Assessment of crop production quality in case of technogenic soil contamination

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Abstract. The article considers the degree of arsenic, cadmium and lead contamination in soils of the municipal settlement the city of Svirsk, Irkutsk region. The responses of various types of agricultural plants to contamination by arsenic, cadmium and lead and their accumulation in green mass and fruits is presented. All cultivated plants accumulate arsenic, cadmium and lead, their content exceeds the maximum available concentration (MPC) and cannot be used for food production, as well as for feeding farm animals. The highest content of arsenic, cadmium and lead was observed in vegetable crops: red beet (Beta vulgaris), cucumber (Cucumis sativus), onion (Allium cepa), pea (Pisum sativum), lettuce (Lactuca), garlic (Allium sativum), potato (Solanum tuberosum), tomato (Solanum lycopersicum), as well as in the green mass of feed crops: alfalfa (Medicago sativa), elytrigia (Elytrigia repens), Hungarian sainfoin (Onobrychis arenaria), highlander spread (Polygonum divaricatum), Turkish wartycabbage (Bunias orientalis). Indicator plants include red beet (Beta vulgaris), excluder plants - potato (Solanum tuberosum), accumulator plants - Turkish wartycabbage (Bunias orientalis). The authors propose that all used agricultural land be withdrawn from agriculture and preserved.

1. Introduction
Excess pollutants in the habitat leads to their increased accumulation by plant organisms, while the size and nature of absorption in different plant species has its own specifics:

- Indicators are plants that accumulate an element are directly proportional to its content in the environment.
- Accumulators are plants that accumulate an element even when its quantity is low in the soil.
- Excluders are plants that do not react with an increase in the content of an element in tissues even with its excess in the medium [1, 2].

Under conditions of increased pollutant content in the growing medium, plants developed various resistance strategies based on two opposite principles - accumulation with subsequent isolation of toxicants and so-called tolerance and avoidance, when the plant reduces the availability of metals in the root zone using various mechanisms [3].
In addition, two types of resistance are distinguished in plant organisms: the main resistance inherent in most plants and hyperactivity to certain substances [4].

Plants use two ways to adapt to high concentrations of excess ions in the environment:

- The restriction of their intake due to the presence of a protective mechanism, the nature of which is not yet clear.
- Inactivation of toxicants entering plants, their withdrawal to less affected compartments, as well as changes in metabolic pathways [5].

Plants that concentrate the element, even in conditions of its relative deficit in the soil, are called accumulators. Species that accumulate an element in direct proportion to its level in the environment are called indicators; it is recommended to use them for biomonitoring. Plants in which the level of an element remains at a low level for a long time even with an excess in the medium are called excluders [6].

Plant resistance to toxicants does not represent a single mechanism, but includes several metabolic processes: selective absorption of ions; low membrane permeability; immobilization of ions in roots, leaves, seeds; removal of ions from metabolic processes by depositing them in fixed or insoluble forms in various organs and organelles; removal of ions from plants during leaching through the leaves, sap flow, dropping leaves and excretion through the roots [7].

The mechanisms of various plant species resistance to an increased content of pollutants are not well understood. The resistance of plants to one element does not extend to another, that is, it is purely specific. Perhaps this resistance is a genetically fixed trait that can be used in various technologies for cleaning the environment using plants.

The formation of tolerance is taking place at a significant pace on a genetic basis.

Genetic analysis of populations of higher plants showed that the main resistance to certain metals (arsenic, copper, zinc) is most likely determined by one or two genes and the work of modifier genes that determine the level of tolerance. Resistance to a certain metal is usually controlled by a gene (or genes) other than the genes that determine resistance to another metal [4].

An important role in protecting plants from an excess of toxicants coming from the soil is played by the root system. By delaying excess ions, the roots thereby contribute to the preservation of favorable (or not harmful) concentrations of chemical elements in the aboveground organs [9].

Pollutants can be extracted by plant roots from deep soil layers and, as shown by radiographic studies with labeled atoms, accumulate in the entire thickness of stems, leaf veins and fruit periphery [10].

The level of toxicants accumulated in the reproductive organs of plants is much lower than in the vegetative ones and is determined by the biological characteristics of the cultivated crop. Thus, for example, in cabbage, the content of all heavy metals increases (about 3-5 times) in the direction from the external leaves of the head of cabbage to cabbage stalk [11].

In different plant species, protective mechanisms to prevent the entry of toxic elements are expressed to varying degrees. Such a mechanism is the selectivity of the permeability of plant cell membranes. With a high content of toxicants in the soil, such quantities enter the plants that the membranes are no longer able to retain. The consequence of this is a disruption to the functions of the enzyme, vitamin and hormone synthesis, to mitochondrial functions and chloroplast functions, disorders of water metabolism, photosynthesis, respiration, transpiration. Ultimately, the toxicity of pollutants occurs through an imbalance in the processes of cell division and replication of deoxyribonucleic acid (DNA) [12, 13].

The relationship between the content of an element in a plant and soil is characterized by a biological absorption coefficient, which is understood as the ratio of the content of an element in the ash of a plant to its content in the soil [14, 15].

To evaluate the intensity of the biological absorption of an element, it is necessary to compare the content of this element in the plant and source, from where this element comes from [16].

According to the degree and rate of absorption - phytoextraction, plants are divided into three groups, each of which can be used for practical purposes. Accordingly, plant excluders can be cultivated with conventional technologies on technologically contaminated soils; indicator plants - during biomonitoring, and accumulator plants - for soil phytoremediation. Plants with an increased rate of
absorption of toxicants from the environment are called hyperaccumulators. Currently, about 450 species of hyperaccumulator plants are known [17].

The levels of toxicant accumulation in plant tissues can be significantly higher than its content in the soil. However, the number of hyperaccumulator plants is limited; therefore, the search for plant species accumulating an excess of heavy metals attracts the attention of researchers.

Currently, two strategies have been developed for using plants to “extract” HM from soils. The first of these is the use of hyperaccumulator plants. These plants can absorb one or two metals; their accumulation in a small biomass correlates with very high concentrations of metal in the shoots. The second strategy is based on the use of highly productive plants, which are not specific, form a large above-ground biomass, but the amount of heavy metals in it is relatively low.

The ability of plants to clear heavy metals from soils is limited by many factors. Among them are the availability of metal in the soil for absorption by plant roots, the rate of absorption by roots, the transport of metal from the root to the shoot, and plant resistance.

2. Research program, facilities and methodology
The research program provided for the study of:
- The degree of soil contamination with arsenic, cadmium and lead.
- Responses of various types of agricultural plants to soil contamination with arsenic, cadmium, lead and their accumulation in green mass and fruits.

The experimental design included vegetable crops widely cultivated in the region, both in large agricultural enterprises, as well as in household and garden plots:
- Vegetables: cabbage (Brassica oleracea), red beet (Beta vulgaris), carrot (Daucus carota), tomato (Solanum lycopersicum), cucumber (Cucumis sativus), pea (Pisum sativum);
- Green vegetables: onion (Allium cepa), garlic (Allium sativa), lettuce (Acetaria), dill (Anethum graveolens), parsley (Petroselinum);
- Potato (Solanum tuberosum);
- Fruit crops: blackcurrant (Ribes nigrum), garden plum (Prunus domestica);
- Feed crops: arctic brome (Bromopsis inermis), elytrigia (Elytrigia repens), alfalfa (Medicago sativa), Hungarian sainfoin (Onobrychis arenaria), oat for green feed (Avena sativa);
- New plants introduced in the region: Turkish wartycabbage (Bunias orientalis), highlander spread (Polygonum divaricatum).

Field studies were conducted on land use of the Astra fruit and vegetable cooperative, located in the city of Svirsk, Irkutsk Oblast. The soil of the experimental plot is chernozem.

The selection of soil samples was carried out at the end of the growing season of cultivated plants (August, early September) in a soil layer of 0-20 and 20-40 cm. The selection was conducted according to GOST 17.4.4.02-84. At the same time, plant samples and samples of cultivated plants were taken.

Air-dried soil samples were crushed, sieved through a 1 mm sieve, after which agrochemical and agroecological indicators were determined: pH of the salt extract using the potentiometric method - GOST 26483-85; mobile forms of phosphorus and potassium by Machigin method - GOST 20205 -91; humus by Tyurin method - GOST 26213-91; gross forms of heavy metals by atomic absorption method - RD 52.18-289-90.

In dried and ground plant samples, the content of pollutants was determined: lead, cadmium - by atomic absorption method - GOST 30178-96, arsenic - GOST 26930-86.

Analytical studies of soil and plant samples were carried out at the Agrochemical Service Centre of Irkutsk Federal State Budgetary Institution.

3. Research results
Information on the content of heavy metals in the surface layer of various soil types in different regions of the world indicates that the lead content in Russian soils ranges from 26 to 40 mg/kg, cadmium 0.07 mg/kg. The arsenic content in the soils of the United States and Canada ranges from 5.1 to 13.6 mg/kg. However, the content of HM in the soil rises sharply under conditions of technogenic pollution [7, 8].
Analytical data on the content of gross and mobile forms of HM and arsenic in the research areas are presented in table 1.

**Table 1.** The content of heavy metals and arsenic from the experimental site.

| Sampling location          | Soil type and soil use | Depth of sampling, cm | Gross forms, mg/kg | Mobile forms, mg/kg |
|----------------------------|------------------------|-----------------------|--------------------|--------------------|
|                            |                        |                       | As                 | Cd                 | Pb                 |
| Astra fruit and vegetable  | Chernozem, virgin      | 0-20                  | 432.0              | 0.55               | 169.7              |
| cooperative, Svirsk         |                        | 20-40                 | 172.0              | 0.37               | 20.62              |
| MPC                        |                        | 20-40                 | 136.0              | 0.40               | 35.8               |

The content of mobile forms of heavy metals is associated with the content of organic matter in the soil, the environment response, the biological cycle of elements in the soil-ground layer and the heterogeneity of the species composition of the vegetation cover.

The presented analytical data indicate that the surface layer of virgin soil of the Astra fruit and vegetable cooperative located in the city of Svirsk is contaminated with lead - 5.6 MPC and arsenic - 216 MPC. Cadmium pollution was at a level of 0.28 MPC.

**Table 2.** Assessment of pollutant content in the vegetative mass of experimental plants, mg/kg.

| Type of plant                | As    | Cd    | Pb    |
|------------------------------|-------|-------|-------|
| potato (Solanum tuberosum)   | 1.29  | 0.07  | 0.75  |
| red beet (Beta vulgaris)     | 4.13  | 0.14  | 3.06  |
| cabbage (Brassica oleracea)  | 0.83  | 0.10  | 0.13  |
| carrot (Daucus carota)       | 1.94  | 0.12  | 0.95  |
| cucumber (Cucumis sativus)   | 3.11  | 0.09  | 1.07  |
| tomato (Solanum lycopersicum) | 1.14  | 0.22  | 0.74  |
| onion (Allium cepa)          | 2.72  | 0.11  | 1.25  |
| garlic (Allium sativum)      | 1.37  | 0.09  | 0.25  |
| dill (Anethum graveolens)    | 0.54  | 0.14  | 1.00  |
| lettuce (Acetaria)           | 2.20  | 0.16  | 1.00  |
| pea (Pisum sativum)          | 2.79  | 0.12  | 1.75  |
| black currant (Ribes nigrum) | 0.27  | 0.09  | 0.75  |
| garden plum (Prunus domestica) | 0.65  | 0.04  | 0.42  |
| alfalfa (Medicago sativa)    | 1.13  | 0.13  | 1.70  |
| arctic brome (Bromopsis inermis) | 0.43  | 0.18  | 1.40  |
| elytrigia (Elytrigia repens)  | 0.96  | 0.15  | 0.58  |
| oat for green feed (Avena sativa) | 0.20  | 0.13  | 0.48  |
| highlander spread (Polygonum divaricatum) | 1.35  | 0.17  | 0.24  |
| wartycabbage (Bunias orientalis) | 1.32  | 0.18  | 0.27  |
| Hungarian sainfoin (Onobrychis arenaria) | 1.07  | 0.14  | 0.31  |
| PC for adults                | 0.2   | 0.03  | 0.5   |
| PC for baby food             | not permissible | 0.01  | 0.1   |

Soil contamination results from the battery plant operation, the thermal power station (TPS) operation, and the metallurgical plant producing arsenic for the needs of the defense industry (it was liquidated in 1949)
The observations showed that with intensive use of soils and annual cultivation of food and feed crops, the degree of pollution gradually decreases: a decrease in the content of gross forms of lead by 2.4 times, cadmium by 1.4 times, arsenic by 2.7 times.

As a result of significant soil contamination with arsenic, cadmium, and lead, all cultivated crops accumulated the indicated pollutants above the maximum permissible concentration (table 2).

Studies have shown that all vegetable crops were unsuitable for nutrition not only for children but also for adults.

Arsenic content was especially high in table beet, cucumber and potato. It should be noted that the presence of arsenic in foods recommended for children is not permissible. Among the green vegetable plants grown in the Astra fruit and vegetable cooperative, pea, lettuce, and onion had the highest content of arsenic.

All studied food vegetables and fruits, as well as feed crops intensively assimilate and accumulate a large amount of cadmium in the green mass and fruits. Of the vegetable crops, the largest amount of cadmium was accumulated in the roots of beet, carrot, cucumber, and tomato. The green mass of lettuce and dill had high cadmium content. Fruit crops — black currant and garden plum — were contaminated with cadmium. Roots of beetroot, pea, onion, dill, lettuce and cucumber had the greatest amount of lead. Abnormal accumulation of lead was observed in fruit crops: black currant and garden plum. Among feed crops, a significant amount of lead was accumulated in the green mass of alfalfa and arctic brome.

The research results indicate the need to withdraw, and subsequently conserve the agricultural land located in the municipality of Svirsk, Irkutsk Oblast.

4. Conclusion
The soil of the fruit and vegetable cooperative located in the city of Svirsk is contaminated with arsenic, cadmium and lead.

All cultivated crops accumulate arsenic in amounts higher than MPC which is unsuitable for food. The arsenic content was especially high in the roots of beetroot (Beta vulgaris).

A high content of cadmium in tomato fruits (Solanum lycopersicum) was revealed, and potato (Solanum tuberosum) was assigned to the group of cadmium excluders.

The greatest accumulation of lead was observed in the roots of beetroot (Beta vulgaris), pea (Pisum sativum), cabbage (Brassica oleracea) was assigned to excluders.

The research results indicate the need for conservation of agricultural land located in the city of Svirsk, for the implementation of measures to detoxify contaminated soils: phytoremediation and land cultivation.

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