imperfect technologies is growing, which increases the risk of toxicity from their use. This, according to B. Shafiq *et al*. (2021), this leads to a deterioration in seed quality and environmental safety. Nitrates, heavy metals (lead, cadmium, zinc, copper, mercury, cobalt), and pesticide residues can be the main environmental factors of seed contamination. Conventionally, sunflower is a crop that can accumulate cadmium in high concentrations, and therefore the issue of quality control and environmental safety of sunflower seeds in intensive farming is becoming increasingly significant.

Therefore, the purpose of this study was to identify the content of toxic substances in the soil at factual soil fertility levels and to trace the accumulation of toxicants in sunflower seeds and determine their hazard in terms of maximum permissible concentrations.

MATERIALS AND METHODS

Field experiments were conducted in 2021-2022 at the Zorya Vasylivka Farm in the village of Vasylivka, Vinnytsia district, Vinnytsia region (Ukraine). The farm grew sunflowers using intensive technology on grey, podzolised medium loamy soils. The predecessor of sunflower was maize. Fertilization of sunflower crops included the introduction of complex ammonium nitrate phosphate fertiliser under pre-sowing cultivation by spreading in the norm of $N_{90}P_{90}K_{90}$. Mechanical care of the crops included two inter-row mechanical cultivation, which was carried out by a row cultivator KRN-5.6 in combination with a tractor MTZ-82 in the phase of the first pair of true leaves and in the phase of the third pair of true leaves of sunflower. Chemical crop care included the application of the herbicide Oreol-Maxi (active ingredient quizalofop-P-ethyl, 125 g/l) at a rate of 0.8 l/ha with a working solution consumption of 200 l/ha by a tractor sprayer in the phase of two to three leaves of annual cereals and at a height of 10-15 cm of perennial cereal weeds. The study also used the fungicide Amistar Gold 250 SC (active ingredient azoxystrobin, difenoconazole) at a rate of 1.0 l/ha with a working fluid consumption of 200 l/ha against diseases such as *Alternaria*, *Phomopsis*, *Puccinia helianthi*, *Septoria*, *Sclerotinia*, and *Phoma oleracea* during the sunflower budding phase by tractor spraying. Desiccation was performed to stimulate plant drying in the pre-harvest period in the second decade of September. The Roundup Max desiccant (active ingredient potassium salt of glyphosate) was used at a rate of 2.4 l/ha in the waxy ripeness phase of seeds with a tractor sprayer using a working fluid of 200 l/ha. Sunflower was threshed by direct combining at the stage of full seed maturity with a John Deere combine.

Therefore, the first step in the study was to determine the parameters of contamination of soil and sunflower seeds, the main type of agricultural product, with toxic substances. This helped to establish the probability of toxicants accumulating in sunflower seeds used for food or technical purposes. The second step of this study was to determine the level of accumulation of toxicants in sunflower by-products: seed husks, stems, leaves, petioles, capitulum pulp, and other parts of the plant. Soil samples were taken before harvesting at ten points along the diagonal of the field to the depth of the topsoil (25 cm). Laboratory soil analysis was conducted in a certified and accredited laboratory of the Zhytomyr branch of the State Institution "DerzhHruntOkhorona" of the Institute of Soil Protection of Ukraine, using standard methods (DSTU ISO 10381-1:2004, 2006). The following soil fertility indicators were determined: humus content, alkaline-hydrolysed nitrogen, mobile phosphorus, exchangeable potassium, and soil solution pH. The content of toxic substances in the soil was also investigated: mobile forms of heavy metals: lead, cadmium, copper, zinc, mercury, iron, cobalt, molybdenum, as well as boron and radioactive caesium according to atomic absorption spectrophotometric method (DSTU ISO 10381-1:2004, 2006). The determined indicators of soil toxicants were compared with their maximum permissible concentrations (MPC).

Sunflower seeds were sampled from one batch using a grain probe. The seeds were analysed for heavy metals: lead, cadmium, copper, and zinc, as well as nitrates. Laboratory studies of sunflower seeds were conducted at the Zhytomyr branch of the State Institution "DerzhHruntOkhorona" (n.d.) of the Institute of Soil Protection of Ukraine according to the atomic absorption spectrophotometric method (DSTU 4117:2007, 2007). The obtained values were compared with the standards of maximum permissible concentrations of these toxicants in sunflower seeds. The coefficient of accumulation of heavy metals by sunflower seeds was calculated as the ratio of their determined content in seeds to the content of mobile forms of these substances in the soil. Experimental studies of plants (both cultivated and wild), including the collection of plant material, were following the institutional, national, or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

With the intensification of farming, sunflower, as one of the most profitable crops, is growing in terms of mineral fertiliser application rates, which can primarily affect the agrochemical composition of the soil. Thus, the humus content in the experimental plot during sunflower cultivation was 1.70±0.03 (%), which corresponds to a "low" value on a six-point scale. With the intensification of farming and an emphasis on fertilising the soil with mineral fertilisers, there will be a further decline in humus content, and thus a reduction in macronutrients readily available to plants in the soil (Table 1).

Table 1. *Agrochemical composition of soil under sunflower cultivation, M±m*

Agrochemical parameters	Value	Content
Humus, %	1.70±0.03	Low content
Alkaline hydrolysed nitrogen, mg/kg	107.3±2.4	Low content
Mobile phosphorus, mg/kg	100.0±1.8	Average content

Table 1. Continued

Agrochemical parameters	Value	Content
Exchangeable potassium, mg/kg	158.0±2.5	High pH of
the soil solution, units	5.37±0.1	Subacidic reaction

***Source**: compiled by the authors*

The supply of alkaline hydrolysed nitrogen to the soil was low and amounted to (107.3±2.4) mg/kg. Alkaline hydrolysed nitrogen in the soil is an indicator of potentially available nitrogen for plants. This form of nitrogen does not factor in nitrate nitrogen, which is extremely mobile in the soil and changes very frequently, especially when applying nitrogen-containing fertilisers, after heavy rainfall or during intensive plant growth. The content of alkaline hydrolysed nitrogen in the soil is stabilised in autumn or early spring before fertilisation, especially with nitrogen-containing fertilisers. Low humus content in the soil will result in a decrease in the content of alkaline hydrolysed nitrogen, and therefore in intensive farming, the reserves of this form of nitrogen in the soil are replenished by applying high rates of nitrogen mineral fertilisers, which briefly contributes to increase the content of alkaline hydrolysed nitrogen in the soil, and then decrease when plants use its reserves for their growth and development. However, together with the mineral nitrogen from fertilisers, soils become excessively acidic, which reduces the effectiveness of all types of mineral fertilisers and increases the mobility of toxic substances that can be present in the soil and accumulate in crop products. It is nitrogen fertilisers that have the most substantial impact on sunflower seed yields, which is why these fertilisers are a priority for growing the crop.

The availability of mobile phosphorus in the soil of the experimental plot was average with its content of (100.0±1.8) mg/kg. The rapid transition of phosphorus minerals that entered the soil with mineral fertilisers to unavailable compounds, as well as the limited absorption of mineral phosphorus by plant roots, leads to the accumulation of phosphorus compounds in soils, an increase in their content, soil overphosphating, and a decrease in the effectiveness of phosphate fertilisers. Since intensive farming uses recommended rates of mineral phosphorus and does not consider its factual content in the soil, this can lead not only to overphosphating the soil, but also to the accumulation of increased concentrations of heavy metals, which phosphate mineral fertilisers are rich in.

The content of exchangeable potassium in the soil was (158.0±2.5) mg/kg, which corresponded to a high content. This form of potassium is readily available to plants. Compared to nitrogen and phosphorus, sunflower crops consume potassium the most, but this element does not have a decisive impact on the yield of sunflower seeds, and therefore moderate rates of mineral potassium are applied to sunflower crops. It is the sufficient content of exchangeable potassium and mobile phosphorus in the soil that decelerates the movement of toxic substances in the soil, such as heavy metals and radionuclides. The reaction of the soil solution pH of the area where sunflower was grown corresponded to a subacidic value with (5.37±0.1) pH. This indicator is formed depending on the nature of the soil type and is also substantially affected by the application of nitrogen fertilisers, which are predominantly acidic. Soil acidity increases especially with the intensification of farming. Acidic soils increase the vertical migration of toxicants in soils and their transfer to plants.

The large and powerful above-ground mass of sunflower plants can substantially dry out the soil and deplete it of nutrients. Toxic substances such as heavy metals, radionuclides, etc., are absorbed from the soil along with the main macroelements. Among the heavy metals, the most dangerous toxicants are lead, cadmium, zinc, mercury, and copper. At the same time, this group includes iron, cobalt, and molybdenum. The main sources of heavy metals in the soil can be mineral fertilisers, especially in high application rates, which is typical for intensive farming, as well as emissions from industrial enterprises and vehicles.

The factual content of mobile forms of lead in the sunflower soil was (1.55±0.1) mg/kg. With a maximum permissible concentration of lead in the soil of 6.0 mg/kg, its content was 0.3 MPC and was safe. The content of mobile forms of cadmium was also below the maximum permissible concentration of 0.14 MPC. A comparable dependence was observed for other toxicants that occurred in the soil during sunflower cultivation, specifically, the content of copper was 0.25 MPC, zinc – 0.15 MPC, mercury – 0.002 MPC, cobalt – 0.2 MPC, molybdenum – 0.01 MPC, boron – 0.05 MPC, and radioactive caesium – 0.3 MPC, which can enter the soil from the earth's interior, as a result of the Chernobyl disaster, as well as with mineral fertilisers (Table 2).

***Table 2.** The content of mobile forms of toxicants in the soil during sunflower cultivation, M±m*

Toxicant	Factual content	Maximum permissible concentration	Content in relation to MPC
Lead, mg/kg	1.55±0.1	6.0	smaller
Cadmium, mg/kg	0.10±0.03	0.7	smaller
Copper, mg/kg	0.75±0.02	3.0	smaller
Zinc, mg/kg	3.35±0.4	23.0	smaller

Table 2. Continued

Toxicant	Factual content	Maximum permissible concentration	Content in relation to MPC
Mercury, mg/kg	0.005±0.001	2.1	smaller
Iron, mg/kg	57.20±2.0	–	–
Cobalt, mg/kg	1.00±0.1	5.0	smaller
Molybdenum, mg/kg	0.10±0.3	10	smaller
Boron, mg/kg	1.64±0.3	30	smaller
Caesium, Ci/km^2	0.30±0.04	1.0	smaller

Source: *compiled by the authors of this study based on personal findings*

If there are residues of toxicants in the soil during sunflower cultivation, the probability of their accumulation in the seeds increases.

The actual content of lead in sunflower seeds was below the maximum permissible concentration and amounted to 0.18 MPC, cadmium – 0.10 MPC, copper – 0.13 MPC, zinc – 0.12 MPC, nitrates – 0.11 MPC (Table 3).

The coefficients of toxicant accumulation in sunflower seeds were calculated. Specifically, the coefficient of accumulation of lead by sunflower seeds was 0.06, cadmium – 0.1, copper – 1.7, zinc – 1.8 (Fig. 1).

Table 3. *Toxicant content in sunflower seeds, M±m*

Toxicant	Factual content	Maximum permissible concentration	Content in relation to MPC
Lead, mg/kg	0.09±0.02	0.5	smaller
Cadmium, mg/kg	0.010±0.02	0.1	smaller
Copper, mg/kg	1.27±0.35	10.0	smaller
Zinc, mg/kg	6.12±1.10	50.0	smaller
Nitrates, mg/kg	32.5±2.60	300.0	smaller

Source: *compiled by the authors*

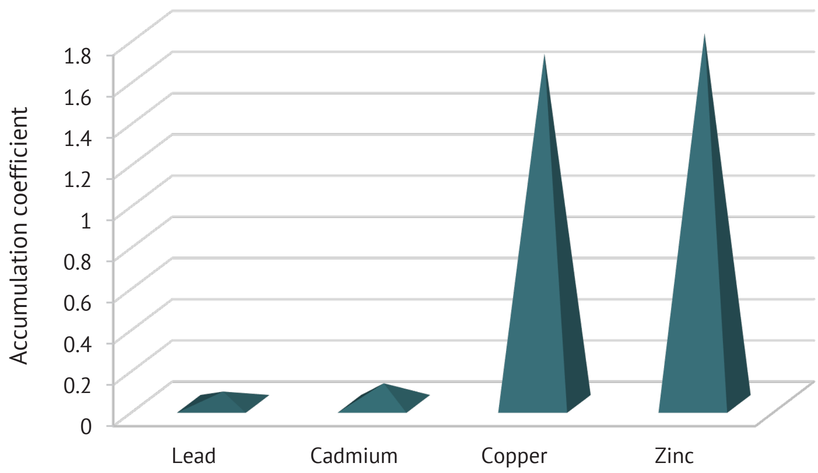

Figure 1. *Coefficient of heavy metal accumulation in sunflower seeds*

Source: *compiled by the authors*

S. Kalenska *et al.* (2020), G. Cecoli *et al.* (2022) agree that if crop rotation is observed during sunflower cultivation, the period of return to the previous place of cultivation and the recommended rates of mineral fertilisers are applied, the environmental safety of the sunflower seeds produced will be satisfactory. However, in case of violation of these indicators, the risk of accumulation of toxic substances in sunflower seeds will increase. Today, in Ukraine, under conditions of intensified farming, sunflower cultivation is characterised by a considerable disruption of crop rotations and a reduction in the time required to return to the previous place. According to V. Almashova and S. Skok (2022), the greatest danger is posed by heavy metals: lead, cadmium, copper, zinc, which can be contained in mineral fertilisers and are applied at increased rates, especially phosphorus-potassium fertilisers, the production process of which involves the use of raw materials and production components containing toxic heavy metals.

According to A. Melnyk *et al.* (2020), there are various methods for cleaning contaminated soils. One of the most promising and inexpensive of these methods is the use of phytoremediation, which is lower in cost, compatible with natural processes and requires fewer resources than other cleaning methods. Sunflower can be an effective phytoremediation for toxic contamination, as it is known for its intensive absorption of both nutrients and toxic substances from the soil. According to O. Bielashov *et al.* (2022), the use of phytoremediation properties of sunflower should be balanced, since the absorption of pollutants by sunflower plants, their accumulation and entry into the food chain can cause various human diseases.

Y. Domaratskyi (2021) found that with an increase in the concentration of toxic substances in the soil, their accumulation in sunflower plants increases, and the toxicity effect increases, which is manifested in a decrease in the efficiency of nutrient absorption from the soil. Laboratory experiments conducted by O. Degani *et al.* (2022) with sunflower plants grown on samples of soil contaminated with heavy metals and on toxicant-free soils showed that the concentration of heavy metals in sunflower plants grown on contaminated soils was several times higher. Yu. Cheng *et al.* (2023) found that the concentration of heavy metals in the roots and leaves of sunflower plants increased substantially. This dependence is confirmed by the present study, which did not reveal high concentrations of heavy metals in sunflower seeds. Therefore, it is probable that all toxicants accumulate in the leaf and stem mass of sunflower plants.

According to M. Hejna *et al.* (2019), a physiological feature of sunflower plants is the intensive accumulation of cadmium in their seeds in high concentrations. Cadmium replaces calcium in the soil, contributing to the acidification of the soil solution. Therefore, control over this element should be mandatory. However, the present study did not find its high content in sunflower seeds, which may be caused by the low content of mobile forms of cadmium in the soil. I. Tkalich *et al.* (2018) found that the intensive uptake of nutrients from the soil by the sunflower root system leads to a strong depletion of nutrients from the soil. Together with them, plants intensively absorb toxic elements contained in the soil. The findings of the present study confirm this thesis only partially, as it found intensive absorption of copper and zinc from the soil, and much less of lead and cadmium.

I. Didur *et al.* (2020) note that under such conditions, there is a risk of not only a substantial decrease in the content of nutrients and humus in the soil when growing sunflower, but also a low content of toxic substances, specifically heavy metals, which entered the soil with mineral fertilisers. This is the reason why laboratory analysis of the soil after sunflower cultivation often fails to detect elevated concentrations of heavy metals. This is confirmed by the present study, as it did not find any excess of mobile forms of heavy metals in the soil during sunflower cultivation.

As noted by H. Pinkovsky (2019), N. Novytska *et al.* (2020), all heavy metals that migrated from the soil accumulate in sunflower plants. According to this manifestation, sunflower plants, as those capable of absorbing and retaining toxic substances in increased concentrations through the formation of a powerful vegetative mass, are phytoremediants, i.e., plants that can cleanse the soil of excess toxic substances (heavy metals, pesticide residues, radionuclides), accumulating them in their tissues in increased concentrations. This is fully confirmed by the findings of the present study.

There were also differences in the uptake of nitrate by sunflower plants. According to D. Hilwa *et al.* (2019), with a sufficient content of nitrate nitrogen in the soil, it is intensively absorbed by sunflower plants and accumulates in their tissues, preventing the supply of other forms of nitrogen to sunflower plants. Research by O. Tymchyshyn *et al.* (2021) shows that these processes are also directly affected by the reaction of the soil solution pH. According to M. Ghaffari *et al.* (2021), nitrate nitrogen plays a much greater role in the growth and development of sunflower plants than ammonium nitrogen. However, this factor contributes to the accumulation of nitrates in the tissues of sunflower plants. According to E. Shahini *et al.* (2022), A. Sher *et al.* (2022), nitrate accumulates most in the petioles of sunflower leaves compared to other parts of the leaves.

Thus, research has shown a low level of soil fertility after sunflower cultivation. This is explained by the strong depletion of nutrients from the soil by this crop. At the same time, current studies have not revealed any excess of mobile forms of heavy metals in the soil. They were also not found in significant amounts in sunflower seeds. This may indicate that this culture has remedial properties.

CONCLUSIONS

Therefore, the study established that for growing sunflowers using intensive technology, which involved the application of complex ammonium nitrate phosphate fertiliser in the norm of $N_{90}P_{90}K_{90}$ and triple application of pesticides (herbicide, fungicide, and desiccant) during the growing season on grey podzolized medium loamy soils with low content of humus (1.7%) and alkaline hydrolysed nitrogen (107.3 mg/kg), medium content of mobile phosphorus (100.0 mg/kg) and high content of exchangeable potassium (158.0 mg/kg), as well as subacidic reaction of the soil solution (5.37 pH) at the end of its growing season, the content of the main toxic substances in the soil was much lower than their maximum permissible concentrations (MPC): lead – 0.3 MPC, cadmium – 0.1 MPC, copper – 0.3 MPC, zinc – 0.1 MPC, mercury – 0.002 MPC, cobalt – 0.2 MPC, molybdenum – 0.01 MPC, boron – 0.05 MPC, caesium – 0.3 MPC.

In addition, no exceedance of the maximum permissible concentrations of heavy metals (lead – 0.2 MPC, cadmium – 0.1 MPC, copper – 0.1 MPC, and zinc – 0.1 MPC) and nitrates (0.1 MPC) was detected in sunflower seeds. The calculated coefficient of accumulation of heavy metals by sunflower seeds showed that a significant level of transfer of toxicants from soil to seeds was observed for copper, which is 1.7 times higher than its content in the soil, and for zinc, which is 1.8 times higher than its content in the soil. At the same time, the level of transfer of lead and cadmium from the soil to sunflower seeds is much lower than their content in the soil and was 0.06 and 0.1 less than in the soil, respectively. According to the research objective, no accumulation of toxic substances (heavy metals, radionuclides, nitrates) in the soil and its seeds was observed on grey podzolised medium loamy soils with average fertility indicators during sunflower cultivation. This may indicate the powerful phytoremediation properties of sunflower plants with the simultaneous production of environmentally safe seeds in terms of heavy metals and nitrates. Proceeding from the data obtained, further research should be conducted to determine the concentrations of toxic substances in sunflower by-products: seed husks, stems, leaves, petioles, and roots.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Екологічна безпечність насіння соняшнику в умовах інтенсифікації землеробства

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Анотація. Вирощування соняшнику за інтенсивних технологій, що проявляється у порушенні чергування культури у сівозміні, внесенні високих норм мінеральних добрив і пестицидів, призводить до зростання ризику одержання продукції забрудненої важкими металами, нітратами, залишками пестицидів. Метою роботи було визначити ризики накопичення токсичних речовин у ґрунті та насінні соняшнику. В роботі використовували атомно-адсорбційний спектрофотометричний метод для визначення вмісту токсичних речовин у ґрунті та насінні соняшнику. Визначено у ґрунті після вирощування соняшнику вміст азоту лужногідролізованого, фосфору рухомого, калію обмінного, реакцію ґрунтового розчину pH, а також вміст рухомих форм важких металів: свинцю, кадмію, міді, цинку, ртуті, кобальту та молібдену; бору, а також радіоактивного цезію. Фактичний вміст забрудників ґрунту був порівняний із їх гранично-допустимими концентраціями. Досліджено вміст важких металів: свинцю, кадмію, міді та цинку, а також нітратів у насінні соняшнику. Проведено порівняння їх вмісту із значеннями гранично-допустимих концентрацій. Розраховано коефіцієнти накопичення досліджуваних важких металів насінням соняшнику. Таким чином з ґрунту найбільш інтенсивно поглинаються і акумулюються у насінні соняшнику мідь та цинк, а найменше – свинець. Проведені дослідження дозволили зробити висновок, що оскільки не виявлено перевищення допустимих рівнів вмісту важких металів і нітратів насінні соняшнику, то зростає ймовірність їх підвищеного накопичення у побічній продукції соняшнику: лушпинні насіння, стеблах, листках, черешках та коренях. Результати досліджень можна використовувати при органічному вирощуванні соняшнику

Ключові слова: важкі метали; нітрати; накопичення; вирощування; родючість ґрунту

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