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STUDY OF PLANT SETS WITH FURTHER DEVELOPMENT OF PHYTOREMEDIATION TECHNOLOGY

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Coal dumps occupy a large area, which could be used for agriculture. These coal dumps have low pH, EC and nutrient concentrations. The concentration of toxic elements exceeds the permissible norm by several times. These toxic elements pollute the lithosphere, hydrosphere and atmosphere. Phytoremediation is one of the ways to solve this problem. The idea of phytoremediation consists in using plants.

In this experiment, plants were considered that are typical for the climatic conditions of the steppe zone of Ukraine. Plants were distributed into 8 sets. In each set there was one representative from the cereal family, one from the legumes and one from the cruciferous family. Such plants as: *Hordeum murinum L., Bromus japonicus., Dactylis, Bromopsis ramosa, Pisum, Trifolium, Sinapis and Capsella bursa-pastoris L.* were used as phytoindicators. Plants were planted in four different environments: 1) water (control); 2) loam (80%) + chernozem (20%); 3) loam (70%) + chernozem (30%); 4) loam (50%) + chernozem (20%) + substrate from coal dump (30%). Loam and chernozem were selected in ecologically clean areas. Substrate from coal dump was selected from mining industry "Heroiv Kosmosy".

The growth experiment showed that *Pisum* and *Sinapis* had good germination on research substrate. *Pisum* germinated on each set and on each substrate. Also, *Pisum* had the highest growth rates and biomass among the plants studied. *Sinapis* did not germinate in only one set № 3 and two environments (water and (70/30). In other sets, *Sinapis* had a high yield and proved to be a potential phytoremediator.

Set № 1 had a better growth results.The results have shown that these plants can be used as pioneers. In this set, all three plants germinated on all studied substrates. The studied plants have high growth rates and high biomass. In the future, these plants can be considered as phytoremediators of coal dumps. It is also possible to consider the technology of phytoremediation based on the obtained results. *Key words:* contaminated substrate, phytoremediation, plant sets, pioneer plants, growth test, biomass.

Дослідження рослинних сетів з подальшим розвитком технології фіторекультивації. Красовський С.А., Ковров О.С.

Вугільні відвали займають велику територію, яку можна було б використовувати для сільського господарства. Ці вугільні відвали мають низький рівень pH, EC та концентрацію поживних речовин. Концентрація токсичних елементів перевищує допустиму норму в рази. Ці отруйні елементи забруднюють літосферу, гідросферу й атмосферу. Фіторемедіація є одним із способів вирішення цієї проблеми. Ідея фіторемедіації полягає у використанні рослин.

У цьому досліді розглядалися рослини, що характерні для кліматичних умов степової зони України. Рослини були розділені на 8 сетів. У кожному сеті були по одному представнику з сімейства злакових, бобових і хрестоцвітих. Як фітоіндикатори використовували такі рослини: *Hordeum murinum L., Bromus japonicus., Dactylis, Bromopsis ramosa, Pisum, Trifolium, Sinapis та Capsella bursa-pastoris L.* Рослини були висаджені в чотирьох різних середовищах: 1) вода (контроль); 2) суглинок (80%) + чорнозем (20%); 3) суглинок (70%) + чорнозем (30%); 4) суглинок (50%) + чорнозем (20%) + субстрат з відвалу (30%). Суглинок і чорнозем відбиралися в екологічно чистих районах. Субстрат з вугільного відвалу був відібраний з гірничодобувної промисловості «Героїв Космосу».

Ростовий тест показав, що *Pisum і Sinapis* мають хорошу схожість на дослідному субстраті. *Pisum* проростав в кожному сеті та на кожному субстраті. Крім того, *Pisum* мав найкращі ростові показники та показники біомаси серед досліджуваних рослин. В сеті під № 3 та двох середовищах (вода та (70/30)) *Sinapis* не проростав. В інших сетах *Sinapis* мав високу врожайність, що дає змогу його розглядати як потенційоного фіторемедіатора.

Сет № 1 показав кращі ростові результати. Результати показали, що ці рослини можна використовувати у якості піонерних видів. У даному сеті всі три рослини проросли на всіх досліджуваних субстратах. Досліджувані рослини мають високі ростові показники та високу біомасу. У перспективі ці рослини можна розглядати, як фіторемедіаторами вугільних відвалів. На основі отриманих результатів також можна розглянути технологію фіторемедіації. *Ключові слова:* вугільний відвал, фіторемедіація, рослині сети, рослини-піонери, ростовий сет, біомаса.

Problem statement. The Ukrainian energy sector is dependent on the coal industry. Coal industry has negative impact on the environment. One of these impacts is the accumulation of rock on a land that could be used for agriculture. These dumps occupy a large territory and have a negative impact on the environment. One of the methods of solving this problem is phytoremediation. Phytoremediation is a method of remediation with the involvement of plants. Due to the specific characteristics of dumps and climatic conditions, it is difficult for plants to adapt and grow. Physico-chemical properties of coal dumps are not favorable for growing plants. Usually, coal dumps have a low pH level, EC and a high concentration of toxic elements. The main idea of this experiment was to select stress-resistant plants for various substrates.

Relevance of the problem. To choose stress-resistant plants for the phytoremediation method. Analyze research plant sets and choose the most effective.

The connection of author's work with important scientific and practical tasks. The authors studied the growth indicators of plants that can potentially be used for phytoremediation of coal dumps, with different substrates. Different plant sets were analyzed to improve phyto conditions on the studied substrates.

Analysis of recent research and publications. The coal industry is one of the main industries that provides the energy sector of Ukraine. Moreover, it has a negative impact on the environment. One of the negative consequences is the formation and accumulation of rock on coal dumps. These landfills contain a substrate with low pH, EC and high concentrations of toxic elements. One of the ways to solve this problem is the use of plants. This method is known as phytoremediation. The main requirements for plant phytoremediators are low requirements for climatic conditions and stress resistance to toxic elements. It was found that *Calendula officinalis and Althaea rosea* are resistant to Cd and can accumulate cadmium [1]. High extraction properties were recorded for species such as sunflower and ryegrass [2]. *Trifolium alexandrinum* has also proven itself as a good phytoextractor. This plant, in addition to being well adapted to the substrate with heavy metals, also has a high biomass and a fast life cycle, which allows it to be effectively used as a phytoremediator [3]. *Oenothera glazioviana* showed high stabilizing properties when grown on soil contaminated with copper. This plant has high tolerance and low copper transport capacity [4]. *Sesbania* proved to be an excellent stabilizer for such metals as Cu, Zn, and Cr. During the experiment, zinc was removed from the contaminated soil, and other metals accumulated in the root system [5]. Representatives of the leguminous family are known to have the ability to fix atmospheric nitrogen and increase the nitrogen content in the soil. But high concentrations of heavy metals in the substrate disturb the metabolic life processes of such legumes as soybeans and peas [6]. Recent research has shown that short-term plants such as: *Vigna, Z. mays, B. juncea, H. annuus, J. Curcas* have high phytoremediation potential [7]. Grasses can be considered as a potential phytoremediator and can be used to mitigate toxic elements from contaminated soil. Herbs belong to the genera *Agrostis, Agropyron, Alopecurus, Andropogon, Anthoxathum, Arrenatherum, Avena, Brachiaria, Cymbopogon, Bromus, Calamagrostis, Chloris, Cynodon, Dactylis, Digitaria, Elymus, Elytrigia, Eremochloa, Festuca, Lolium, Lygeum, Miscanthus, Panicum, Paspalum, Pennisetum, Phleum, Phragmites, Piptatherum, Poa, Setaria, Sorghum, Secale, Spartina, Stipa, Typha, Vetiveria* are often used to remove toxic metals from polluted areas [8]. Among the cereal family, corn *(Zea mays)* is the largest producer of biomass that is highly tolerant to toxic metals. Other species, such as *Triticum aestivum and Hordeum vulgare*, are used to reduce the concentration of toxic elements in the soil. Plants such as *Hordeum murinum and Japanese brome (Bromus japonicus)* have adapted perfectly to the coal dump substrate. When the pH was lowered, the plants studied showed their stress resistance [9]. It was established that the investigated plants, *H.murinum and B.japonicus* have adaptive resistance to heavy metals, both plants are capable of accumulating heavy metals in the root system and shoots, and accumulate these elements, which allows considering these plants as "pioneer plants" with the subsequent possibility of phytoremediation of coal mining waste dumps [10]. The results of the study showed that *Bromopsis inermis holub* grows better not only when watering is increased, but also when adding solutions with different concentrations of MPC of heavy metals [11]. Some species of cruciferous plants are able to produce significant amounts of biomass, which is an undeniable advantage in phytoremediation. Accumulation of biomass can be directed both above-ground (forage or leafy types of vegetables) and underground (root crops – rutabaga, turnips). *Capsella bursa-pastoris* has been found to grow well in cadmium contaminated soil.

Highlighting previously unresolved parts of the general problem, to which the article is devoted. The growth indicators of plant sets were studied. The growth indicators of the studied plants on different substrates were analyzed. On the basis of the obtained results, it is possible to choose plants for further phytoremediation of coal dumps.

Originality. During the experiment, the growth rates of the plants under study and their biomass were determined. On the basis of the obtained data, it is possible to select a set of plants that showed the best result for reclamation of coal mining dumps.

Methodological and scientific significance. Analysis of growth parameters of plants. Development of technologies for phytoremediation of coal dumps.

Presentation of the main material. To conduct this experiment, scientists used their own plant set. It has the name of the «brotherhood plant». Its foundation was the use of three plants from different families. Each plant set had one representative from the cereal family, one from the legume family, and one from the cruciferous family. In this way, the authors tried to investigate the effect of wild cereals with nitrogen-fixing plants. The authors' idea was to use pioneer plants, undemanding to substrate conditions and climatic conditions, which will enhance the growth and biomass indicators of each other**.** Such plants as: *Hordeum murinum L., Bromus japonicus., Dactylis, Bromopsis* *ramosa, Pisum, Trifolium, Sinapis and Capsella bursa-pastoris L.* were used as phytoindicators of the typical ruderal plants vegetation of the steppe region of Ukraine 8 sets were created (Table 1).

Table 1

Plant sets

The number of the set	Plants
1	*Hordeum L., Trifolium, Sinapis*
2	*Hordeum L., Pisum, Capsella L.,*
3	*Bromus j., Pisum, Sinapis*
4	*Bromus j., Trifolium, Capsella L.,*
5	*Dactylis, Trifolium, Capsella L.,*
6	*Dactylis, Pisum, Sinapis*
7	*Bromopsis r., Pisum, Capsella L.,*
8	*Bromopsis r., Trifolium, Sinapis*

Plants were planted in four different environments: 1) water (control); 2) loam (80%) + chernozem (20%); 3) loam (70%) + chernozem (30%); 4) loam (50%) + chernozem (20%) + substrate from coal dump (30%). Loam and chernozem were selected in ecologically clean areas. Substrate from coal dump was selected from mining industry "Heroiv Kosmosy". Substrate from coal dump have a low concentration of pH, EC and nutrients. Also, have a high concentration of heavy metals [9]. Each 8 sets with plants were planted in the corresponding 4 environments. Petri dishes were used for experiment. 8 of them were filled with tap water. 24 of them were filled with a suitable environment (50 g). Twenty seeds of each plant species were transferred to the dishes. The humidity of the growth substrate level was maintained at 70% of field capacity throughout the experiment. The experiment lasted 21 days.

The growth experiment showed that *Pisum* better adapted to other plants and substrate conditions. Firstly, this plant germinated in all sets and in all substrates. Secondly, *Pisum* showed better growth results, than other plants (Fig. 1). *Pisum* had longer roots, higher shoots length and higher biomass (Fig. 2).

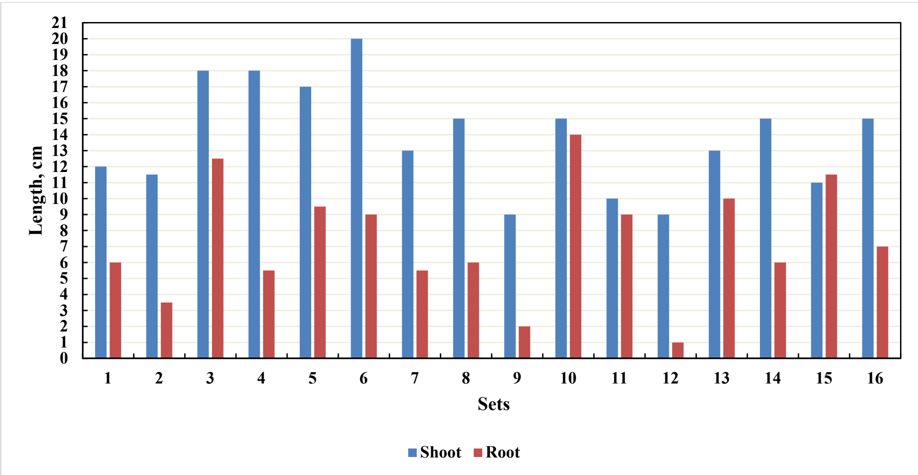

Fig. 1. The length of the root and shoot systems of Pisum in different plant sets

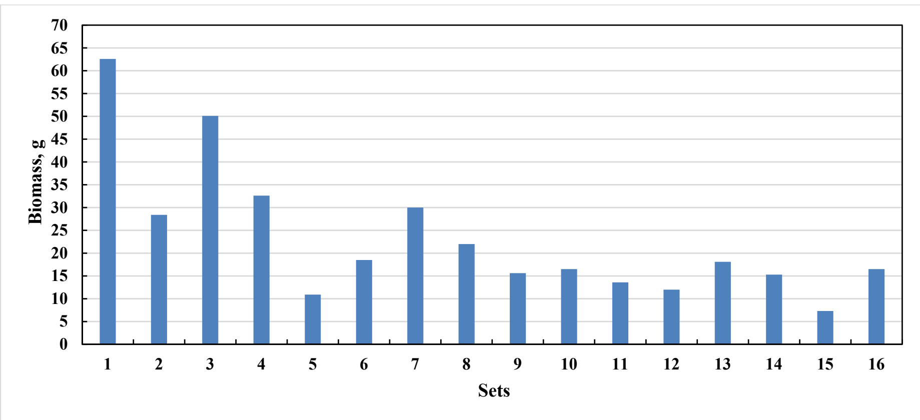

Fig. 2. Biomass of Pisum in different plant sets

*1 – set № 2 on the water; 2 – set № 3 on the water; 3 – set № 6 on the water; 4 – set № 7 on the water; 5 – set № 2 (80/20) ; 6 – set № 3 (80/20); 7 – set № 6 (80/20); 8 – set № 7 (80/20); 9 – set № 2 (70/30); 10 – set № 3 (70/30); 11 – set № 6 (70/30); 12 – set № 7 (70/30); 13 – set № 2 (50/30/20); 14 – set № 3 (50/30/20); 15 – set № 6 (50/30/20); 16 – set № 7 (50/30/20)

The obtained results show that *Pisum* adapt to different substrates and have high biomass, which makes it possible to consider it as a phytoremediator.

High growth rates were also recorded in *Sinapis*. The results are presented in figures 3 and 4.

Sinapis did not germinate in only one set № 3 and two environments (water and (70/30). In other sets, *Sinapis* had a high yield and proved to be a potential phytoremediator.

Set № 1 showed the best results among plant sets. Figure 5–6 shows the growth indicators of the plants from this set and their biomass. The results show that *Hordeum L.,* germinates well on any substrate. *Trifolium and Sinapis* have a big biomass.

The obtained results indicate that this set is best suited for the remediation of the contaminated area. After all, in this set, representatives of the cereal, legume and cruciferous families showed good results.

The main conclusions. The results of the growth test are presented in this article. Various variations of plant sets were considered, for potential use in phytoremediation of contaminated lands. The results show that plants like *Pisum* and *Sinapis* are versatile plants and can be used as pioneer plants. These plants had high growth rates and a large biomass on all the studied substrates. Set № 1 (*Hordeum L., Trifolium, Sinapis*) proved to be the best growth set. All plants from this set germinated and had high growth rates. In other researched sets, at least one representative of each species did not germinate. This can be explained by biological competition of species. In the future, it is planned to emphasize the study of set № 1, with further development of phytoremediation technologies.

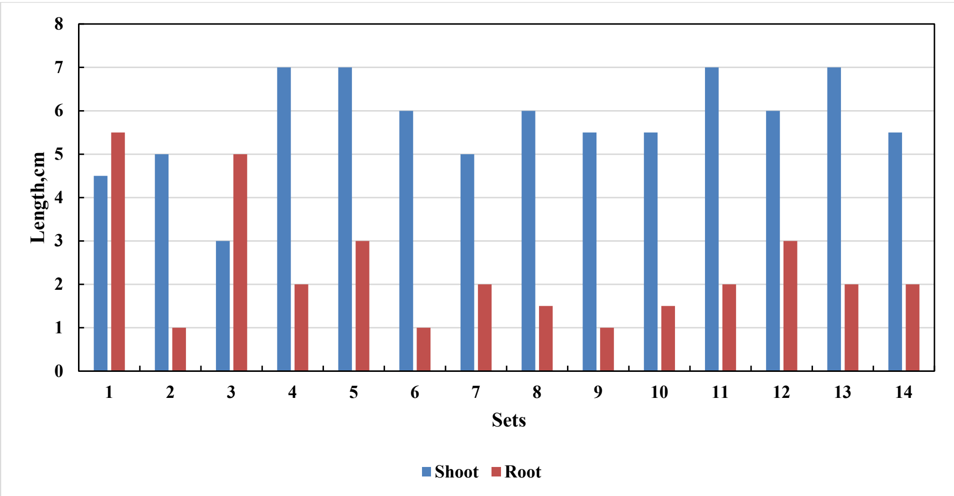

Fig. 3. The length of the root and shoot systems of Sinapis in different plant sets

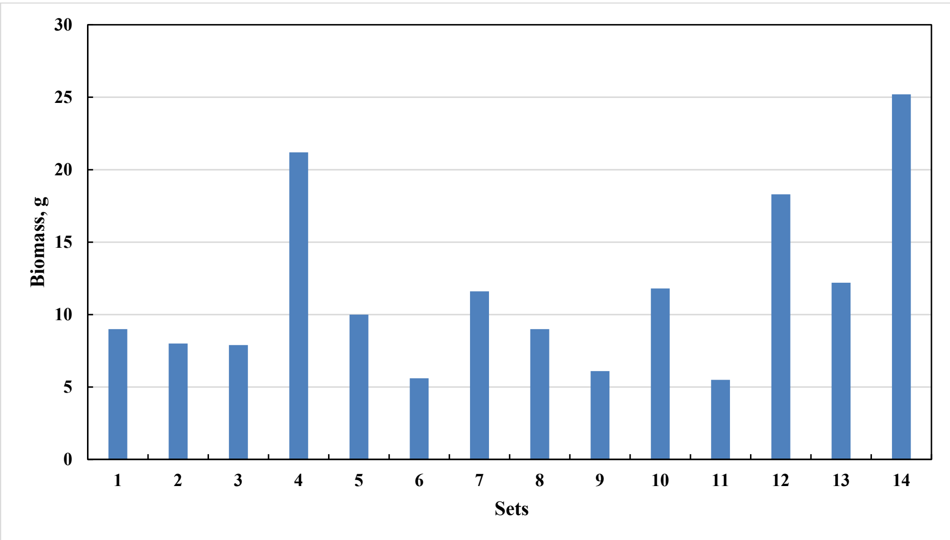

Fig. 4. Biomass of Sinapis in different plant sets

*1 – set № 1 on the water; 2 – set № 6 on the water; 3 – set № 8 on the water; 4 – set № 1 (80/20); 5 – set № 3 (80/20); 6 – set № 6 (80/20); 7 – set № 8 (80/20); 8 – set № 1 (70/30); 9 – set № 6 (70/30); 10 – set № 8 (70/30); 1 – set № 1 (50/30/20); 12 – set № 3 (50/30/20); 13 – set № 6 (50/30/20); 14 – set № 8 (50/30/20)

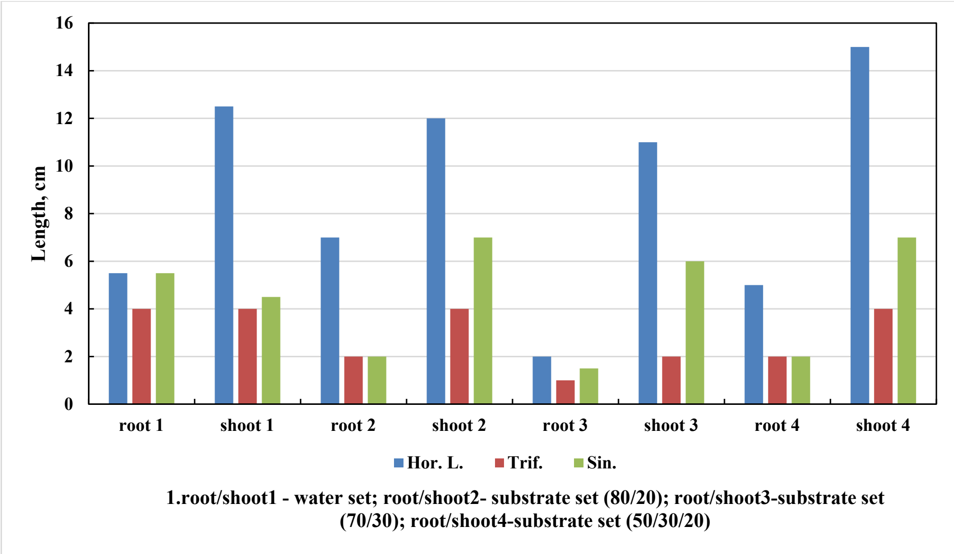

Fig. 5. The length of the root system and shoots of plants from set № 1

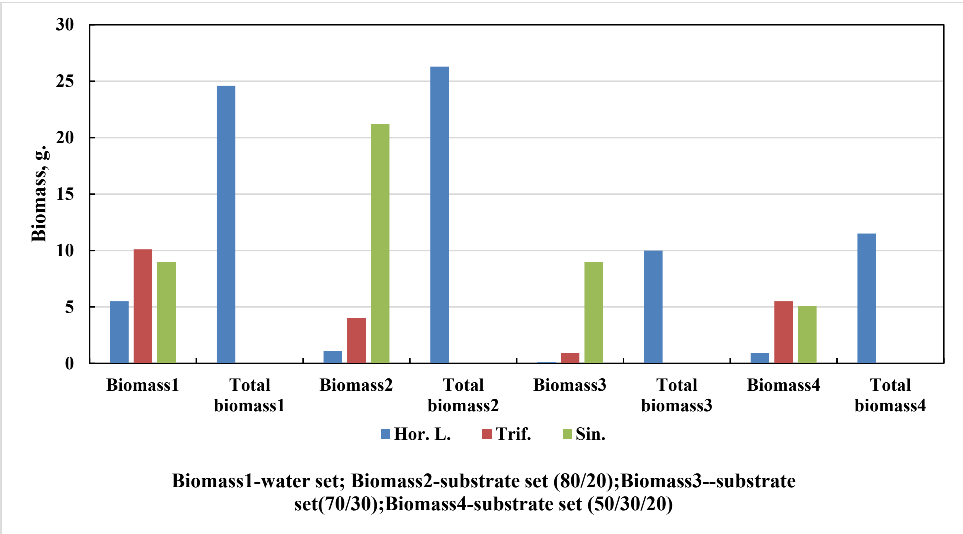

Fig. 6. Biomass of plants from set № 1

Prospects for using the research results. The obtained results make it possible to analyze the studied plants and to choose the most adaptable to salted substrates. This makes it possible to develop the technology of phytoremediation of coal dumps, which makes it possible to return polluted lands to agriculture sector.

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