COMPARISON OF THE EFFICIENCY OF PHYTOREMEDIATION OF SOIL CONTAMINATED WITH DIFFERENT TYPES OF OIL PRODUCTS

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ABSTRACT

Object of study. Effectiveness of phytoremediation of soil contaminated with different types of oil products.

Investigated problem. When studying the problem of soil contamination by oil products and when looking for ways to restore soils disturbed by the chemical effects of hydrocarbon fuels, the type of oil product is not always taken into account. And a generalization is used for this type of pollution, as pollution by oil products, which does not take into account the difference in the component composition of hydrocarbon motor fuels and their different impact on the ecological state of the soil.

The main scientific results. The research results established the dependence of the effectiveness of phytoremediation of soil contaminated with oil products on the type of oil product. The obtained data made it possible to draw a conclusion about the nature of the dependence of qualitative and quantitative indicators of the level of soil phytoremediation by a certain type of plant, depending on the hydrocarbon composition of the oil product.

The area of practical use of research results. The results of the research will be used in practice when choosing the type of plants to restore the quality of soil contaminated with a certain type of oil product.

Innovative technological product. The results of the study created the basis for the development of a scientific and methodological approach to the resolved issues of restoring the quality of soil contaminated by various types of petroleum products. What can be used by specialists in the future in the development of new technologies for the restoration of soils contaminated with petroleum products.

Scope of the innovative technological product. Research results and the proposed scientific and methodological approach concern the sphere of environmental protection and transport enterprises.

1. Introduction

1. 1. The object of research

The study was conducted to determine the dependence of the effectiveness of phytoremediation of soil contaminated with various types of petroleum products.

1. 2. Problem description

Today, soil pollution with oil products is a serious problem for the environment. Soil is an ecological base that provides life for all living things. The intensive development of the technosphere is accompanied by an increase in the load on the environment. In particular, the level of soil pollution by oil products in technogenically loaded territories is increasing.

[1] indicate that an uncontrolled fuel spill can lead to a deterioration of the quality of the environment, especially with regard to the negative impact of petroleum hydrocarbons on the properties of soil and water due to their different periods of decomposition and high toxicity for living microorganisms.

[2] note that soil contamination with hydrocarbons, which are part of petroleum products, leads to serious changes in soil properties and affects microbial biodiversity. Given the mutagenicity, carcinogenicity and toxicity of petroleum hydrocarbons, remediation of disturbed areas contaminated by petroleum products is an important technological and environmental challenge for sustainable growth and development.

[3] point out that petroleum hydrocarbons are highly toxic to plants, living microorganisms and pose a potential health risk that increases as the resistance of hydrocarbons to degradation increases. The damage caused by the effects of petroleum hydrocarbon pollution depends on the type and concentration of the pollutant. It is generally accepted that the susceptibility of hydrocarbons to microbial attack decreases in the following order: n-alkanes > branched alkanes > low molecular weight aromatic compounds > cyclic alkanes.

[4] note the different influence of different fractions of oil on the morphological, physical, physicochemical and chemical properties of soils and patterns of vertical and lateral migration of oil along the soil profile.

Therefore, the level of negative impact on the soil should depend on the composition of the fuel. Taking into account the type of petroleum product and its component composition when developing technologies for restoring soil quality, in particular with the use of phytoremediation, is important for achieving the required level of restoration of the ecological state of the soil. With this in mind, the study investigated how the effectiveness of soil phytoremediation depends on the type of oil product.

1. 3. Suggested solutions to the problem

The study proposed a solution to solve the identified problem. It is suggested that, when developing and implementing technologies for remediating soils contaminated with oil products, if possible, take into account the type of oil product with which the soil is potentially contaminated. In particular, in the case of emergency spills and soil contamination with a certain type of oil product, use appropriate phytoremedial plants, taking into account their phytoremediation ability in relation to the component composition of the oil product.

Research questions.

The study generated answers for the following questions:

1. Does the level of negative impact of oil products on the soil depend on the type of oil product?

2. Does the effectiveness of soil phytoremediation using a certain type of plant differ in relation to soil contaminated with different types of petroleum products?

3. What are the advantages of taking into account the type of petroleum product when choosing a method of remediation of soil contaminated with petroleum hydrocarbons?

4. What scientific and methodological approaches can be used to increase the efficiency of restoration of the ecological state of the soil disturbed by oil products?

2. Conceptualization, theoretical framework and literature review

[5] note that the systematization and generalization of literature data on the peculiarities of oil pollution of soils and their reclamation point to the prospects of using phytoremediation technologies. Phytoremediation of soil contaminated with oil products is a method of cleaning the polluted environment with the help of plants. This process is based on the ability of certain plants to extract, metabolize or decompose petroleum products that pollute the soil.

Some plants have the ability to efficiently use petroleum products as a source of carbon and energy or actively break them down through phytodegradation characteristics.

Phytoremediation is a natural and environmentally safe method that can be used both on a small scale (for example, restoring a garden) and on large industrial sites where oil spills occur [5].

The first step in soil phytoremediation is the selection of suitable plants capable of extracting and breaking down petroleum products. Certain types of plants, such as willow, nightshade, mustard, ginger, and others, are known for phytoextraction (removal of oil products from the soil) and phytodegradation (breakdown of oil products into harmless compounds) [6].

Infected soil must be prepared before planting. This may include aeration, laboratory soil testing to determine the extent and characteristics of contaminants, and application of appropriate nutrients and pH regulators to promote plant growth [7].

Plants selected for phytoremediation are planted on the contaminated soil. To ensure maximum phytoextraction and phytodegradation of petroleum products, it is important to consider optimal planting density and growing conditions. In the process of phytoremediation, it is necessary to systematically observe the contaminated territory and, if necessary, make corrections to determine the effectiveness of the process. The assessment includes the concentration of oil products in the soil and plants, physicochemical properties of the soil, biodiversity, etc., including the analysis of qualitative and quantitative parameters.

The main advantages of phytoremediation of oil-contaminated soil are:

– phytoremediation uses the biological processes of plants and microorganisms to restore soils. It is a less invasive method than traditional physical and chemical cleaning methods;

– plants are a renewable resource, meaning they can be grown over and over again for reuse in phytoremediation. This allows for effective cleaning of large areas of contaminated soil;

– phytoremediation can be a cost-effective way of cleaning contaminated soil compared to other technologies. This can be a less expensive and more affordable solution, especially on the scale of large contaminated areas;

– phytoremediation of soil with petroleum products uses natural processes and ecosystems for cleaning. This method contributes to the preservation of biodiversity and environmental sustainability [8, 9].

It is important to note that phytoremediation of oil-contaminated soils can be a long-term process and requires systematic monitoring and intervention. The time required for complete remediation of contaminated soil depends on various factors, including the type of pollutant, its concentration, soil type, climatic conditions, and the effectiveness of selected plant species [6].

[10] note that phytoremediation of oil-contaminated soils is a promising approach to the restoration of a polluted environment. It combines natural processes that interact between plants, microorganisms and soil to achieve effective treatment. Continued research in this field and the development of new technologies can help to further optimize phytoremediation and expand its application in practical situations.

3. Materials and Methods

Methods: to establish the comparative effectiveness of phytoremediation of soils artificially polluted with three types of petroleum products, an experimental study was conducted, which took place in several stages.

Stage I. Germination of seeds of oat and common vetch plants for 10 days according to the standard method on samples of soil contaminated with various types of petroleum products (car gasoline, aviation kerosene and diesel fuel) of common vetch (*Vicia sativa*) and oat (*Avena sativa L.,*) soil with subsequent determination of growth characteristics of plants.

Stage 2. Chromatographic analysis of soil samples before and after phytoremediation.

Stage 3. Determination of the weight of oil products in the soil by the gravimetric method before phytomediation and after soil restoration

Materials: aviation kerosene brand TS-1, gasoline brand A-95, diesel fuel brand DP, soil samples, *Vicia sativa* and *Avena sativa L.,* thermostat, analytical balance, chloroform, hexane, aluminum oxide, chromatograph, Petri plates.

Before starting the experiment with the use of phytoremediation, the soil was artificially contaminated with these types of petroleum products: gasoline, kerosene, and diesel fuel in the amount of 1 ml of polluting substance per 500 g of soil.

For further research, 18 soil samples were prepared, which were filled in Petri plates. Petri plates were filled with soil to a height of 0.5 cm and numbered.

Next, plant seeds were sown on the surface of the soil: 9 Petri plates for 100 *Avena sativa L.,* seeds and 9 Petri plates for 200 *Vicia sativa* seeds.

Next, the Petri plates were covered with lids and placed in a thermostat at room temperature (20–22 °C) for germination.

On the third day, the number of germinated seeds was counted. After that, the lids were removed from the Petri plates and continued watering of the plants with periodic moistening. The soil was periodically moistened as it dried.

On the 10th day from the beginning of the experiment, the growth characteristics of plants were determined, after which the soil was dried from residual moisture and prepared for further determination of the content of oil products in it.

Further, chromatographic analysis of reference samples of three petroleum products, which were pollutants of the studied soil samples, and samples after plant germination was carried out. This made it possible to establish which chemical compounds are present in the contaminated soil before phytoremediation and after phytoremediation.

A DB-5MS capillary column (30 m, 0.250 mm) was used for the research. During the measurement, the following GC column temperature program was used: 40 °C for 4 min, then the temperature was increased to 70 °C at a rate of 4 °C/min, then increased to 250 °C at a rate of 20 °C/min and held for 10 min. The injector and detector temperatures were 250 and 200 °C, respectively. Helium purity 5.0 was used as a carrier gas. The 20–700 m/z range was used for the qualitative determination of the studied samples. The sample injection volume was 1 µl.

At the final stage of the research, the mass of oil products was extracted from the contaminated soil with chloroform, which is one of the methods for determining the level of soil contamination with oil products. The determination of the content of petroleum products in the soil was carried out by the gravimetric method according to MVV No. 081/12-0116-03 "Soils. Methodology for measuring the mass fraction of oil products by the gravimetric method".

This method consists in extracting petroleum products from contaminated soil using chloroform as a solvent. The procedure for extracting the mass of oil products with chloroform from contaminated soils can be carried out as follows: first, samples of contaminated soil were taken before and after phytoremediation and cleaned of solid residues, and then crushed in a mortar. The prepared soil was moistened with chloroform, and the filtered, then obtained liquid was placed in 200 cm^3 beakers for further evaporation. The resulting precipitate was dissolved in 10 cm^3 of hexane, after which quartz wool was placed in the prepared glass column and 8 g of aluminum oxide was poured on top, then the contents of the glass with the extracted liquid were poured out. In this way, petroleum products are separated from the obtained hexane solution and the element is purified from impurities of polar compounds. Next, the liquid was evaporated in pre-weighed glasses with a capacity of 200 cm^3. After complete evaporation, the glass was weighed on an analytical balance.

4. Results and Discussion

According to the standard method of research, the first shoots of plants should have appeared on the third day. In practice, in the course of the experiment, the emergence of seedlings of only a few seeds was observed according to the time determined by the method.

The results of the study of plant seed germination are presented in **Table 1**.

Table 1

Characteristics of plant seedlings in the investigated soil samples

No. of the sample	*Vicia sativa*/fuel	The appea-rance of seedlings (days)	Seedlings, quantity	*Avena sativa L.*/fuel	The appea-rance of seedlings (days)	Seedlings, quantity
1	Aviation fuel	6	8	Diesel fuel	6	3
2	Diesel fuel	3	1	Automobile gasoline	6	4
3	Aviation fuel	5	3	Automobile gasoline	5	14
4	Diesel fuel	1	5	Automobile gasoline	6	7
5	Diesel fuel	1	8	Aviation fuel	6	7
6	Aviation fuel	1	8	Aviation fuel	5	31
7	Automobile gasoline	–	–	Diesel fuel	5	12
8	Automobile gasoline	–	–	Aviation fuel	–	–
9	Automobile gasoline	–	–	Diesel fuel	10	1

Samples No. 7–9, the age of ordinary, did not germinate, and sample No. 8, on which oats were also planted.

In our opinion, the reason for this may be: an acute toxic effect on plants of a certain concentration of hydrocarbons (according to the component composition of the fuel) in one or another type of fuel.

Next, the growth characteristics of the grown plants of *Vicia sativa* were determined (**Table 2**).

Table 2

Growth characteristics of *Vicia sativa*

No. of sample	Fuel type	Seedlings, quantity	Root length, cm	Stem length, cm
1	Aviation fuel	8	6	6,5
2	Diesel fuel	2	5	5
3	Aviation fuel	4	4	4
4	Diesel fuel	2	1	1
5	Diesel fuel	5	2	2
6	Aviation fuel	2	4.5	4.5

After analyzing the obtained results, it can be stated that all plants without exception were affected by the pollutant. A control sample of plants on the 10^{th} day has 4–10 leaves, a height of up to 20 **cm** and a branched rhizome.

Also, not a single sample germinated on soil contaminated with automobile gasoline. Therefore, it can be assumed that this oil product is the most toxic for this type of the plant.

Also, on the 10^{th} day, the growth characteristics of *Avena sativa L.* grown on 9 samples of contaminated soil were measured (**Table 3**).

Table 3

Growth characteristics of *Avena sativa L.*

No. of sample	Fuel type	Seedlings, quantity	Root length, cm	Stem length, cm
1	Diesel fuel	3	6	5
2	Automobile gasoline	4	9	7
3	Automobile gasoline	17	14	5
4	Automobile gasoline	10	14	5
5	Aviation fuel	10	13	6
6	Aviation fuel	36	12	4
7	Diesel fuel	16	15	7
9	Diesel fuel	1	0,5	4,5

After analyzing the results, it can be concluded that the obtained growth indicators of most oat plants are lower than the obtained values for the control sample by 1–2 cm, which indicates the insignificant influence of the pollutant contained in the substrate. In addition, during the experiment, it was found that *Avena sativa L.* are more resistant to pollutants and germination conditions than *Vicia sativa*.

At the next stage of research, chromatographic analysis of reference samples of three oil products that were pollutants and samples of extracted oil products from the studied soil samples before and after phytoremediation with two types of plants was carried out. This made it possible to establish which chemical compounds are present in the contaminated soil before phytoremediation and after phytoremediation.

Firstly, the component composition of the control sample of automobile gasoline was investigated using chromatographic analysis. After that, a study of the composition of the oil products extracted from the soil was conducted. A comparison of the quantitative indicators of the content of the components in the mixture, for the three studied fuels and the soil after phytoremediation showed the dependence of the change in quantitative indicators depending on the type of plant.

The results of comparison of two chromatograms (before and after phytoremediation of soil, polluted with automobile gasoline), have shown the presence of chemical compounds in the soil contaminated with automobile gasoline before and after phytoremediation but also have shown the quantitative changes in this mixture. According to the results of the analysis of the obtained data, it was established that there were no qualitative changes in the mixture but were quantitative difference of the fuel content in the soil (before and after phytoremediation) (**Fig. 1**).

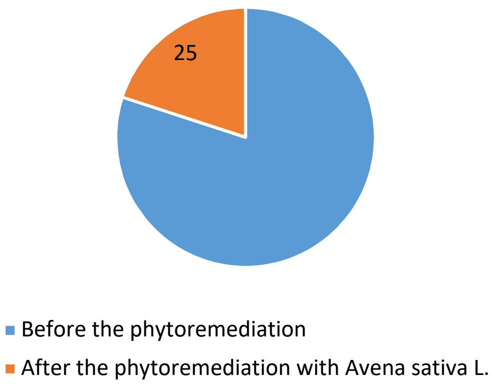
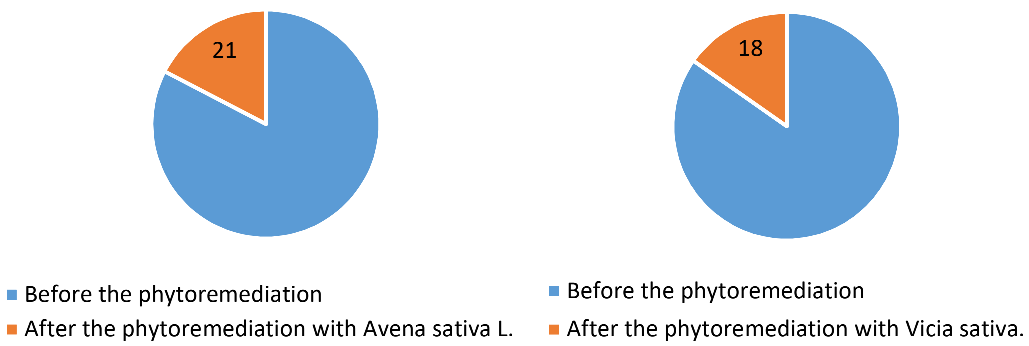


Fig. 1. Automobile gasoline content in the soil before and after phytoremediation with the *Avena sativa L.*, %

Chromatographic analysis of aviation kerosene and diesel fuel (**Fig. 2**) samples was carried out using a similar methodology (**Fig. 3**).

The presence of chemical compounds in the soil contaminated with diesel fuel before and after phytoremediation showed quantitative changes and no qualitative changes in the composition of the pollutant (**Fig. 2**).



a *b*

Fig. 2. Diesel fuel content in the soil before and after phytoremediation, %: *a* – with the *Avena sativa L.*; *b* – with the *Vicia sativa*.

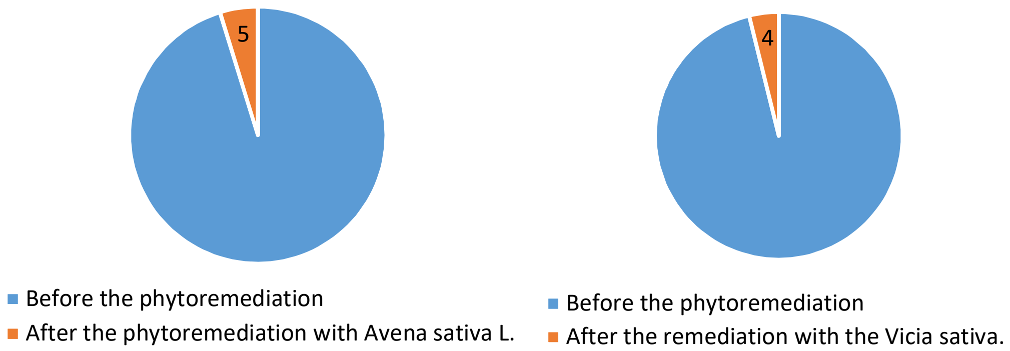
The chromatograms analyses for the sample of aviation kerosene using a similar methodology showed quantitative changes and no qualitative changes in the composition of the pollutant (**Fig. 3**).

None of the two types of planted plants completely cleaned the soil of these substances, but in percentage terms, the common vetch showed better results. Therefore, it is a more promising species for use in phytoremediation technologies of soil contaminated with these types of fuels.

At the third stage of research, the mass of petroleum products was determined for soil contaminated with three types of petroleum products, namely gasoline, aviation kerosene, and diesel fuel without phytoremediation measures.

Next, oil products were extracted from the soil after phytoremediation with previously selected plants (*Vicia sativa* and *Avena sativa L.*). Chloroform was chosen as the solvent, and hexane was used for evaporation at the second stage. The obtained results are presented in **Table 4**.

It was established that a decrease in the content of oil products in the soil is characteristic for all the studied samples. And the process of phytoremediation of the soil shown that the efficiency *Vicia sativa* is higher than for *Avena sativa L.*



a *b*

Fig. 3. Aviation kerosene content in the soil before and after phytoremediation, %: *a* – with the *Avena sativa L.*; *b* – with the *Vicia sativa*.

Table 4
Results of the study of the effectiveness of phytoremediation of soil contaminated with different types of the fuels

Fuel type	Oil product content, g		
	Soil sample before phytoremediation	After germination of the *Vicia sativa*	After germination of the *Avena sativa L.*
Automobile gasoline	0.0305	0.005	0.0055
Aviation fuel	0.2445	0.0014	0.0011
Diesel Fuel	0.4991	0.0076	0.009

Limitations of the study. The study of the effectiveness of phytoremediation of soils contaminated with oil products was conducted using only two types of plants.

Prospects for further research should. The obtained data and the proposed methodology of experimental analysis can be used in the study of phytoremediation of the soils contaminated with other types of oil products and with the use of a greater variety of plant species.

5. Conclusions

As a result of the analysis of the dependence of the efficiency of phytoremediation of soil contaminated with various petroleum products, let's come to the conclusion that the degree of soil purification depends on the type of fuel for the same plant. A comparison of the quantitative indicators of the content of the components in the mixture, for the three studied fuels and the soil after phytoremediation showed the dependence of the change in quantitative indicators depending on the type of plant. None of the two types of planted plants completely cleaned the soil of these substances, but in percentage terms, the *Vicia sativa* showed better results. Therefore, it is a more perspective species for use in phytoremediation technologies of soil contaminated with these types of the fuels.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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