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Phytotesting as a Tool in Assessing the Effectiveness of Salt Dump Reclamation

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Abstract

The utilisation of potash reserves has various environmental consequences, such as the generation of substantial volumes of solid waste containing high levels of sodium chloride. The accumulation of environmental harm gives rise to an unfavourable environmental scenario in potash production areas, which requires the investigation of waste management solutions. The predominant approach to reducing surface waste involves backfilling mined areas. In other countries, salt dump reclamation is utilised alongside backfilling. The distinctive characteristic of salt dump reclamation lies in the water-solubility and phytotoxicity of the dump rock. This research aims to evaluate the morphometric and biochemical parameters (using phytotesting) of vegetation throughout the process of salt dump reclamation using different variants. A model reclamation was carried out in a laboratory setting, where three different variants were subjected to experimentation. A reduction in the thickness of the protective clay barrier resulted in a decline in morphometric aspects of the experimental crops as well as the woody vegetation. Reducing the thickness of the protective clay barrier leads to an elevation in the redox activity of the examined crops, thus pointing towards potential environmental toxicity. Superior morphometric and biochemical parameters were noted in vegetation possessing a substantial protective covering, hinting at the feasibility of utilising insulating layers for salt dump reclamation. Phytotesting serves as an indicative approach to assessing soil toxicity and as a parameter for determining soil resilience against pollution. The findings hold potential for application in further research within the field of biological reclamation in areas with dump sites.

1. Introduction

Mining is regarded as one of the primary economic sectors, yet it persists in inducing serious environmental damage [1]. It alters the landscape beyond its original condition.

The extraction of potassium salts (sylvinite and carnallite) constitutes the primary utilisation (90% of the mined potassium) for the fertiliser production and holds significance for agriculture due to its role as the fundamental element for the creation of solely potassium fertilisers and mixed nitrogen-phosphorus-potassium fertilisers [2]. Despite the pivotal role of potash fertilisers in agriculture, potash mining poses a range of environmental risks, including the generation of substantial volumes of solid waste containing high levels of sodium chloride alongside sulphates, potassium, and calcium. Solid waste accumulates in large quantities in various countries, including Belarus, Canada, Germany, Russia, Spain, and the UK [3]. The amount of solid waste generated per unit of final product ranges from 0.99 to 4.97 tonnes, depending on the mineralogical composition of the mined ore and the processing methods used [4, 5]. Notably, Belarus has already accumulated over 950 million tonnes of solid waste, Russia has over 270 million tonnes, and

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Canada has over 250 million tonnes [3, 6]. The solid halite waste deposited in salt dumps (Figure 1) is predominately composed of chlorides, sulphates, potassium, sodium, and calcium, which gradually precipitate over the course of several decades [7].

Figure 1. Conveyor line for transportation of halite waste to a salt dump at one of the potash enterprises of the Verkhnekamskoe Potash Deposit, Perm Krai, Russia.

Rainwater and meltwater transfer substantial quantities of dissolved ions to both groundwater and surface water. The insoluble fraction of the waste retains its porous nature, with 75–94% of precipitation seeping through dumps [8].

Filtration water, along with the amount of potash waste and natural conditions, has the potential to alter the chemical composition of water bodies and soils. This alteration can result in various consequences, such as subsidence of the earth's surface, the formation of halophytes, inhibition of vegetation growth, the occurrence of hazardous geological processes (rock collapse and intra-salt karst) and soil salinisation in the affected areas [9, 3, 6]. An increase in potash production poses a challenge to environmental protection due to its direct and indirect influence on natural components. The cumulative environmental harm caused by potash production is leading to an unfavourable environmental scenario in these areas, highlighting the urgent need for innovative waste management strategies.

In the process of designing potash production facilities, the emphasis should be placed on the implementation of functional and technological strategies to manage the recycling and neutralisation of potash waste. The management of potash waste involves intricate ecological, technological, and economic challenges, including safe storage and the potential for recycling or neutralisation.

Backfilling of mined areas (underground storage) stands out as the main and prevalent technique for minimising surface waste, albeit being the most expensive. Some countries opt for a hybrid approach involving backfilling and reclamation of salt dumps [3].

To this day, extensive experience has been acquired in the reclamation of coal dumps [10–15] as well as shale and other dumps, the rocks of which are fully or partially used to establish the fertile layer. Reclamation activities on such dumps are typically carried out for agricultural or forestry purposes.

The process of salt dump reclamation is distinctive due to the solubility of the rocks, known as halite waste, and their phytotoxic nature. The most effective method for potash dump reclamation is both sanitary and hygienic, involving minimal excavation and posing minimal geological risks such as erosion, karst formations, etc. Given the phytotoxic properties of salt waste, the use of insulation layers becomes essential to prevent the dump material from being utilised as soil for plant growth.

Foreign expertise in the reclamation of salt dumps shows the complexity and multi-phased characteristics of environmental interventions, encompassing a range of technical, technological, and biological strategies.

In Germany and France, two approaches to salt dump reclamation have been developed and implemented in compliance with environmental regulations. The first approach involves altering the shape of the salt dump (by cutting off a section), applying a layer of clay and bitumen to its surface, and establishing a soil-vegetative layer [16, 17]. The second approach revolves around either the natural or induced dissolution of the dump material and the subsequent collection of the wastewater in treatment wells, which are then released in a controlled manner into the tributaries of the Rhine [18]. The need for reclamation arises due to the proximity of salt dumps to agricultural areas, posing a risk of severe soil salinisation and potential degradation of agricultural produce yield and quality in the future.

The research examined how natural vegetation is restored on potash mine dumps. As part of the natural succession, the dumps become covered with plant species (shrubs and grasses) that show the greatest resistance to environmental conditions [19].

Lothar [20] studied ways to enhance the ecological condition of the areas near potash dumps. The experiments focused on leaching salts and introducing shrubs and trees. The findings indicated that the patented planting method facilitated the growth of shrubs and trees even in unfavourable conditions under similar circumstances.

A pilot experimental salt dump reclamation has been conducted in the Verkhnekamskoe Potash Deposit (VPD), the largest in Russia. The experiment included both technical and biological stages [21]. While the experimental reclamation showed effectiveness, it was not widely adopted.

This research introduces, for the first time, the findings of experiments on the establishment of stable plant communities on salt dumps under laboratory conditions. An experimental model was implemented using phytotesting, which is part of a diverse array of biotesting methods that assesses the accumulation of contaminants in natural, anthropogenic, technogenic, and agricultural soils. Integral indicators of soil quality were derived, including the condition and biomass of plants inhabiting them. The sensitivity of plants to external factors is evidenced through alterations in biochemical processes that influence the morphological characteristics of their growth and development.

The objective of the research was to evaluate the morphometric and biochemical parameters of plants throughout the reclamation process using different variants. This research presents the results of a laboratory model experiment focused on the reclamation of a salt dump in the VPD to mitigate the harmful effects of the filtration water from salt dumps on the environment.

The findings can be applied to conducting further experimental investigations in the field of biological reclamation in areas with dump complexes, particularly those involved in the design of waste management facilities within the potash industry.

2. Materials and methods

2.1. Study area

The VPD is located in Perm Krai, Russia (Figure 2) and is one of the leaders in terms of potassium salt reserves. According to geological estimates, the VPD has 96.4 billion tonnes of carnallite rock, 113.2 billion tonnes of sylvinites, and 4.65 trillion tonnes of rock salt [22].

The deposit is located only in the central part of the Solikamsk depression in the Pre-Ural foredeep [22]. In terms of geological formation, the VPD belongs to the Paleozoic era, the Permian period [23]. The entire salt mass of the deposit consists of a multilayer of potassium-magnesium and sodium salts. The underlying rock salt, sylvinite and carnallite zones, as well as the covering rock salt, are arranged in a sequence from bottom to top. The VPD covers an area of approximately 8200 km^2, extending for 206 km in the meridional direction and up to 56 km in the latitudinal direction [24].

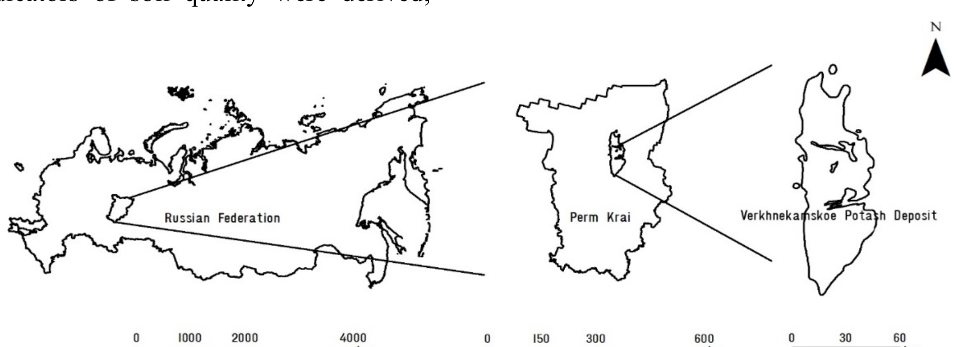


Figure 2. Study area.

Currently, 11 license areas with a total area of 1055 km^2 have been thoroughly examined on site [25]. In the VPD, potassium salt is mined underground. Potassium salts are currently extracted in six mines, and two mines are under construction [26].

Three major potash companies are currently operating in the VPD area: Uralkali, EuroChem Usolskiy, and Verkhnekamsk Potash Company. Dumps contain solid waste from the enrichment of sylvinite or carnallite ores through flotation or halurgical methods, along with solid waste from shaft sinking for potassium salt extraction and drilling. A total of 10 such dumps in Perm Krai and the Volgograd Region were identified in the State Register of Waste Disposal Facilities as of July 12, 2021, with an average area of about 1,000 thousand m (up to 1,900 thousand m), formed between 1964 and 1992 [27]. This waste is stored in specially designated areas, surrounded by dams, and conveniently accessible via roads (Figure 3).

The VPD salt dumps have an average height of 60 to 80 m, with their location determined by the mining and processing facility (Figure 2). According to Earth remote sensing data, the total area of land designated for salt dumps is 8.69 km^2.

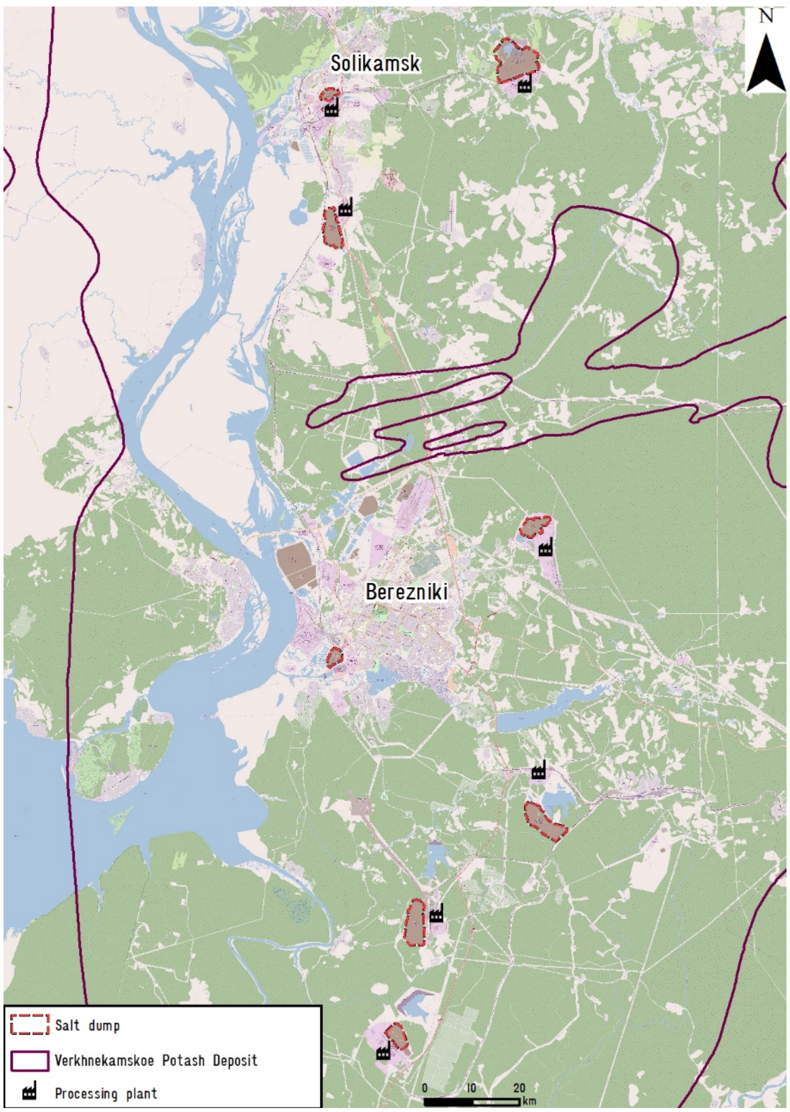


Figure 3. Location of salt dumps on the territory of the Verkhnekamskoe Potash Deposit.

2.2. Methodology

The experiment model involved phytotesting [28] of the fertile layer to determine the morphometric (height and weight) and biochemical parameters (redox activity) of test crops.

To isolate the waste, a protective screen was made as an intermediate layer. In this research, a typical natural geochemical clay barrier with various thicknesses was used, as referenced in [27].

The experiment (ratios of waste material – clay barrier – soil layer – sowing of grass mixture and woody vegetation) was conducted in a laboratory setting, considering the size and quantity of laboratory setups. The dimensions of the laboratory setups were as follows: wall thickness - 3 mm, volume of one container - 3 L, and internal dimensions: LxWxH - 100x100x300 mm. All materials used in the study (waste material, zonal soddy-podzolic soil, and clay) were sourced from the VPD near Berezniki. Three background samples were collected for comparative analysis: zonal soddy-podzolic soil from the VPD (from secondary mixed forest), fertile dark grey soil from Kungur, and vermiculite with Knop solution.

Dump material, natural clay, and zonal soil were placed in laboratory setups (Table 1, Figure 4). The thickness of the dump material in these laboratory setups remained uniform, mirroring the typical levelling process carried out during the technical phase of reclamation activities, resulting in a cohesive and solid structure.

Table 1. Laboratory experiment variants.

Variants	Thickness of the waste layer from the salt dump, cm	Thickness of the protective screen made of natural clay, cm	Soil layer thickness, cm
1	8	3	16
2	8	6	13
3	8	9-10	10
1.1	8	3	16
2.1	8	6	13
3.1	8	9-10	10
1B	8	3	16
2B	8	6	13
3B	8	9-10	10
Control SP (soddy-podzolic soil)	-	-	10
Control DG (dark grey soil)	-	-	10
Control V (vermiculite with Knop solution)	-	-	10

Figure 4. Laboratory setups according to data from Table 1 (from left to right: control DG, control SP, control V).

The thickness of the clay barrier varied depending on the soil layer, which should be at least 10 cm (root layer), as well as the size of the laboratory setups. Subsequently, the grass mixture was sown (Table 2) following the initial estimation of the sowing rate (Table 3), along with *Betula pubescens* seedlings. The experiment began on June 16, 2022, and the test crop was harvested on July 7, 2022 (21 days post planting); the tree crop was harvested on August 26, 2022.

The use of the grass mixture in the experiment was predicated on the resilience of the plants to suboptimal soil and adverse weather conditions. For example, the inclusion of cereal plants (*Festuca rubra* L., *Festuca pratensis* Huds., and *Phleum pratense* L.) was informed by their capacity to thrive in various soil and climate settings, in addition to their ability to actively grow in soils with limited agrochemical qualities.

Festuca rubra L. displays resistance to soil acidity, a common characteristic in the taiga zone of the VPD. *Phleum pratense* L. is capable of providing a projective cover reaching 70%, coupled with rapid growth and minimal upkeep demands.

The grass mixture contained only one legume plant, namely *Trifolium rubens* L. This particular plant demonstrates a propensity for vigorous growth in environments exposed to technogenesis. Additionally, *Trifolium rubens* L. exhibits resilience to mildly acidic and slightly turfy soils, thriving especially in nitrogen-deficient soil conditions.

All the seeds were categorised as high-quality seeds obtained through subsequent propagation of the original seeds. The selection of grasses for the grass mixture ensures the turfing of the reclamation area and resilience to frost and drought. The ratio of perennial grasses (Table 2) and seeding rates (Table 3) were determined according to the recommended practices for plant cultivation in forest areas for municipal solid waste (MSW) landfills [29], considering the size of laboratory setups. Following the sowing standards for forest areas, the quantity of seeds was doubled as the target for biological reclamation was a waste dump.

Table 2. Assortment of perennial grasses for biological reclamation.

No.	Plant	Contribution
1	*Festuca pratensis Huds.*	50%
2	*Festuca rubra L.*	20%
3	*Phleum pratense L.*	15%
4	*Trifolium rubens L.*	15%

Table 3. Sowing rates for perennial grass seeds.

No.	Plant	Sowing rate, kg/ha	Total for a 100 cm^2 plot according to contribution (×2), g
1	*Festuca pratensis Huds.*	31	0.062
2	*Festuca rubra L.*	31	0.062
3	*Phleum pratense L.*	18	0.036
4	*Trifolium rubens L.*	20	0.04
	Total grass mixture, g		0.2

From the date of the woody vegetation evaluation experiment on June 16, 2022 (Figure 5) and continuing until the withering of the birch stems on August 26, 2022, data regarding the height of the stems and quantity of leaves were recorded.

Figure 5. *Betula pubescens* seedlings at the beginning of the experiment (from left to right: 1B, 2B, 3B).

Phytotesting was conducted for the assessment of test crops in accordance with the patent [28]. On the 21st day (June 16, 2022–July 7, 2022) following the initial planting, the morphometric parameters (plant height and weight) and biochemical parameters (redox activity) of the test crops were measured. To evaluate and compare the growth and development rates of plants in various experimental scenarios, the height and weight of all plants were determined through the examination of a sample comprising 20 plants. This evaluation involved using an engineering ruler and electronic laboratory scales GR-202 (verification date: August 20, 2021).

The evaluation of plant response to a harmful environment involved the analysis of redox activity using a specific method [28]. In a study by Eremchenko et al. [30], it was observed that exposure to various stressors like ionising radiation, drought, salinity, and heavy metals led to the formation of organic radicals. These radicals impact the electron acceptor (free oxygen), resulting in the generation of peroxide radicals. Consequently, the development of oxidative stress due to the excessive production of reactive oxygen species (ROS) can be viewed as a general physiological and biochemical response to unfavourable environmental conditions in higher plants [30].

Soil samples selected before and after the experiment underwent analysis in the chemical laboratory at the Institute of Natural Science, Perm State National Research University. The analysis included the determination of chloride ions, potassium, sodium, and the pH level of the water extract. The identification of chloride ions was conducted through the argentometric method, as outlined in GOST 26425-85 [31]. The pH of the aqueous extract was measured using the potentiometric method on an RX-150 ion meter, following GOST 26423-85 [32]. The content of potassium and sodium was found using flame spectrophotometry on a PFA-378 flame photometer, in accordance with GOST R 54650-2011 [33]. The data derived from morphometric and biochemical analyses were processed using Excel software.

3. Results and Discussion

3.1. Morphometric parameters

A reduction in the morphometric characteristics of test crops [34] and woody vegetation is observed in correlation with a decrease in the thickness of the protective clay barrier.

The maximum plant height was reached (Figure 6, Figure 7) in background samples (control DG and control V). The elevated values can be attributed to favourable conditions promoting plant growth and the absence of a hostile environment. For instance, in the Control DG, the soil is rich in P_2O_5 (364 mg/kg) and K_2O (834 mg/kg) [34].

In experiment variants 3 and 3.1, where the clay screen had a maximum thickness (9–10 cm), the plant height was at its maximum compared to the remaining experiment variants.

The plant heights in experiment variants 1, 1.1 and 2, 2.1 exhibited subtle differences among one another, yet were considerably distinct from the plant heights in experiment variants 3, 3.1, and the control DG and control V. The most notable differences were observed between all experiment variants and the control SP. These differences can be attributed to the accumulation of macro- and micro-components in the soil brought in from the dump material or introduced during the sodding of the soil layer.

Based on the data obtained regarding the height of the birch stem, the most optimal outcomes were noted in the experiment variant 3B (Figure 8, Figure 9). This variant had the thickest protective screen barrier. The thicker the protective layer, the better the growth and development of plants, alongside heightened biological activity within the soil.

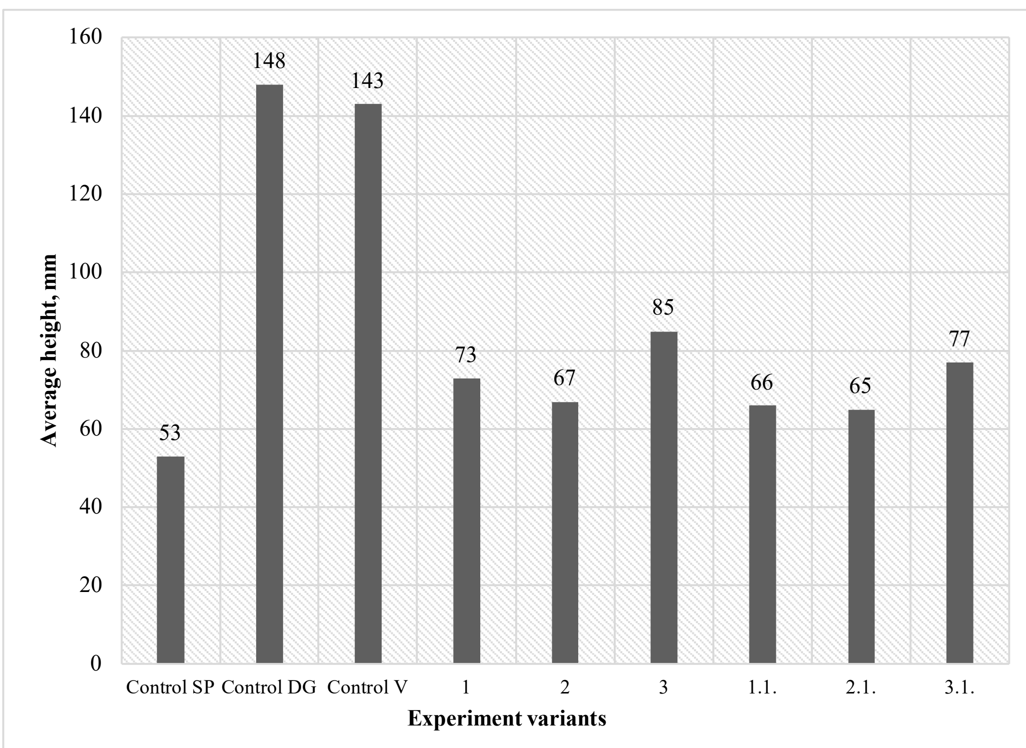
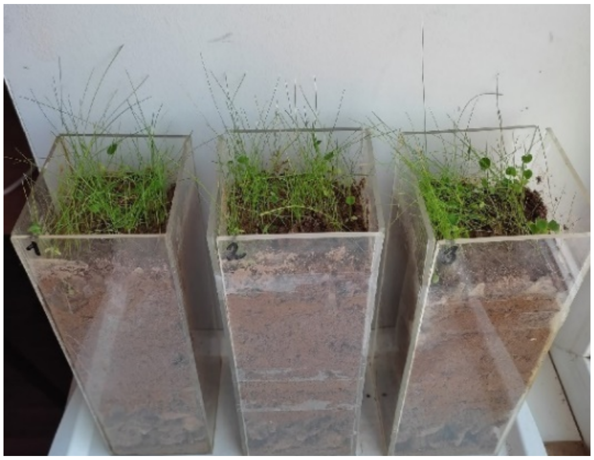
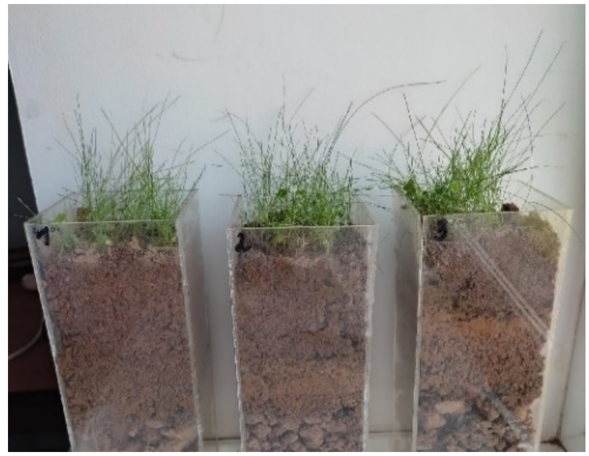


Figure 6. Average height of test crops, mm.



(a)



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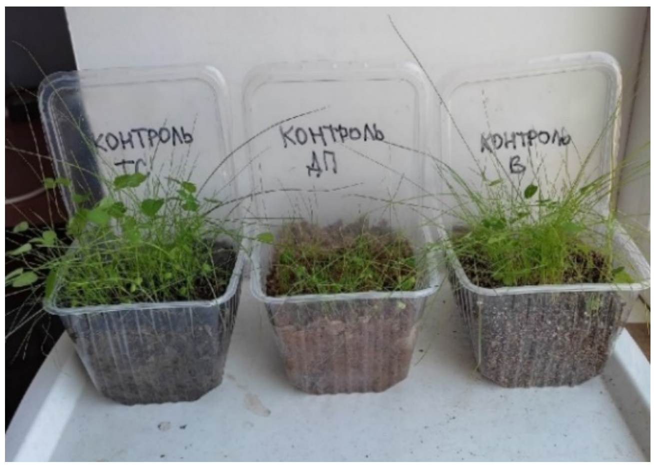

(c)

Figure 7. Height of test crops on the day of the experiment (21 days after planting (July 7, 2022)): A) experiment variants 1,2,3; B) experiment variants 1.1, 2.1, 3.1; C) controls (from left to right: control DG, control SP, control V).

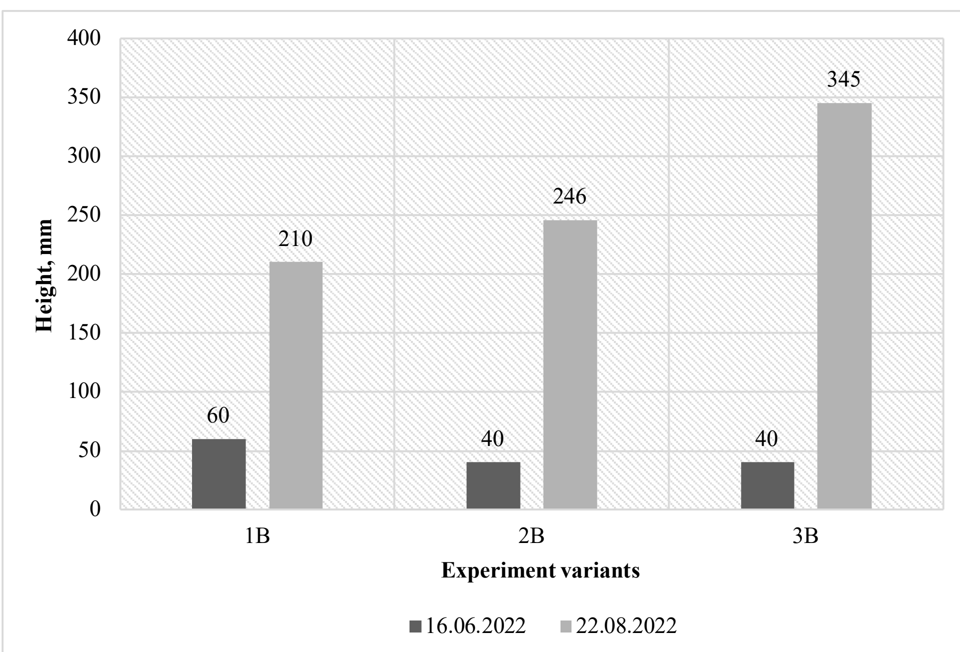

Figure 8. Height of birch stems before and after the experiment, mm.

(a)

(b)

Figure 9. Birch stem height: a) on the day of planting (June 16, 2022); from left to right: 1B, 2B, 3B; b) on the day of the experiment (August 26, 2022); from left to right: 3B, 2B, 1B.

Minor deviations (~0.002 g) were noted in the average biomass outcomes across all experiment variants (Figure 10). The control DG exhibited the highest plant mass values, which can be attributed to the soil's agrochemical properties. Concurrently, the trend of active biomass growth in the presence of thicker protective barriers persists.

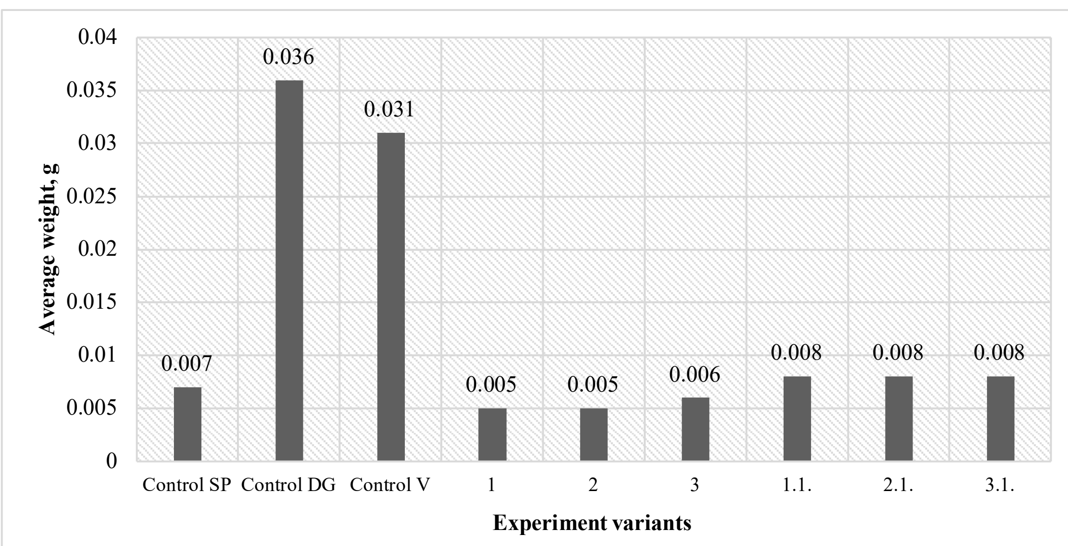

Figure 10. Average weight of test crops, g.

In comparison to the "ideal" control V (Figure 11), the growth rates were the lowest in control SP and in experiment variants 1, 1.1 and 2, 2.1. Experiment variants 1 and 2 with clay screen thicknesses of 3 cm and 6 cm, respectively, exhibited the lowest biomass value.

In relation to the "ideal" control DG (Figure 12), it was observed that control SP, along with experiment variants 1, 1.1 and 2, 2.1 exhibited the lowest growth rates. The experiment variants 1 and 2 with clay screen thicknesses of 3 cm and 6 cm, respectively, displayed the lowest biomass values.

Consequently, the plant height of experiment variants 3 and 3.1 was merely "satisfactory" based on the biological activity of the soil, compared to vermiculite and dark grey soil. The mass of plants across all experiment variants fell short of the threshold (exceeding 50%), indicating the toxicity of the environment.

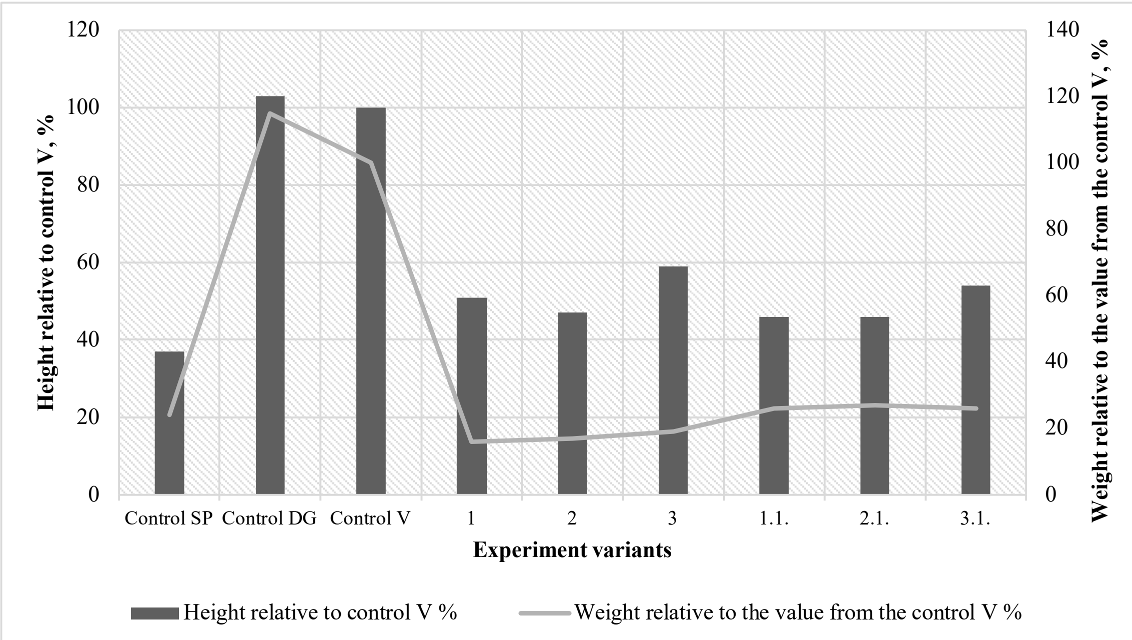

Figure 11. Height and weight of the test crop (relative to control V).

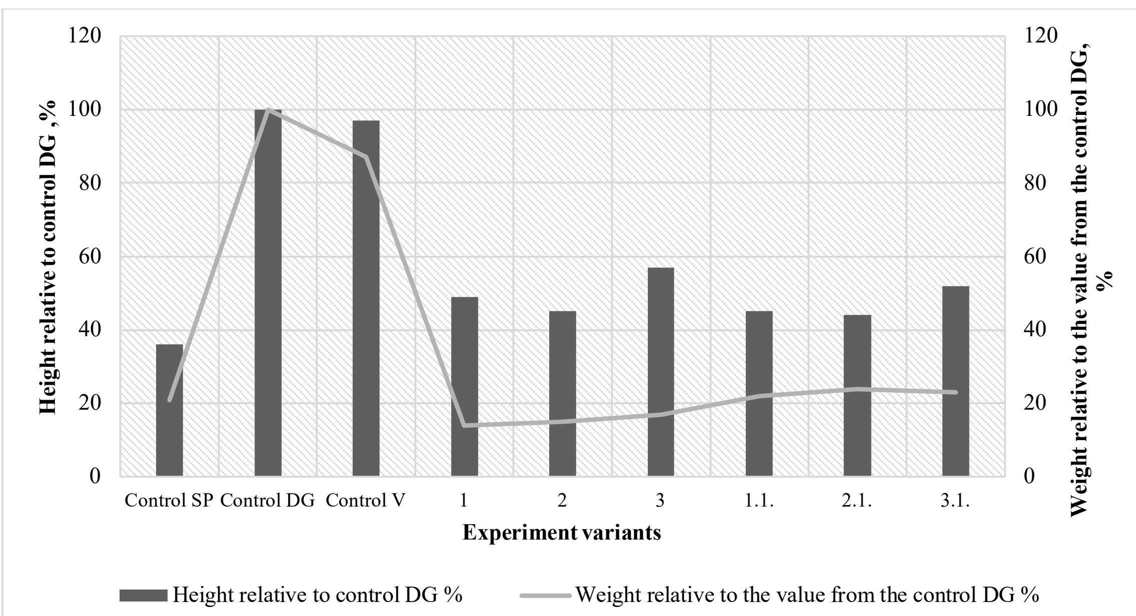

Figure 12. Height and weight of the test crop (relative to control DG).

Therefore, in the presence of a thinner protective layer of natural clay (up to 9–10 cm), despite the thick soil layer, plants become exposed to a toxic environment due to the vertical migration of salts from waste into the soil.

The selected grass mixture establishes a fairly stable phytocenosis on salt dumps, despite the limited agrochemical properties of the zonal soil and the toxic environment. However, ensuring an optimal projective cover and biological activity of soils largely depends on the technical stage of reclamation and the establishment of an effective protective layer to minimise the plant exposure to the hostile environment induced by the waste.

Woody vegetation, similar to grass mixtures, exhibited optimal growth and development indicators when using a thicker and denser protective layer of natural clay (9–10 cm). The occurrence of necrosis and wilting was noted on August 22, 2022, as a result of plant roots penetrating the clay barrier, consequently breaching it and entering the hostile environment of the dump material.

3.2. Biochemical parameters

As the thickness of the protective clay screen layer decreases, the redox activity of the test cultures increases.

Experiment variant 1, as well as 1.1 and 2, exhibited high redox activity (oxidative stress), with clay screen thicknesses of 3 cm and 6 cm, respectively (Figure 13). Under these conditions, plants are subjected to oxidative stress, which indicates the presence of a toxic environment [34]. In control SP, the stress was higher, which can be attributed to the acidic environment and poor agrochemical properties of the soil. These factors contribute to the degradation of plant growth and development. The most favourable conditions were observed in control DG and in experiment variants 3, 3.1, and 2.1.

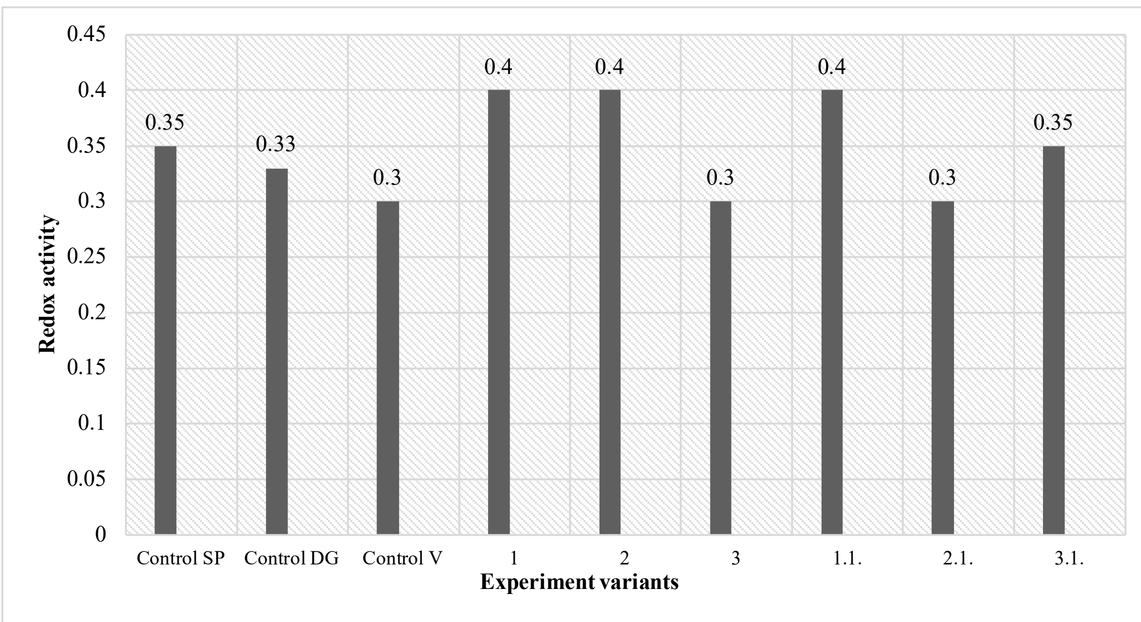

Figure 13. Oxidative stress of test cultures.

In comparison to control V, elevated stress levels were noted in experiment variants 1, 1.1, and 2, where the clay screen thickness was up to 6 cm. Plants in experiment variants 3, 3.1, and 2.1 (with clay screen thickness ranging from 6 to 9–10 cm) exhibited the least amount of stress compared to control V (Figure 14) and control DG (Figure 15).

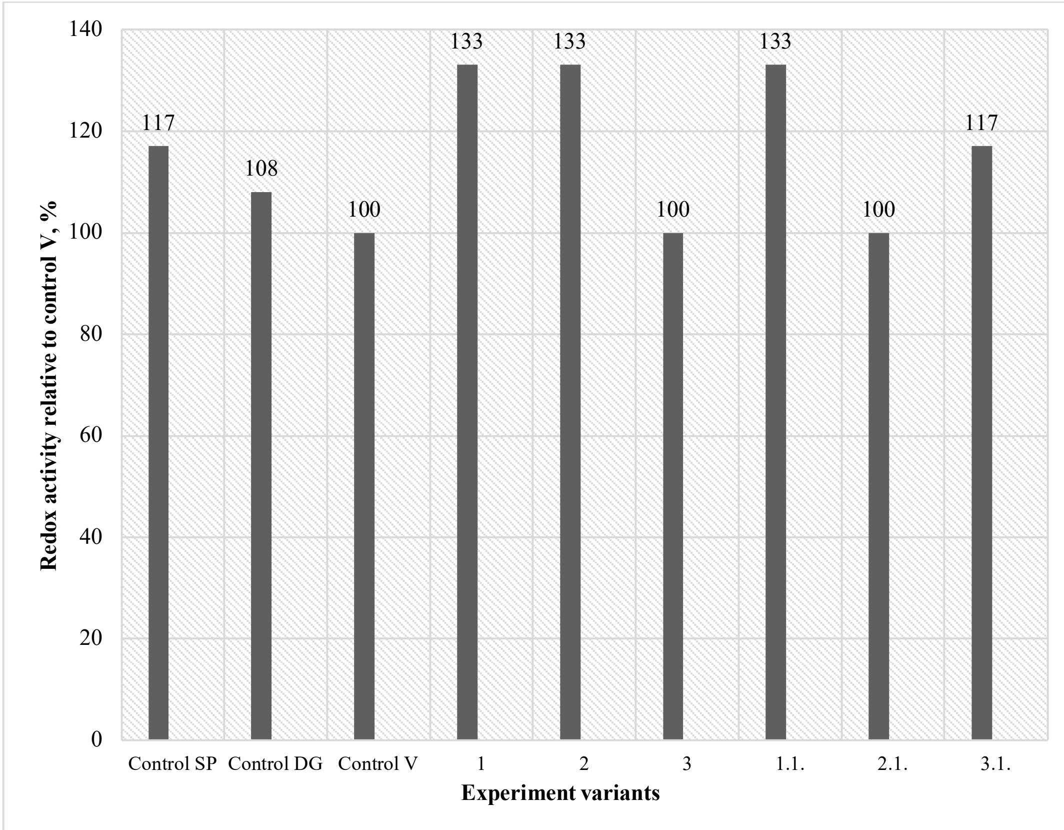

Figure 14. Oxidative stress of test crops (relative to control V).

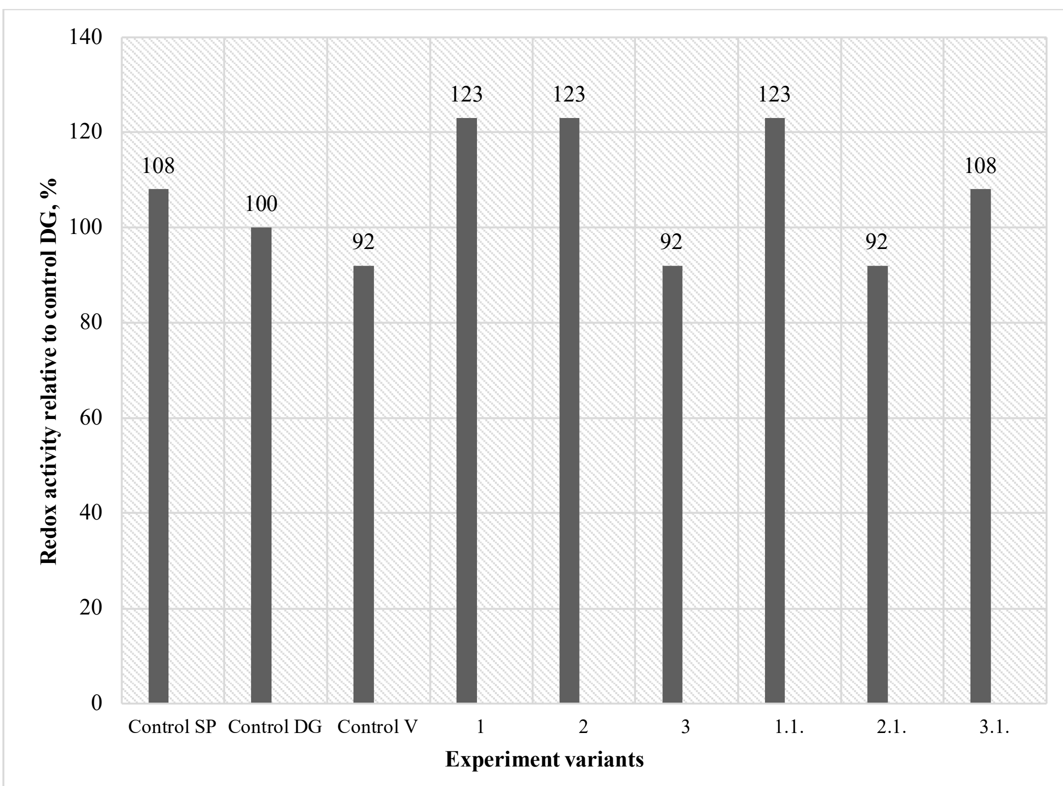

Figure 15. Oxidative stress of test crops (relative to control DG).

Therefore, the redox activity of the plant extract from experiment variants 3 and 3.1 indicates the absence of toxicity in the environment compared to vermiculite and dark grey soil. Experiment variants 1 and 1.1 were "moderately toxic" at best (up to 30%), which indicates the presence of oxidative stress in the test crops.

The findings also indicate that application of a thin protective layer of natural clay (up to 9–10 cm) leads to plants being subjected to a toxic environment due to the vertical migration of salts from waste into the soil, despite a thick soil layer. Vegetation on zonal acidic soddy-podzolic soil exhibited signs of stress. Therefore, the use of fertilisers is deemed necessary for zonal soils.

3.3. Chemical and analytical studies

When biologically reclaiming a salt dump, it is important to consider the vertical capillary movement of salts through soil pores due to moisture evaporation. To avoid the accumulation of salts in the fertile soil layer, efficient implementation of the technical stage of reclamation is essential. This involves the isolation of the fertile soil layer from the toxic waste environment as much as possible, including establishing an optimal projective cover in order to reduce soil moisture evaporation and increase transpiration.

Through the examination of potassium, sodium, and chloride levels in soils, the buildup of these elements in experiment variants 1B, 2B, and 3B is prominently evident (Table 4). The accumulation of salts depends on the duration of the experiment.

The most substantial concentrations of chlorides, sodium, and potassium can be observed in the experiment variants with the thinnest clay screen (1B). Therefore, as the protective screen layer increases in thickness, the rate of accumulation decreases. However, even with the clay barrier, the salts still managed to enter the root layer.

When examining the experiment variants with grass mixtures, the results exhibit ambiguity due to the brief duration of the experiment and the limited sample range. The findings also reflect the salt accumulation process in the soil layer compared to the background sample. However, the greater the projective cover (formation of a dense phytocenosis) and the greater the thickness of the protective barrier (9–10 cm), the lower the content of chloride ions in the soil, as evidenced in experiment variants 3 and 3.1, for instance. The environmental conditions experienced a shift towards increased acidity in comparison to the background (Table 4).

Table 4. Chemical analysis of soils.

	pH of aqueous extract, pH units	Chloride, mmol/100 g	Sodium, mmol/100 g	Potassium, mmol/100 g
Control SP	5.5	0.07	0.20	0.02
1.1	4.3	4.03	2.45	0.04
2.1	4.2	4.20	1.90	0.04
3.1	4.3	2.59	0.65	0.03
1	5.2	0.12	0.06	0.01
2	5.2	0.15	0.05	0.01
3	5.1	0.10	0.15	0.02
1B	4.4	39.80	38	0.06
2B	4.6	20.50	17.70	0.03
3B	4.6	10.16	5.95	0.03

Therefore, the optimal biological activity of soils and the development of plants on salt dumps depend on the technical stage of reclamation, agrochemical soil characteristics, as well as climatic and environmental factors. It is necessary to explore alternative approaches for using the protective barrier, either natural (composed of clay or heavy loam) and/or artificial (using geomembranes or synthetic materials), as well as soils, fertilisers, biological products, and other plants, to enhance the efficacy of salt dump conservation during reclamation.

4. Discussion

Environmental pollution arising from mining waste, specifically soil salinisation, poses a pressing issue in industrial settings. The majority of saline areas are used for agriculture, yet the proportion of lands disrupted by human activity due to salinisation grows annually. Adverse environmental impacts linked to soil salinisation emerge from the inappropriate selection and implementation of reclamation strategies, incidents of oil leakage, potassium salt extraction, and the application of de-icing agents.

Salt mining and production enterprises are distinguished by the occurrence of technogenic salinisation, wherein soil salinisation takes place even in humid climate conditions [6, 9, 35]. The presence of easily soluble salts in the soil solution may lead to soil salinisation. Harmful to vegetation are substances such as chlorides ($NaCl$, $CaCl_2$, $MgCl_2$), sulphates (Na_2SO_4, $MgSO_4$), carbonates (Na_2CO_3, $NaHCO_3$) and nitrates ($NaNO_3$, KNO_3). The most common waste products from potash plants are sodium chloride and potassium chloride, with the latter serving as a primary plant nutrient. Within soil environments, potassium exists in forms that are exchangeable and water-soluble, as well as being a component of clay minerals in the soil [36]. Potassium enhances the stability of cell biocolloids and influences metabolic processes, boosting system vitality, facilitating water movement into cells, and raising osmotic pressure levels. The toxic effect of potassium chloride stems from the toxicity associated with chloride ions. The toxic effect of chlorine ions can be elucidated by their high mobility and proficient ability to quickly penetrate into plant root cells without remaining in the soil solution [37, 38]. Among the salinities, one of the most toxic to plants is sodium chloride salinity ($NaCl$) [37; 38]. Toxic effects are induced by specific doses of sodium chloride. The presence of surplus sodium and chlorine ions in the soil solution results in their effective outcompeting of K^+, Ca^{2+}, and Mg^{2+} ions upon entry into plant cells. This phenomenon induces metabolic stress, impedes growth, disrupts the stomatal apparatus, and leads to plant death [39]. A notable disparity exists in the response of chloride ions within the soil contaminated with potassium and sodium chlorides. When exposed to sodium chloride contamination, there is a notable decline in the water filtration rate, leading to a reduced release of chloride ions from the contaminated soil, as influenced by the impact of sodium on soil structure degradation. The higher the concentration of sodium, the slower the removal of chloride ions from the soil [38]. The inhibition of stomatal conductivity caused by the harmful effects of sodium chloride results in compromised photosynthesis attributed to diminished carbon dioxide assimilation, destruction of the pigment system, ion imbalance, and disturbances in the water regime.

A model experiment using phytotesting falls within a wide array of biotesting techniques. This approach indicates the extent of pollutant buildup in various types of soils, including natural, anthropogenic, technogenic, and agricultural ones. Typically, the determination of pollutant levels in these soils relies on physicochemical and chemical methods. However, while analytical control methods confirm the presence of pollutants, they do not offer insights into the potential effects of the identified pollutants on organisms inhabiting the environment [40]. Higher plants play a crucial role as the primary test subjects, as they form the foundation of trophic and energy interactions within the biocenosis. The condition and biomass of plants inhabiting a particular area are recognised as the fundamental and essential measure of soil quality [41]. The response of plants to external influences is evident through alterations in biochemical processes and is reflected in the morphological parameters of growth and development. The main principle behind the phytotesting procedure lies in the documentation of these parameters in plant organisms evolving in the experimental samples in comparison to control variants that do not contain the examined substances. The basis of the phytotesting method is the capacity of plants to react to environmental shifts, thereby enabling the evaluation of the toxicity or bioactivity of various entities [41, 42]. The method is relevant in model studies concerning the regulation of contaminants [43] and the assessment of the bioactivity of various chemicals and industrial wastes [44-49]. The cultivation of the test culture is conducted under conditions involving direct exposure to the test object. It is imperative that the control and experimental soils exhibit a high degree of similarity in terms of their structure and composition (with the exception of the chemicals and pollutants being tested). Phytotesting as a method for assessing soils has a longstanding history in the assessment of soil fertility in agricultural lands. More recently, it has been applied in the environmental sector to evaluate the ecological integrity of natural environments such as water and soil [50]. Due to considerable variations in resistance levels among species, the use of multiple test cultures is advised [50].

The research conducted by Lisovitskaya [50] demonstrates the efficacy of using *Lepidium sativum*. This test culture proved to be valuable for detecting contamination in the investigated entities caused by a variety of pollutants such as heavy metals, hydrocarbons, radioactive materials, and others, especially in instances of complex contamination. Any adverse impact on the experimental system would be reflected in alterations to specific parameters. These test parameters include seed germination, germination vigour, germination density, root length, seedling length, raw and dried biomass, and plant length, including roots [42, 50].

In the research conducted by Kosareva and Vishnevskaya [51], the focus was on investigating the levels of sodium and potassium ions present in plants belonging to the genus *Medicago sp.* (alfalfa), which differ in degrees of salt tolerance. The results of the study revealed that all perennial alfalfa samples exhibited an accumulation of sodium ions exceeding normal levels. However, a definitive link between sodium content and salt tolerance in the samples was not established. Certain samples displayed a resistance to high levels of sodium ions, suggesting the activation of plant adaptation mechanisms such as excess ion accumulation and neutralisation in vacuoles.

The impact of chloride salinity on the germination and growth of seedlings of *Brassica napus* L. was examined in the research by Hasan et al. [52]. Various concentrations of NaCl ranging from 50 to 200 mM were investigated. The morphometric parameters of plants were assessed on days 3.5 and 7. The presence of salinity resulted in the inhibition of seed germination, suppression of hypocotyl growth, and reduction of root growth.

In the study by Chartzoulakis [53], it was observed that cultivation of *Cucumis sativus* L. in soil with varying NaCl concentrations ranging from 0 to 190 mM within a greenhouse environment. Notably, salinity levels at 8.5 mM exhibited no significant impact on plant productivity. However, exposure to elevated salinity levels (25, 50, 120, and 190 mM) resulted in stomatal closure and a notable reduction in photosynthetic rate [53]. Furthermore, there was a linear decrease in both leaf expansion rate and final leaf size with the increase in external NaCl concentration. These findings indicate that salinity affects the growth of cucumbers by reducing photosynthesis and the overall photosynthetic area [53].

Some researchers go beyond mere morphological changes, encompassing biochemical responses [54] and mutagenic effects [55, 56]. Phytotesting serves not only as a tool for assessing soil toxicity but also as a criterion for soil resilience against contamination [57, 58]. The weaker the response of the test culture to pollution, the greater the soil's resilience to such toxicants. Soil that, in spite of being polluted, has retained its ecological functions for supporting plant growth and development will exhibit more stability compared to polluted soil, where plants possess weaker biometric parameters. Thus, phytotesting emerges as a valuable approach to forecasting the repercussions of harmful effects on the environment. The experimental response encapsulates the impact of all biologically harmful factors, including both physical and chemical influences, along with the effect of present biotic factors [59].

5. Conclusions

The environmental implications of prolonged mining and production of potash fertilisers are clearly visible. Operations related to mining and disposing of processing waste play a major role in causing environmental impacts. In order to improve the ecological condition of the areas, the outcomes of a model laboratory experiment concerning the reclamation of a salt dump for the Verkhnekamskoe Potash Deposit (Perm Krai, Russia) are presented using phytotesting. The primary objective was to evaluate the toxicity levels and the aggressive environmental impact. Research conducted on the biological reclamation of a salt dump in laboratory conditions indicates that the efficacy of biological reclamation depends on the successful execution of the technical stage of reclamation.

Several conclusions can be drawn from the collected data:

1. A decrease in the thickness of the protective clay screen layer from 10.0 to 6.0 cm or more results in a reduction in the morphometric characteristics of the test crops (such as height and weight) and woody vegetation, leading to the creation of an unfavourable setting for the growth and progression of plants;
2. The reduction in thickness of the protective clay screen layer is correlated with an increase in the redox activity of the test crops, thereby indicating environmental toxicity;
3. An evaluation comparing the cereal and legume crops utilised in the study revealed a higher level of stability and sod in the experiment variants featuring cereal crops (*Festuca rubra* L., *Festuca pratensis* Huds., *Phleum pratense* L.);
4. Birch seedlings displayed elevated morphometric parameters, such as rapid growth, until their roots breached the clay screen, reaching the halite waste, resulting in leaf necrosis and wilting in the seedlings;
5. The accumulation of potassium, sodium, and chlorides in soils was clearly visible in experiment variants with woody vegetation, which is associated with the duration of the experiment. The experiment variants with the thinnest clay screen layer (1B) exhibited the

highest accumulation of chlorides, sodium, and potassium.

Therefore, based on experimental data, phytotesting serves as a valuable method for assessing soil toxicity and a parameter for the soil's resilience against pollution. The weaker the response of the test culture to pollution, the higher the soil's resilience to this type of toxicant. The test response serves as a comprehensive evaluation of all detrimental biological factors, encompassing both physical and chemical impacts, thus offering a dependable depiction of the biological vitality of soils under adverse conditions.

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آزمایش گیاهی به عنوان ابزاری در ارزیابی اثربخشی احیای زباله نمک

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چکیده:

استفاده از ذخایر پتاس پیامدهای زیست محیطی مختلفی دارد، مانند تولید حجم قابل توجهی زباله جامد حاوی سطوح بالای کلرید سدیم. تجمع آسیب‌های زیست محیطی باعث ایجاد یک سناریوی زیست محیطی نامطلوب در مناطق تولید پتاس می‌شود که نیازمند بررسی راه حل‌های مدیریت پسماند است. رویکرد غالب برای کاهش زباله‌های سطحی شامل پر کردن مناطق استخراج شده است. در کشورهای دیگر، احیای زباله نمک در کنار پرکردن پس‌پوش استفاده می‌شود. ویژگی متمایز احیای زباله نمک در حلالیت آب و سمیت گیاهی سنگ تخلیه نهفته است. این تحقیق با هدف ارزیابی پارامترهای مورفومتریک و بیوشیمیایی (با استفاده از آزمایش گیاهی) پوشش گیاهی در طول فرآیند احیای زباله نمکی با استفاده از انواع مختلف انجام شده است. احیای مدل در یک محیط آزمایشگاهی، که در آن سه نوع مختلف تحت آزمایش قرار گرفتند، انجام شد. کاهش ضخامت سد رسی محافظ منجر به کاهش جنبه‌های مورفومتریک محصولات آزمایشی و همچنین پوشش گیاهی چوبی شد. کاهش ضخامت سد رسی محافظ منجر به افزایش فعالیت اکسیداسیون و کاهش محصولات مورد بررسی می شود، بنابراین به سمت سمیت بالقوه محیطی اشاره می‌کند. پارامترهای مورفومتریک و بیوشیمیایی برتر در پوشش گیاهی دارای پوشش محافظ قابل توجهی مشاهده شد که به امکان استفاده از لایه‌های عایق برای احیای زباله نمک اشاره کرد. آزمایش گیاهی به عنوان یک رویکرد شاخص برای ارزیابی سمیت خاک و به عنوان پارامتری برای تعیین انعطاف پذیری خاک در برابر آلودگی عمل می کند. یافته‌ها پتانسیلی برای کاربرد در تحقیقات بیشتر در زمینه احیای بیولوژیکی در مناطق دارای مکان‌های تخلیه دارد.

کلمات کلیدی: نمک های پتاسیم، سنگ های سربار، سمیت گیاهی، احیا، آزمایش گیاهی.