Ecological and methodological foundations of the system of conservation of natural ecosystems, the system of protection of biotopes from degradation and pollution by pollutants

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Abstract. The study presents data on establishing the limits of plant resistance and tolerance to pollutants, specifically mercury salts, products from the oil and gas industry (illustrated by WD-40), and surface-active substances (SAS). It has been established that hydroponics serves as the most efficient and precise model for examining the impact of pollutants on plant organisms. Critical thresholds of pollutant concentrations have been identified for the following species: tomato, leek, clover, peas, rye, and oats. It is recommended to utilize a hydroponic solution enriched with metal ions in chelate complexes to reduce chemical reactions between hydroponic solution components and heavy metal salts in pollutants. A concept has been developed to establish methodological foundations for employing hydroponics as an analytical tool to identify the most resilient plant species for phytoremediation of wastewater and contaminated sites with elevated heavy metal levels.

1 Introduction

In the era of the reign of post-industrial society and the introduction of scientific and technological progress into social and economic society, humanity uses the latest high-tech, energy-saving, and "green" technologies [1].

After the Industrial Revolution, about 19% of existing agricultural land became unsuitable for growing agricultural land. It's all the fault of industrial effluents from various enterprises, whether it's a mining and mining mine, mining fields and production plants [2]. Example: Usolekhimprom, a former chemical enterprise located in the Irkutsk region of the Russian Federation. After a large chemical company went bankrupt, this enterprise was abandoned in the 90s of the last century. Over the years, due to rusting protective barriers, capsules and containers, a fairly large amount of caustic and harmful substances began to enter the surrounding areas: heavy metal salts, mercury, cadmium, etc. The entire territory

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and the sanitary zone around it were gradually saturated with harmful substances, poisoning the city of Usolye itself [3].

Chemical analysis of soils and reservoirs is not enough to understand the limits of plant growth and its resistance to various harmful environments. The previously proposed options for studying plant tolerance to various pollutants (of organic and inorganic origin) are not suitable for assessing the impact of industrial facilities on biota. For this study, it is recommended to use hydroponics, a unique technology familiar from ancient times – a method of growing plants in a nutrient medium without soil [4]. Here you can grow plants and observe them from the first shoots to the fruits, as well as manually control many parameters: the amount of illumination, the amount of nutrients added, temperature and humidity control, pH, EC control, etc. This medium allows us to accurately deduce correlations of the influence of certain factors on the growth and viability of plants. A block diagram of the controlled parameters when using hydroponics is shown in Figure 1.

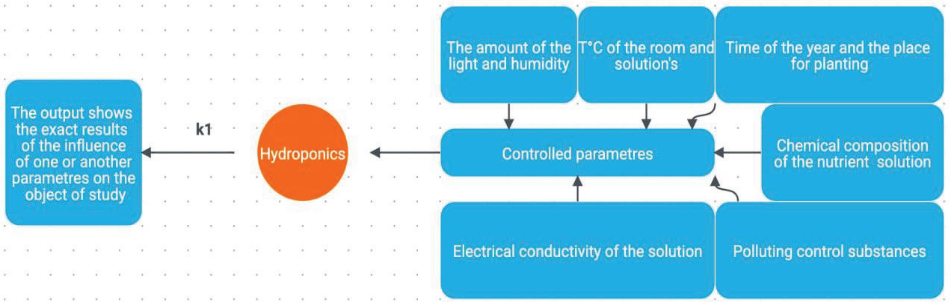

Fig. 1. Flowchart of Controlled Parameters for Hydroponic Systems.

The introduction of hydroponics as a tool for studying plant tolerance and resistance to pollutants is considered one of the most modern ways to study the ability of plants to be affected by harmful factors. The use of hydroponics to analyze the detection of heavy metals in plants accounts for approximately 1.5% of the total number of studies on the topic of "Hydroponic technologies". This method is effective and allows you to quickly and accurately identify heavy metals in various plant species.

The use of hydroponics as a method for analyzing plant tolerance to heavy metals involves growing plants in a hydroponic solution containing various concentrations and combinations of heavy metals such as zinc, copper, cadmium, nickel and chromium. Then, the accumulation of metals by plants and their resistance to various concentrations and combinations of heavy metals is compared. To conduct field research, it is necessary to stock up on labor, financial resources, as well as time. To conduct laboratory studies with model soil types, we must avoid various factors that will affect the result. There are many factors in the soil that affect the results: humic acids, various organic inclusions, as well as a different imbalance of nutrients and impurities of heavy metals, etc. A block diagram of the controlled parameters when using soil technology is shown in Figure 2.

Therefore, the entry point for conducting a comprehensive and independent study is the use of hydroponics. The results obtained in an ideal environment can be approximated for different soil compositions. Also, the results of the study will differ in different environments. For approximation, the coefficient "k1" and "m2" should be calculated, with which the results can be compared in different environments and states. To calculate a certain coefficient, it is necessary to conduct many experiments with plants and various chemical compositions of nutrient media.

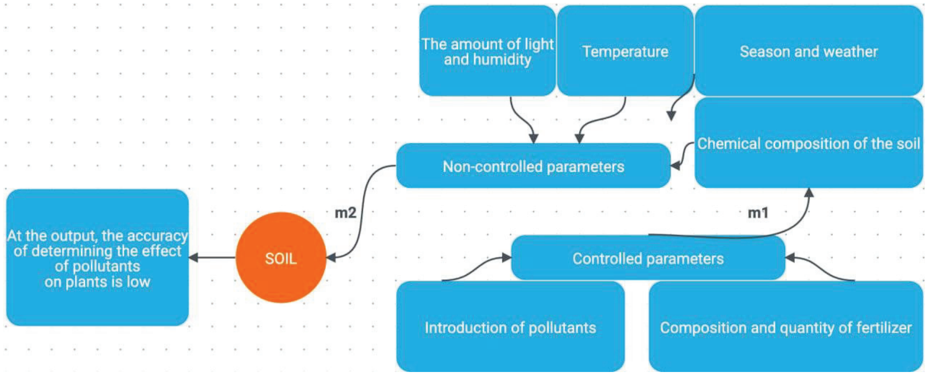

Fig. 2. Flowchart of Controlled Parameters in a Traditional Soil Experiment.

2 Materials and methods

In studies on the effect of heavy metals on plant growth in hydroponic environments, the following methods have been used:

- A review of literature on the impact of heavy metals in hydroponic settings has been conducted. To date, 46 articles and two patents have been identified in this area of research.
- Experiments have been conducted with varying concentrations of heavy metals, comparing them to control samples. Gradations of heavy metal concentrations were studied, including levels exceeding the maximum permitted concentration (MPC) by factors of 5, 10, 100, and 200. Additionally, organic components were tested at concentrations of 0.5, 1, 2, and 4 milliliters per liter.
- Heavy metal content in plants was determined using atomic absorption spectroscopy and mass spectrometry techniques.
- Plant tolerance to changing growth conditions was assessed.
- Statistical analysis of data to determine the effects of heavy metals on plant growth. The researchers will use these techniques to study the influence of heavy metals in hydroponic environments, determining optimal levels for plant development and assessing the capacity of plants to adapt and thrive.

In order to achieve this objective, we will employ laboratory research, data analysis, statistical methods, and a structured approach that combines analytical and synthetic techniques, field observations, experiments, and modeling. Furthermore, we will implement quantitative analysis methods such as measurement, computation, and mathematical analysis in order to interpret the data.

3 The course of the experiment

3.1 Plant selection

Plants capable of accumulating or transferring heavy metals are selected: mustard, daikon radish, clover and basil. The seeds were disinfected and sterilized. The seeds at the germination stage are shown in Figure 3.

Fig. 3. The stage of germination and disinfection of seeds.

3.2 Preparation of the experimental setup

A hydroponics system has been set up to grow selected plants under controlled conditions, providing optimal conditions for their growth. A hydroponic setup with a periodic flooding system has been assembled for the experiment. The schematic of the hydroponic system used with periodic flooding can be seen in Figure 4.

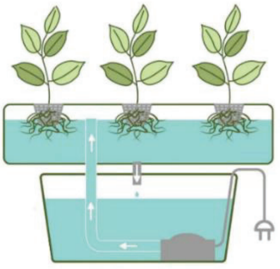

Fig. 4. The scheme of hydroponics with periodic flooding.

To conduct the vegetation experiment, a specialized hydroponic facility was constructed for the purpose of researching and experimenting with various plant species and solution formulations, as well as determining optimal ratios of elements within the solution. It is important to acknowledge that developing a novel hydroponic solution formulation can be a time-consuming process, and it is essential to regularly test and optimize the solution in order to ensure maximum efficiency and quality in cultivated plants [8].

Through the efforts of the ecologists at D.I. Mendeleev Russian Technical University, a formulation of a hydroponic nutrient solution with a higher nitrogen content and a wider range of trace elements in a chelated form has been developed, as well as enhanced stability of the final solution. This approach was necessary to minimize the impact of unstable metal forms in the nutrient solution on free heavy metal ions, which we will examine in terms of their effect on plants.

An experimental nutrient solution was employed in the hydroponic study [9]. The solutions had a minimum guaranteed composition in a ratio of 4:4:2 (drops per 1 liter of water). The developed nutrient formulation contained more nitrogen, less phosphorus, and more potassium, boron, and molybdenum compared to the GHE solution, as revealed by elemental analysis. These alterations in the composition of the nutrient medium had a beneficial impact on the processes of hydroponics, particularly on the assimilation of nitrate nitrogen.

Plant materials under study were planted in plastic pots (7 pcs.), measuring 17 centimeters by 17 centimeters in diameter and 17 centimeters deep. Seven pots were

utilized for each treatment, with each pot receiving a different nutrient solution. The concentration of the nutrient solution employed for each plant was 75% for clover, peas, and rye, and 50% for leeks. To maintain aeration, the nutrient solution in each pot was continuously aerated at a rate of 3.8 liters per minute using air pumps equipped with two small air filters [10]. The block diagram of the experimental setup is shown in Figure 5.

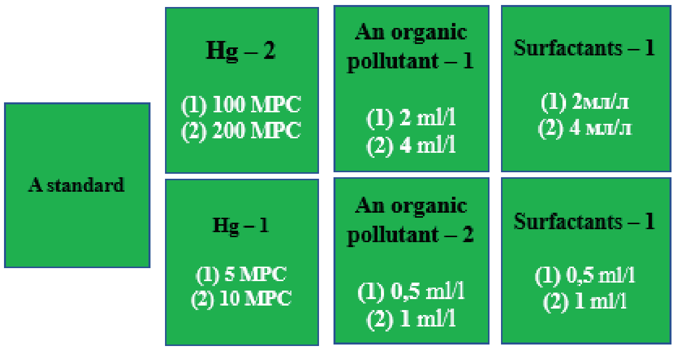

Fig. 5. A diagram of containers indicating concentrations of pollutants.

3.3 Toxic metal addition

The pollutants under study were introduced into the hydroponic environment in various concentrations, resulting in a polluted environment.

In the control container, plants were grown only in a hydroponic solution without the addition of pollutants or growth stimulants.

Mercury nitrate ($Hg(NO_3)$) was added to containers "Hg-1" and "Hg-2" at different concentrations on the 10th day of the experiment: 5 MPC and 100 MPC, respectively. Subsequently, on the 20th day, the concentration was doubled to 10 MPC and 200 MPC in each container. The increase in concentration occurred in two stages, in accordance with the plant's growth stages.

On the 10th day of the experiment, organic substances were added to containers Org-1 and Org-2 - a WD-40 solution containing common organic pollutants: white spirit (n-C4-155/200 nefras), mineral engine oil, gasoline, and paraffins. The concentrations of organic pollutants were 0.5 mL/L and 2 mL/L of the hydroponic solution, respectively. Subsequently, on the 20th day of the plant growth experiment, the concentrations were increased by a factor of 2 to 1 mL/L and 4 mL/L, respectively.

On day 10 of the experiment, a sodium laureth sulfate surfactant, which is an amphiphilic compound found in detergents, was added to containers PAV-1 and PAAV-2. The surfactant concentrations were 0.5 mL/L and 2 mL/L in the hydroponic solutions, respectively. Later, on day 20 of the plant growth experiment, these concentrations were increased twofold to 1 mL/L and 4 mL/L, respectively.

3.4 Monitoring

Regular monitoring of plant growth, development, and health under the influence of heavy metals was conducted. Measurements of the level of metal accumulation and changes in physiological parameters were taken. Figure 6 shows the containers with the test plants.

Fig. 6. Containers with experimental plants.

4 The results of the experiment and their discussion

4.1 Data analysis

Throughout the experiment, plant growth measurements were carried out with a frequency of 3 days; visual assessment; electrical conductivity of the solution; control of humidity, temperature of the solution and medium, pH of the solution.

As a result of the experiment, data on plant growth were obtained and graphs were created reflecting their growth and development. Figures 7-10 show graphs of plant growth (basil, clover, mustard, daikon) in various concentrations of pollutants. The first stage of contamination was carried out on the tenth day of the vegetation experiment. Contamination at this stage is indicated with the mark "1". Further, on the 20th day of the experiment, repeated contamination was carried out. At this stage, the graph clearly shows that the solution used for growing daikon radish, clover and basil showed the best increase in biomass throughout the experiment.

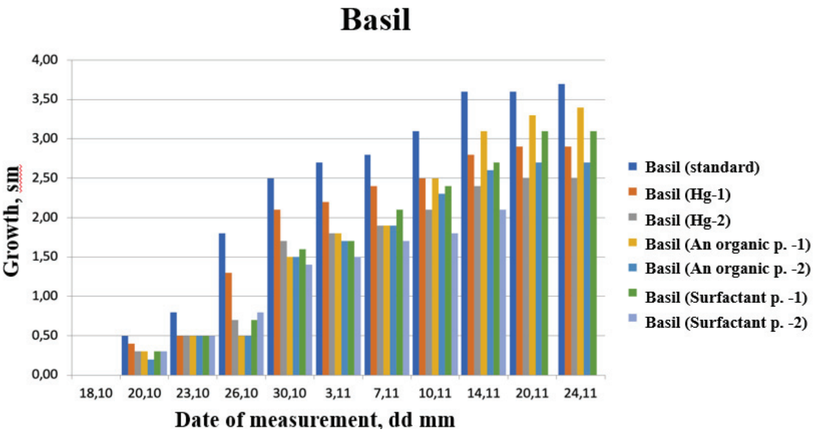

Fig. 7. Basil growth chart in various media.

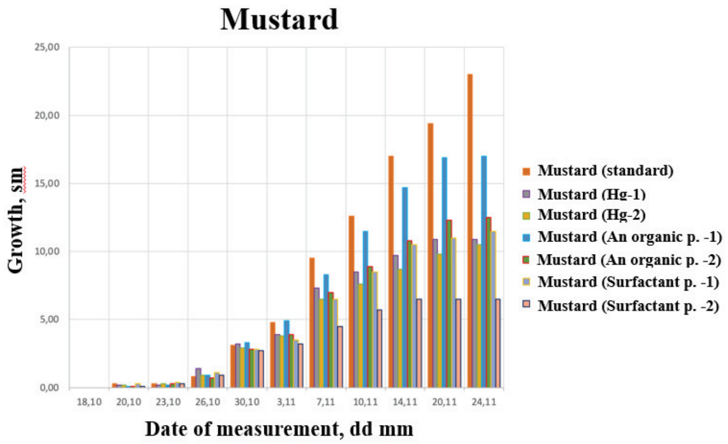

Fig. 8. Mustard growth chart in various media.

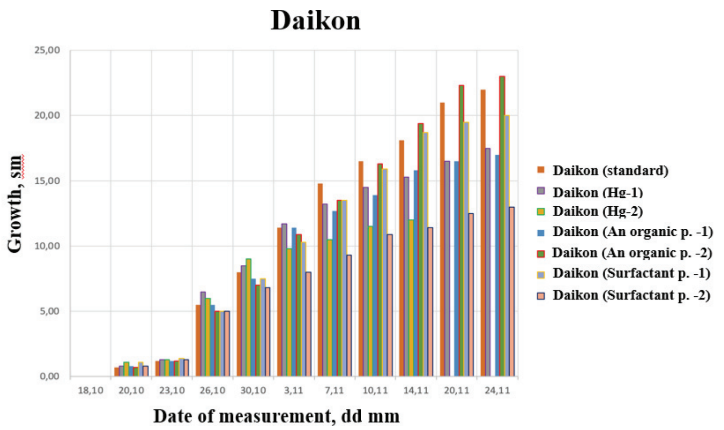

Fig. 9. Daikon growth chart in various media.

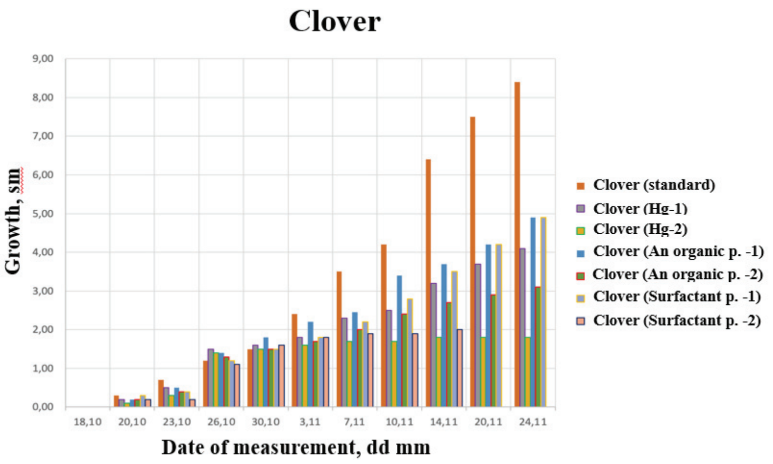

Fig. 10. Clover growth chart in various media.

Based on the results of the study, it has been determined that the average green mass of plants grown is 8% greater when surfactants are used in concentrations ranging from 0 to 1 mL/L of a hydroponic solution. However, concentrations exceeding 0.5% have a detrimental effect on plant growth and development, and therefore, this may negatively impact the ecosystem as a whole.

An increase in surfactant concentration from 1 mL/L to 4 mL/L also resulted in inhibition of plant growth. Additionally, even the smallest concentrations of mercury present in the solution slowed plant growth by an average of 12-18%.

Figure 11 demonstrates that daikon appears to be the most resilient to the tested pollutants, exhibiting an average resistance of 25% greater than clover, mustard, and basil. Conversely, basil and clover were found to be most susceptible to pollution, reducing their biomass by approximately 30-40% following the addition of pollutants to the hydroponic solution.

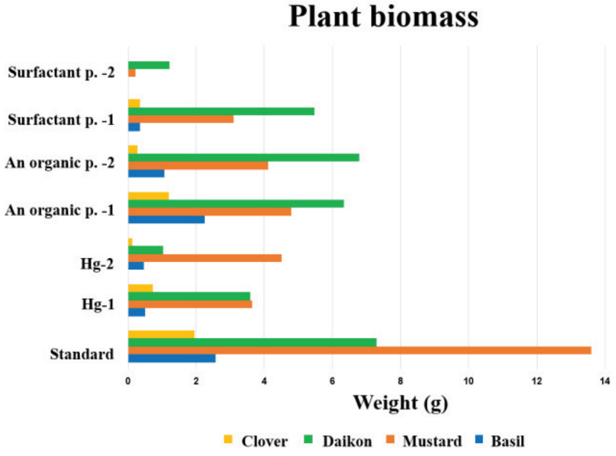

Fig. 11. Chart of plant biomass in different environments.

Figure 12 presents a graph of the plant resistance coefficients under different environmental conditions with pollutants. The graph shows that the resistance of the daikon plant is 20%-25% higher than other plants tested, despite the fact that its resistance does not depend on the type or nature of the pollutant. Even when the concentration of the pollutants is doubled, the average resistance decreases by 15%.

Table 1 presents the stability coefficients for the tested plants under various environmental conditions.

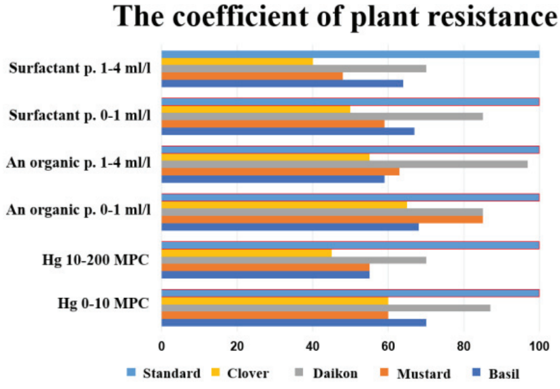

Fig. 12. Chart of the coefficient of plant resistance in various environments.

4.2 Interpretation of the results

Draw conclusions about the ability of plants to tolerate heavy metals and their potential effectiveness for phytoremediation and other purposes.

During the analysis, critical concentrations of mercury salts were identified that, when exceeded, adversely affect plant growth:

- Concentrations up to 10 times the maximum permissible concentration (MPC) of mercury salts reduce plant growth and survival by 35–40%.
- Concentrations between 100–200 times the MPC slow down plant growth on average by 45–55%. Daikon plants showed the best tolerance to mercury, with 70–87% survival compared to the reference, while Clover plants showed the worst.
- Concentrations of organic substances (WD-40) at 1 milliliter per liter (ml/l) reduce growth and survival of the tested plants by 20–35%.
- Concentrations of WD-40 at 4 ml/l slow down plant growth by 30–40% on average. Daikon plants again showed the best tolerance, with 90–95% survival compared to the reference. Clover plants showed the lowest tolerance.
- Concentrations of surfactants (organic substances) at 1 ml/l reduce growth and survival of the plants by 45–55%.
- Increasing the surfactant concentration to 4 mL/L slows down plant growth by an average of 60–70%. Daikon demonstrated the best tolerance to organic pollutants (surfactants), with 65–85% survival compared to the reference, while Clover demonstrated the worst tolerance. (With concentrations above 2 mL/L, mortality of both clover and daikon occurred.)

By using hydroponics, it will be possible to more precisely control experimental conditions and investigate plant responses to heavy metals in a controlled environment.

Table 1. The coefficient of plant resistance in % (the index of plant endurance in the reference environment is taken as 100%).

Pollutants/Plant	Basil	Mustard	Daikon	Clover
Hg 0-10 MPC	70	60	87	60
Hg 10-200 MPC	55	55	87	45
An organic p. 0-1 ml/l	68	85	85	65
An organic p. 1-4 ml/l	59	63	97	55
Surfactant p. 0-1 ml/l	67	59	85	50
Surfactant p. 1-4 ml/l	64	48	70	40

5 Conclusion

Mercury Salts:

- When the maximum permissible concentration (MPC) of mercury salts is exceeded by 35-40%, plant growth and survival decrease.
- Increasing the mercury concentration up to 100-200 MPC reduces plant growth by 45-55%.
- Daikon showed the highest tolerance to mercury, with 70-87% tolerance compared to the reference.
- Clover showed the lowest tolerance.

Organic Substances (WD-40):

- Increasing WD-40 concentration to 1 ml/L reduces plant growth and survival by 20-35%.

- Increasing concentration to 4 ml/L slows plant growth down by 30-40%.
- Daikon has shown the highest tolerance towards organic pollutants, with 90-95% tolerance compared to reference.
- Clover has the lowest tolerance.

Surfactants:

- Increasing surfactant concentration to 1 mL/L reduces growth and survival by 45-55%.
- Increasing to 4 mL/L slows growth by 60-70%.

Daikon demonstrated the highest tolerance for organic pollutants, with a tolerance range of 65-85% compared to the reference.

Clover, on the other hand, showed the lowest tolerance, with mortality observed at concentrations above 2 ml/l.

Based on the presented data, it is worth noting that daikon exhibits remarkable resilience to a wide range of contaminants, including mercury salts, organic compounds such as WD-40, and surfactants. In contrast, clover appears to be more susceptible and sensitive to these harmful substances.

The tolerance threshold for pollutants varies among plant species, and this information is not provided for each species in modern reference books or rationing systems.

To determine this threshold, it is necessary to conduct experiments with various plants and concentrations, measuring the limiting concentration at which plant growth is slowed or halted.

Studying this phenomenon in natural ecosystems would be impractical due to the high costs and time constraints associated with conducting experiments in specific seasons. Therefore, hydroponics can serve as an effective platform for investigating plant tolerance and resistance to harmful influences. Hydroponic systems are known for their rapidity and lack of interference with experimental purity, allowing for precise measurement of the maximum concentration at which plants succumb.

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