MODELING AND STUDY OF THE DISTRIBUTION OF HEAVY METALS IN S OIL

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Abstract - Research was conducted to model and assess the impact of the concentration and form of heavy metals contained in soil under laboratory and field conditions on the ability of agricultural plants (using sunflower as an example) to accumulate these metals. Predicted metal accumulation rates in sunflower were calculated. Calculations showed that a sunflower harvested from the field (including the root system) will accumulate 54.06 kg of metals/ha.

Keywords - Agriculture, Heavy Metals, Sunflower, Soil

I. ACQUAINTANCE

The pandemic and rapid climate change have given a powerful impetus to the development of the Internet of Things (IoT) and enabled the creation of automated monitoring systems for decision-making to reduce resource consumption and production costs in all areas of life. In these circumstances, the need for a global initiative to raise awareness of the economic impacts of such an important resource as land and the importance of promoting sustainable land management is undeniable. This initiative should focus on a global study of the economic benefits of terrestrial and terrestrial ecosystems. The authors [1] emphasize the relevance of a global approach to analyzing the economics of land degradation and the need to consider this subject as an integral part of policy and decision-making strategies by raising awareness among politicians and the public about the costs and benefits of land and terrestrial ecosystems.

Rational use of agricultural land and soil conservation in a market economy require the appropriate application of new scientific and methodological approaches. One such system-analytical approach is the combination of traditional ground-based methods with geographic information system (GIS) technologies, leveraging the widespread use of aerospace imagery of varying resolutions. This approach underlies agricultural geographic information systems in developed countries, where soils are a key subsystem of this information product. Research development in this area meets the requirements of the State Program for Accelerated Industrial and Innovative Development of the Republic of Kazakhstan, Digital Kazakhstan, and the Program for the Development of Space Activities in the Republic of Kazakhstan.

A review of domestic and international literature revealed that digital mapping methods are actively developing and offer a wide range of approaches and tools for studying soil cover. The development of digital soil mapping and the capabilities of modern computing technology and software offer extensive opportunities for mapping and studying the organization of soil cover structure at various levels. Digital soil mapping methods offer a new approach to establishing and formalizing soil-landscape relationships, while a systematic approach to utilizing precision farming elements, based on remote sensing, UAVs, satellite geodesy, GIS technologies, and agricultural management, will enable the implementation of resource-saving approaches in the development of organic agricultural production.

Previous studies have used topographic data such as elevation and slope, geological data such as soil and surface geology, and the soil precipitation index as variables. Soil degradation due to intensified agricultural production has become a global problem: more than a third, or approximately 2 billion hectares, of the world's agricultural soils have been degraded and lost their fertility [2]. Under conditions of climate change, unsustainable use, and increased anthropogenic pressure, active degradation processes are occurring in arid lands, leading to irreversible changes in ecosystems—the loss of natural soil bioproductivity, its gradual drying out, and the loss of vegetation species diversity.

One-fifth of the world's population suffers from the effects of desertification. Its spread is noticeable in all corners of the globe—in Asia, the Americas, and the Mediterranean coast. In Peru, for example, due to desertification, one in five farmers is forced to abandon their land and move to the city. According to UNESCO experts, over the past 50 years, slightly less than half the area of South America has turned into barren desert. An effective fight against desertification must be carried out taking into account natural factors and the level of socio-economic

development of countries. According to [3], approximately 30 million km2 (19%) of the Earth's land is at risk of desertification. The development of GIS has made it possible to combine spatial location with various information and visualize it using maps and 3D scenes. Maps are used as geographic containers for incorporating layers of data and analytics. GIS reveals a deeper understanding of data, patterns, relationships, and provides a more intuitive presentation of data [4].

The concept of big data in agriculture is associated not only with large volumes, but also with the variety and speed of data collection. Big data is a key concept for the future development of agriculture, as it offers unprecedented opportunities and enables the use of various tools and services that can change its current state. Towards Smart Agriculture: Systems, Structures, and the Use of Multiple Sources GIS systems are a special category of software that organizes, analyzes, processes, and visualizes field data in the form of digital maps [5].

They may include statistical analysis, modeling information, and data provided by various database systems used to extract useful insights and make decisions. A GIS system consists of the following elements: a) a spatial data input system, including information from maps, satellite images, multispectral images, etc., b) a data storage system, c) a data visualization system containing information presented as maps, tables, and figures, d) a data analysis system, responsible for eliminating possible data errors and analyzing geospatial data, e) a user interface system. A successful example of the use of mathematical modeling, namely the creation of the AquaCrop model, is presented in [6].

The authors [7] used a combination of Parrot Sequoia and red-green-blue (RGB) multispectral UAVs to evaluate a new modeling approach using high-resolution UAV imagery to monitor forest health in priority riparian forests. The data were analyzed using classical random forest (RF) and simple and robust three-stage logistic modeling to identify the most important forest health indicators while adhering to the parsimony principle. A total of 34 remotely sensed variables were considered by these authors, including a set of vegetation indices, textural characteristics from the normalized difference vegetation index (NDVI) and digital surface model (DSM), topographic data, and structure data obtained using digital aerial photogrammetry from the DSM to the crown level. The obtained results were used to combat forest degradation, which in turn leads to soil erosion, expressed in the growth of ravines, the washing out of the fertile soil layer, and an increase in the greenhouse effect due to the release of carbon into the atmosphere in the form of CO2.

The aim of this study is to investigate in laboratory conditions the influence of the concentration and form of heavy metals contained in the soil on the ability of agricultural plants to accumulate these metals, as well as to study in field conditions (using the example of an agricultural crop - sunflower) the possibility of accumulation of heavy metals in a plant from one hectare.

II. RESEARCH OBJECTS AND METHODS OF WORK

A. Research objects

- soils artificially contaminated with heavy metals;
- agricultural lands located in the zone of contamination by heavy metals.

B. Methodology of work

The methodology for this stage is based on standard physicochemical and physicomechanical methods for studying the composition of the soil. The data from experiments on the effect of heavy metals on the growth and development of sunflower, conducted in laboratory conditions, are the average of three experiments. Field studies were carried out on three agricultural lands with different soil composition (ordinary leached chernozem, medium mechanical composition; dark chestnut soils of light mechanical composition; chestnut soils of light mechanical composition, highly susceptible to water and wind corrosion).

For the research, sunflower seeds from one of the farms in eastern Kazakhstan, growing these plants in their fields, were used (Figure 1). The experiment was carried out in wooden boxes with a perforated bottom (500 × 500 mm). 4 boxes were prepared, 2 for each seed type. 20 kg of soil were loaded into each box (Figure 2).



Figure 1 – General appearance of seeds used in laboratory research



Figure 2 – External appearance of experimental boxes

Tables 1 and 2 show the compositions of the conditionally clean soil and the soil artificially contaminated with heavy metals used in the experiment.

Item No.	Element	
	Name	Content, mg/kg
1	Sulfur (S_{total})	131
2	Nitrogen (N_{total})	2900
3	Phosphorus (P_2O_5)	149
4	Potassium (K_2O)	317
5	Lead (Pb)	0.64
6	Iron (Fe)	2.26
7	Copper (Cu)	0.5
8	Zinc (Zn)	1.17
9	Nickel (Ni)	0.78
10	Manganese (Mn)	2.57
11	Calcium (Ca)	131
12	Magnesium (Mg)	363
13	Chromium (Cr)	1.46
14	Humus, % (mass)	5.28
15	pH	7.75

Table 1 – Chemical analysis of a sample of conditionally clean soil

Item No.	Element	
	Name	Content, mg/kg
1	Sulfur (S) general	131
2	Nitrogen (N_{total})	2900
3	Phosphorus (P_2O_5)	149
4	Potassium (K_2O)	317
5	Lead (Pb)	96
6	Iron (Fe)	2.26
7	Copper (Cu)	198
8	Zinc (Zn)	330
9	Nickel (Ni)	120
10	Manganese (Mn)	2.57
11	Calcium (Ca)	131
12	Magnesium (Mg)	363
13	Chromium (Cr)	300
14	Humus, % (mass)	5.28
15	pH	7.75

Table 2 – Chemical analysis of a soil sample artificially contaminated with heavy metals

Ready-to-plant seeds were planted in appropriate boxes. The number of seeds from the studied plants planted in the corresponding boxes is shown in Table 3.

The temperature of the room where the boxes with planted seeds were kept was maintained between 25 and 30°C. After ripening, the crops were removed from their respective boxes and processed individually. Sunflower roots from each box were excised, rinsed with copious amounts of water to remove soil particles, and dried. All other parts of the studied crops (stems, leaves, etc.) were also rinsed with water and dried. Drying was carried out in a vacuum drying oven at a temperature of 60°C.

Name of plant seeds	Number of seeds, pcs		
	A box with uncontaminated soil	Artificially contaminated soil with TM	
		Soil without Na_2EDTA treatment	Soil treated with Na_2EDTA
Sunflower	6	6	6

Table 3. - Number of seeds of the studied plants planted in the corresponding boxes

After drying, all parts of the studied crops were crushed (each separately) and sent for analysis.

C. Results and discussion

The results of the studies showing the dependence of the accumulation coefficients of lead, iron, copper, nickel, manganese, chromium and zinc in the studied agricultural crop depending on the method of soil cultivation are presented in Table 4.

Crop name	Element	Accumulation coefficient
Sunflower	Pb	0.07
	Fe	11.81
	Cu	0.35
	Zn	0.08
	Ni	0.06
	Mn	4.80
	Cr	0.05

Table 4 – Values of the accumulation coefficient in agricultural crops in contaminated soil

The next stage involved field studies to determine the impact of heavy metal levels in artificially contaminated soil on their accumulation in agricultural crops. The study was conducted on a 46.23-hectare field belonging to a farm located within the city of Ust-Kamenogorsk, where sunflowers were planted. Chernozem soils predominate in the study area, although gray forest soils are also present. Industrial metallurgical plants are located near the study fields. The field studies were conducted on one of the sunflower-growing fields (46.23 hectares).

Nine diagonal plots, each measuring 1 square meter, were identified within the study field (Figure 3). Ten plants, including their roots, were sampled from each plot at full maturity. The field image was taken using a senseFly eBee X unmanned aerial vehicle. The field shows the NDVI index of the sunflower at full maturity.

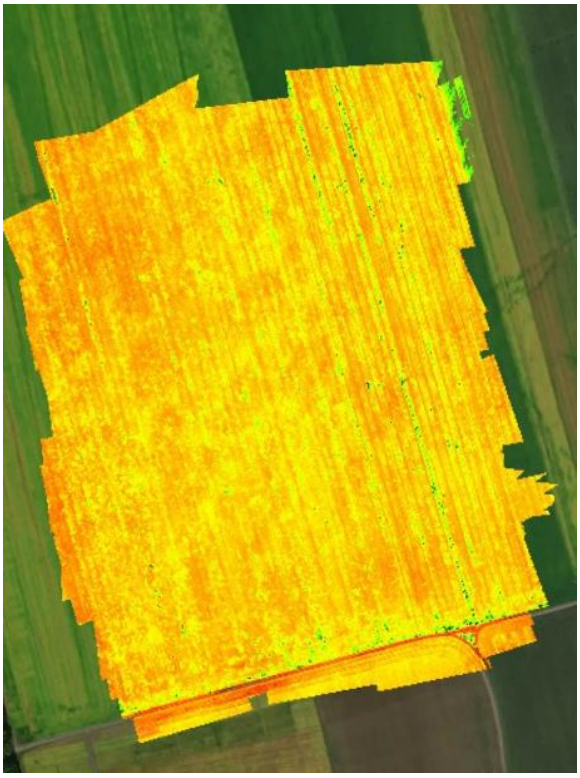


Figure 3 – Sampling scheme at the experimental site

Item No.	Before sowing sunflower	
	Name	Content, mg/kg
1	Lead (Pb)	0.516
2	Iron (Fe)	360,000
3	Copper (Cu)	1,280
4	Zinc (Zn)	6,701
5	Nickel (Ni)	0.616
6	Manganese (Mn)	10,200
7	Chromium (Cr)	0.490
After harvesting sunflowers		
8	Lead (Pb)	0.136
9	Iron (Fe)	346,145
10	Copper (Cu)	1,211
11	Zinc (Zn)	3,372
12	Nickel (Ni)	0.603
13	Manganese (Mn)	6,530
14	Chromium (Cr)	0.375

Table 5 – Metal content in soil before sowing and after harvesting

Calculations showed that sunflowers harvested from the field (including the root system) will accumulate 54.06 kg of metals per hectare. Figure 4 shows the accumulation rates of heavy metals in sunflowers based on their concentration in the soil.

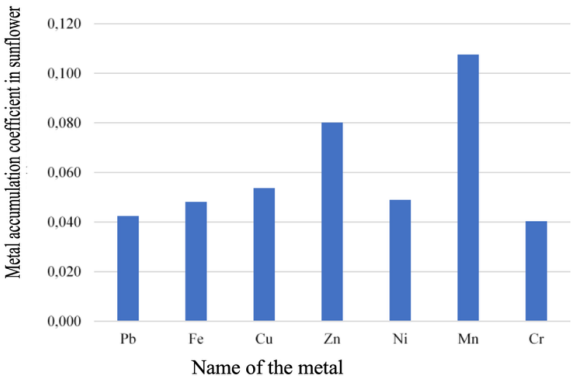


Figure 4. Metal accumulation coefficient in sunflower

The most economically promising and safest method of cleaning agricultural soils is plant-based cleaning, known as phytoremediation. It should be noted that certain chemical elements are essential for the vital functions of many plants. Elements such as zinc, copper, iron, cobalt, and others are essential for plant development and participate in processes occurring within the plant cell. It is known that with increasing concentrations of heavy metals in the environment, their concentrations in roots, stems, and leaves, as well as in seeds and fruits, also increase. In this regard, research into the problem of heavy metal pollution of soils, and especially of agricultural crops grown on them, is of great importance. Lead is one of the most toxic elements in soil [8, 9, 10]. Increasing lead concentrations above 100 mg/kg of soil can cause significant harm to plants grown on such soil [11]. Therefore, reducing the concentration of lead and other heavy metals in soils within the agro-industrial complex is a pressing issue.

III. CONCLUSION

The influence of heavy metal concentration and form in soil on the ability of agricultural plants to accumulate these metals was studied in the laboratory. The potential for heavy metal accumulation in a single hectare of sunflower was investigated in the field.

It was found that sunflower grown in a field (area of 46.23 hectares) can accumulate heavy metals in the amount of 54.06 kg/ha.

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