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## JUSTIFICATION OF THE METHOD FOR PHYTOREMEDIATION OF DEGRADED AND CONTAMINATED LANDS BY COMPOSITE VERMICOMPOST BRIQUETTES

Об'єктом дослідження є ефективність використання біогумусових продуктів вермікультивування в практиці фіторе mediaції деградованих та техногенно забруднених земель. Одним із проблемних аспектів у вирішенні наукової проблеми рекультивації деградованих внаслідок техногенної діяльності земель є тривалий у часі етап біологічного відновлення порушеного ландшафту. Для більш ефективної та швидкої рекультивації доцільно створити фітоценоз з деревинно-чагарниковою рослинністю, стійкий до негативних впливів навколишнього середовища. Добре апробовані біотехнології вермікультивування створюють передумови для використання продуктів життєдіяльності колоній хробаків роду *Eisenia* у вигляді композитних біогумусових брикетів для потреб фіторе mediaції земель, що і було доведено у дослідженні.

Виконано аналіз літературних джерел стосовно сучасних технологій вермікультивування і використання біогумусових продуктів для потреб сільського господарства і фіторекультивації земель. Досліджено процес росту біомаси хробаків виду *Eisenia fetida* та накопичення біогумусу у часі залежно від температури середовища. Наведено результати лабораторних біоіндикаційних експериментів з композитними брикетами, що складаються з біогумусу, суглинку та насіння диких злаків. Визначено, що найбільш оптимальне для ростових показників рослин співвідношення біогумусу та суглинку у складі композитних брикетів становить 60:40 і 40:60 за масою, що дозволяє обґрунтовувати робочі суміші фітомеліорантів для технологій біологічної рекультивації земель.

Виконані лабораторні дослідження свідчать про перспективність використання біогумусу, як продукту вермікультивування, у вигляді композитних брикетів в практиці фіторекультивації порушених земель.

**Ключові слова:** фіторе mediaція земель, технології вермікультивування, біогумусові продукти, Каліфорнійський хробак, композитний брикет.

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### 1. Introduction

The industrial activity of enterprises, in particular the mining industry, is a powerful factor in the technological impact on the environment, which is associated with the alienation and disturbance of land, the removal of significant volumes of rocks from the bowels, and the disposal of mining and mineral processing waste on the earth's surface. Dumps of bulk or alluvial rocks are formed on specially designated areas within the mining allotment. Their environmental impact is associated with the processes of surface erosion and suffusion, the filtration of heavy metals into groundwater, the development of foci of combustion and the spread of emissions of solid and gaseous substances in the adjacent territories.

The soil-natural substrate of overburden dumps after completion of operation begins to overgrow with natural vegetation, but very slowly. The intensity of this process is determined by toxicity, the increased content of certain chemical elements in the deposits, in particular iron, lead, manganese, nickel, tin, sulfur, etc. In general, for dumps composed of non-toxic oar rocks located in the zone of sufficient moisture for the first ten years after the end of the operation of dumps, simple plant groups are formed

with a predominance of local flora species [1]. Therefore, in order to accelerate the process of restoring the landscape to its natural state, mountainous territories need to carry out a complex of engineering and technical work on the restoration of disturbed lands, which is divided into two main stages: mining and biological.

### 2. The object of research and its technological audit

*The object of research* is the effectiveness of the use of vermicompost products of vermiculture in the practice of phytoremediation of degraded and technogenic contaminated lands.

Reclamation of degraded lands, in particular mining, covers a complex of engineering, mining, land reclamation, biological, sanitary and hygienic and other measures aimed at returning the disturbed territories to their natural state. Phytoremediation, as one of the areas of biological reclamation, aimed at creating a sustainable vegetation cover on the surface of degraded lands and an important prerequisite for a stably functioning ecosystem.

Now in the practice of agriculture and phytoremediation of degraded lands, various organic and mineral fertilizers

are widely used. The most ecological approach is the use of vermicompost, a waste product of red California worms of the species *Eisenia fetida*.

Vermicompost is a homogeneous mass of dark brown color, is a product of vermiculture (vital activity) of worms of the genus *Eisenia*. This natural, organic, completely environmentally friendly and the best known fertilizer allows to solve a number of socio-environmental problems, namely:

1. Disposal of various organic wastes.
2. Non-toxic and safe fertilizer for green agribusiness.
3. Ensuring sustainable ecobiocenosis of soils and preserving their properties by enriching vermicompost with colonies of microorganisms.

4. Replacement of chemical fertilizers with organic vermicompost.

When worms process 1 ton of dry biomass by worms, up to 600 kg of vermicompost is obtained containing 25–40 % of humic substances, and the remaining 400 kg of organic substances are transformed into 100 kg of biomass of living worms.

Based on the foregoing, the justification of the method of phytoremediation of degraded lands by composite vermicompost materials is of scientific and applied value, which this work is devoted to.

### 3. The and objectives of research

*The aim of research* is determination of the effectiveness of the use of composite vermicompost briquettes for land phytoremediation.

To achieve this aim, the following research objectives are solved:

1. To study the growth indicators and productivity of a colony of worms of the species *Eisenia fetida* depending on the temperature of the environment.
2. To carry out bioindication experiments with composite briquettes consisting of vermicompost, loam and seeds of wild cereals, and determine their optimal ratio for plant growth parameters.

### 4. Research of existing solutions of the problem

**4.1. The problem of degradation of mining lands and their restoration.** The total area of disturbed lands in Ukraine is more than 265 thousand ha. Each year, 7–8 thousand ha are allocated for the needs of the mining industry, which mainly belonged to agriculture or forestry. So, with the open-pit mining method for 1 million tons of mineral raw materials, land losses amount to:

- for manganese ore – 76–600 ha;
- for iron ore – 14–640 ha;
- for coal – 2.6–43.0 ha;
- for non-metallic materials – 1.5–583 ha.

In the mine method, 1 million tons of coal is allocated to 4.4 hectares of land in dumps and tailings [2].

One of the main directions of optimization of mining areas today is their restoration. Existing land reclamation technologies do not sufficiently take into account the environmental and environmental aspects of the problem, and it does not allow improving the overburden technology and subsequent technical land reclamation with risk reduction [3, 4].

The objects of phytoremediation can be quarries, heaps, dumps, tailing ponds and sedimentation tanks, as well as territories disturbed during the extraction and enrichment of minerals (deformation troughs, karst dips, erosion excavations, etc.) [5].

One of the best practices in the phytoremediation of mountain lands was the restoration of the surface of the dumps of Annivka career at the Northern Mining and Processing Plant in Kryvbas. The project provided for the excavation of chernozem, its placement in special warehouses with subsequent use for paving prepared for the reclamation of dumps. Seedlings of maple, acacia, poplar and other trees took root well in the dumps, and the average growth of trees was 0.36–0.60 m/year [1].

In the quarries of the Pokrovsk ore mining and processing plant, where about 60 % of manganese ore is mined in Ukraine, the restoration of disturbed lands is carried out in several stages. Land disturbed by mining operations is subject to planning with the application of layers of soft loamy rocks, and then with a layer of black soil 0.5 m high, followed by sowing of agricultural crops. The yield of perennial grasses on the reclaimed land is 45 kg/ha, annual – 27.5 kg/ha, winter wheat – 34.5 kg/ha, corn for grain – 38.2 kg/ha, corn for silage – 287 kg/ha [6].

Significantly contributes to the restoration of mining geosystems technology of replanting (land) of the soil layer, when a soil-replant is applied to an infertile surface [7].

A suitable method of mining and biological reclamation provides for further efficient use of land, given the need to improve the ecological condition of the area by arranging agricultural land or forest stands, creating recreational territories, etc. [8].

Moreover, the complex of phytoremediation and phytomelioration of land is crucial for the sustainable functioning of the landscape [9].

**4.2. Vermiculture biotechnology: advantages, disadvantages and prospects of application.** Vermiculture is one of the promising ways to obtain biomass, as well as the disposal of various organic wastes. Typically, the products of this biotechnology are the biomass of worms and vermicompost, which are widely used in agriculture. However, modern research significantly expands the range of application of products of vermiculture.

So, in [10], current trends in the production of kitchen organic waste and their prospects are analyzed in the context of the requirements defined in the directives of the European Union on the management of organic waste. The advantages of biotechnology of vermiculture are presented and the produced vermicompost features are characterized.

In [11], the possibilities of using vermiculture products not only in the field of organic farming, but also in the practice of using vermicompost aquacultures for hydroponic cultivated plants, were shown.

In modern biotechnologies, vermiculture of the red California earthworm (*Eisenia foetida andrei*) is used as a food product in aquaculture, as well as for the restoration of various soils [12].

Earthworms are part of the natural diet of some farm animals, such as poultry, due to their high protein content. However, worms can accumulate some toxic substances found in the soil, which can lead to toxic effects in animals [13].

In [14], the results of a study of the biomass of worms on a cobalt enriched medium are presented. It is established that the biomass of worms grown in a nutrient medium with the addition of 40 mg/kg cobalt can be used for breeding fish as a protein supplement with a high content of cobalt.

In [15], a model for the disposal of organic solid waste in biological composting and vermiculture technologies is presented, which allows one to reduce greenhouse gas emissions into the atmosphere and reduce the costs of neutralizing organic waste in landfills.

It is shown in [16] that composting waste from households or microdistricts can help solve the problems of managing household organic waste in the context of the economic development of urban communities.

In the practice of phytoremediation of lands contaminated with heavy metals [17], vermicompost is used, which affects the bioavailability of elements such as Zn, Cd, Pb, Co, and Ni in soils. Vermicompost provides nutrients for the rapid growth of *Panicum virgatum* plants, which is useful for phytoremediation, but excessive use of compost can leach nutrients and cause water pollution.

In the study [18], the results of the cultivation of seeds of trees and shrubs with the addition of vermicompost in different concentrations are presented. It is established that seeds that are incubated with vermicompost have better germination and growth rates compared to the usual cultivation practice, which can be useful for phytoremediation of the land.

In [19], a comprehensive assessment is made of changes in the chemical properties of the soil in response to the application of vermiculture technologies. It has been established that the application of vermicompost increases the pH of the soil, increases the content of metabolic calcium and the content of phosphorus and potassium is available.

In general, all types of vermicompost obtained from cheap and readily available plant and animal residues have great potential for use as alternative fertilizers, as well as for phytoremediation of contaminated or degraded soils.

The analysis of literary sources allows to conclude that the use of vermicompost products is a promising direction in the field of organic waste disposal and in the practice of phytoremediation of degraded lands.

## 5. Methods of research

The following scientific methods are used:

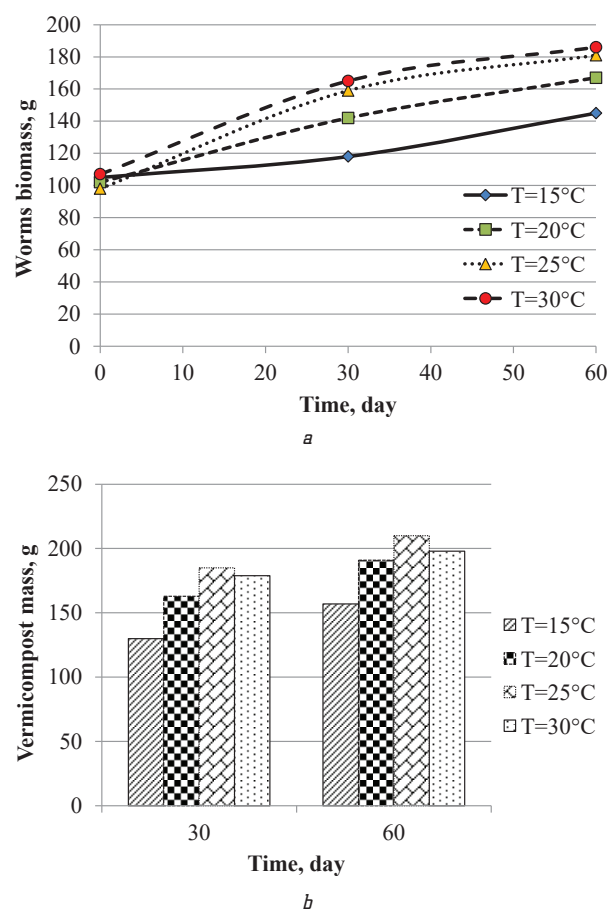
- method of analyzing information sources and world experience in formulating a scientific goal and research objectives;
- methods of vermiculture of worms of the *Eisenia fetida* species on organic waste;
- methods for bioindicating the effectiveness of composite vermicompost briquettes for phytoremediation of degraded lands of mining enterprises.

## 6. Research results

**6.1. Vermiculture of the *Eisenia fetida* species on organic waste.** The intensity of physiological and biochemical processes in the body of worms is directly dependent on the temperature of the environment. At temperatures above 32 °C, especially with excess moisture in the substrate, in response to a temperature stimulus, the activity and body

weight of the worms decreases due to an increase in the secretion of protective mucous secretions. The most favorable temperature at which *Eisenia fetida* grows at maximum speed and maintains high activity is 18–28 °C [20].

Fig. 1 presents the results of vermiculture of the *Eisenia fetida* species on organic waste, for which fallen leaves and organic food waste were selected. The objective of the experiment is studying the growth indicators and productivity of a colony of worms of the *Eisenia fetida* species depending on the temperature of the medium.



**Fig. 1.** The results of vermiculture of the *Eisenia fetida* species on organic waste: *a* – changes in the worms biomass  $m_w$ ; *b* – vermicompost mass  $m_{hum}$

For cultivation, plastic double bottom containers with dimensions of 50×30 cm with a perforated bottom were used for drainage and removal of excess moisture. In each container, crushed fallen leaves and food waste in a proportion of 60:40 were placed as a nutrient substrate for the worm colony. The total weight of the biological substrate was 500–600 g. To initiate the biological processes of decomposition of organic matter due to microbiological activity, 150 g of the upper layer of chernozem, taken in the forest park zone from under the layer of fallen leaves, was also introduced into the container. The initial weight of the worms of the *Eisenia fetida* species was 100±7 g per container. 150 ml of water was added to the container to moisten the biological substrate. The duration of the experiment is 60 days. During the experiment, the average humidity of the substrate was maintained in the range of 60–80 % due to the partial covering of the container with a transparent film.

From the results presented in Fig. 1 it can be concluded that the range of 25–30 °C is most favorable for the growth of a worm colony under conditions of supporting the indicated level of substrate moisture. The average increase in biomass for the indicated period, depending on the temperature of the environment, is 38.1–73.8 % for the biomass of worms and 10.6–20.8 % for vermicompost, respectively. It should be noted that at a temperature of 30 °C the rate of biological activity is somewhat slowed down even with satisfactory wetting of the organic substrate.

Vermicompost has accumulated a large number of macro- and microelements directly assimilated by plants, contains a number of growth substances, vitamins, antibiotics, amino acids and beneficial microflora. The nutrients here are in organic form, more reliably stored from leaching and serve as a source of prolonged action. Its decomposition by microorganisms releases macro- and microelements and provides plants with carbon, which is necessary for plant photosynthesis. According to agrochemical studies [21], vermicompost has the following indicators:

- humidity – 45.8–55.2 %;
- content of organic matter – 44.8–54.2 %;
- humus – 9.7–12.3 %;
- acidity (pH) – 7.2–8.0;
- total nitrogen – 1.8–3.1 %;
- phosphorus (P<sub>2</sub>O<sub>5</sub>) – 1.3–2.6 %;
- potassium (K<sub>2</sub>O) – 1.6–3.8 %;
- calcium – 6.2–7.5 %;
- magnesium – 1.4–2.1 %;
- iron – 0.5–2.5 %;
- copper – 13.1–18.4 mg/kg;
- manganese – 0.02–0.03 %;
- zinc – 0.20–0.30 mg/kg;
- sulfur – 0.24–0.30 %.

## 6.2. Bioindication assessment of the use of vermiculture products for phytoremediation of degraded lands.

In laboratory conditions, experiments were carried out on the potential for using vermiculture products for phytoremediation of degraded lands. The main idea of the experiment was to determine the optimal composition of composite vermicompost briquettes for phytoremediation of degraded or polluted lands, in particular mining enterprises. The complex three-component mixtures consisted of the following ingredients (Table 1): yellow-brown loam, vermicompost (product of vermiculture) and seeds of wild cereals, in particular common wild oat (*Avena fatua*), and awnless brome (*Bromus inermis*).

Table 1

The composition of the composite briquette mixture and the growth test results

Sample	The composition of the composite briquette mixture, g			Growth test results		
	Vermicompost	Loam	Seeds	The number of seedlings, pcs.	The mass of roots, m	Green mass, g
1	10	100	2	4	0.28	1.11
2	20	80	2	16	0.51	8.23
3	40	60	2	45	2.77	39.0
4	60	40	2	51	3.58	51.0
5	80	20	2	25	1.06	32.0
6	100	10	2	23	0.75	21.0

As a result of the studies, the most appropriate ratio of the components of the three-component mixture for the production of briquettes for use in technologies for the restoration of degraded lands is determined. So, in samples 3 and 4, the seeds sprouted more actively than in other samples. This indicates that the ratio of components (40:60 and 60:40) is most appropriate for the manufacture of composite mixtures and briquettes for targeted phytoremediation of disturbed lands (Fig. 2).

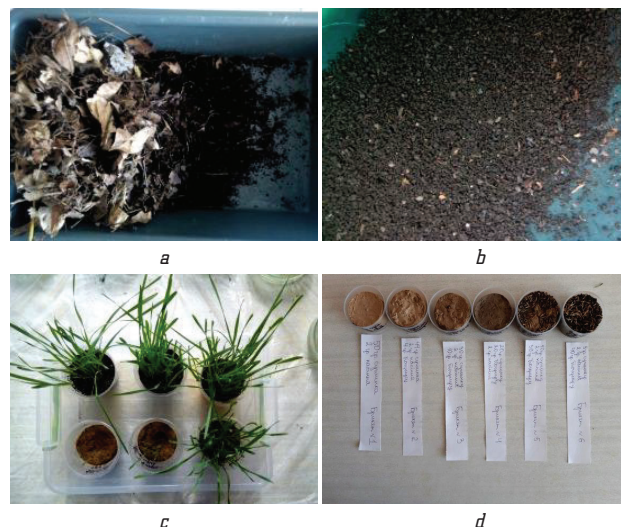


Fig. 2. The results of the experiment to determine the optimal composition of composite vermicompost briquettes: a – capacity for the cultivation of worms with a substrate of fallen leaves; b – vermicompost – a product of vermiculture; c – a vegetative test on three-component substrates with vermicompost; d – composite briquettes

Thus, laboratory studies have been performed that testify to the prospects of using vermiculture vermicompost in the form of composite briquettes in the practice of phytoremediation of disturbed lands.

## 7. SWOT analysis of research results

**Strengths.** Compared with traditional approaches to phytoremediation of degraded and polluted lands, the proposed phytoremediation method using composite vermicompost briquettes allows accelerating the restoration of man-made landscapes to their natural state, promoting biodiversity and developing a stable ecological system. The use of natural and environmentally friendly fertilizers is considered as an appropriate option for the implementation of «green technologies» of the future.

**Weaknesses.** Despite the satisfactory results obtained regarding the prospects for the use of vermiculture products in biological land reclamation technologies, certain difficulties may arise in finding a reliable supplier of a sufficient amount of vermicompost, given the volume of reclamation work. Also problematic is the collection and procurement of seed for briquettes.

**Opportunities.** The use of composite briquettes consisting of vermicompost, loam and seeds of wild cereals opens up the possibility of large-scale phytoremediation of mining landscapes. It is known that the reclamation of slopes in quarries is the most complicated technology through slope processes and soil erosion. The use of composite briquettes will make it possible to easily fix the

seed of wild cereals on the surface of slopes of dumps or on the sides of quarries during reclamation works due to the content of astringent loams. In turn, organic matter serves as a breeding ground for seed germination.

**Threats.** Potential threats to the proposed method of land phytoremediation using vermicompost briquettes include a certain uncertainty with the quality, origin and possible toxicity of the initial organic substrate on which the California worm colony is cultivated. The worm only processes an organic substrate that could potentially contain toxic substances or heavy metals, so there is a risk of environmental pollution when using products of vermiculture.

## 8. Conclusions

1. The growth indicators and productivity of a colony of worms of the *Eisenia fetida* species are studied depending on the temperature of the medium. It is found that the range of 25–30 °C is most favorable for the growth of a worm colony under conditions of maintaining a substrate moisture level of 60–80 %. The average increase in biomass over a period of 60 days depending on the temperature of the environment is 38.1–73.8 % for the biomass of worms and 10.6–20.8 % for vermicompost, respectively.

2. The results of laboratory bioindication experiments with composite briquettes, consisting of vermicompost, loam and wild cereal seeds, are presented. It is determined that the ratio of vermicompost and loam in the composition of composite briquettes, which is most optimal for plant growth indicators, is 60:40 and 40:60 by weight. This allows to justify the phytomeliorant mixtures for biological land reclamation technologies.

Thus, laboratory studies have been performed that indicate the prospects of using vermicompost products of vermiculture in the practice of phytoremediation of disturbed lands.

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