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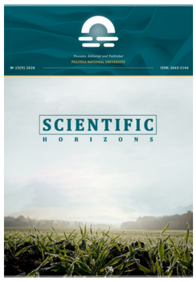

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Obtaining an important component of humate-enriched organomineral fertiliser based on oxidised lignite from Kyrgyzstan

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Abstract. The study of methods for the production and processing of humate-enriched organomineral fertilisers based on oxidised lignite represents a key aspect for modern agriculture, due to the need to improve resource efficiency, soil quality, and sustainability of production. The purpose of this study was to determine the best methods of obtaining and processing humate-enriched organomineral fertilisers based

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on oxidised lignite. To fulfil this purpose, experimental research was carried out in the laboratory of the Institute of Natural Resources of the Southern Branch of the National Academy of the Kyrgyz Republic and the educational and scientific laboratory of the Department of Ecology and Environmental Protection of the Osh Technological University named after M.M. Adyshev. The findings of the study indicate significant changes in soil characteristics after application of vermicompost and glauconite. Analyses of vermicompost revealed that it has a significant content of nutrient elements and organic compounds. The potassium content of vermicompost increased by 40%, while silicon and phosphorus content increased by 39% and 28.5%, respectively. As a result of vermicomposting, there is an improvement in soil characteristics: pH increases to 7-7.5, organic matter content increases to 35-45%, while C/N-ratio decreases to 10-12, which creates more favourable conditions for plant growth and increases nitrogen use efficiency. After addition of glauconite, an increase in potassium oxide by 0.6%, iron (III) oxide by 2.34%, and aluminium oxide by 0.41% was observed. Silicon oxide content increased by 4.9%, while the content of humic substances – by 1.1%. These changes in soil characteristics contribute to higher yields and better soil quality. The results of the study have practical significance for agriculture in improving soil characteristics, increasing yields and soil quality, and reducing dependence on chemical fertilisers

Keywords: nutrients; soil; environmental sustainability; macronutrients; glauconite; *Eisenia foetida*

INTRODUCTION

In modern agriculture, the continuous drive to increase yields and product quality necessitates the search for effective and environmentally friendly fertiliser solutions. In this context, humate-enriched organomineral fertilisers based on oxidised lignite are attracting increasing attention as a potential key component for improving soil properties and stimulating plant growth. The approach of using oxidised lignite to produce such fertilisers is an area promising considerable results in sustainable agriculture and food security (Suleymenov & Kolesnikova, 2020). The process of obtaining an essential component of humate-enriched organomineral fertilisers is based on a carefully developed technology that allows for the efficient conversion of the organic mass of oxidised lignite into biologically active and organic-rich components. This process involves not only chemical transformations but also biological processes to enrich carbon structures with nutrients and microorganisms that promote healthy plant growth (ur Rehman *et al.*, 2023; Didur *et al.*, 2023).

Z. Aslam *et al.* (2024) and T.J. Sitzmann *et al.* (2024) stress that the use of oxidised lignite in fertiliser production has considerable environmental benefits. This reduces dependence on conventional chemical fertilisers, which can have a negative impact on soil and the environment. Humate-enriched organomineral fertilisers derived from oxidised lignite contribute to the conservation of soil microflora and microfauna biodiversity, as well as to the improvement of soil structure and fertility. Moreover, according to O. Trembitska and S. Bohdan (2023), such fertilisers can have a positive effect on plant resistance to stress conditions, including drought or soil salinity, which is an important aspect in a changing climate. Thus, the development and application of humate-enriched organomineral fertilisers based on oxidised lignite represent an innovative and promising approach to agricultural production, contributing to its sustainable development and increased efficiency.

Kyrgyzstan, as a country with a high potential for agricultural development, faces challenges related to declining soil fertility and declining crop yields (Omarov *et al.*, 2024). The introduction of humate-enriched organomineral fertilisers based on oxidised lignite represents a major step towards improving soil quality and increasing crop yields in this region. Considering the limited resources and the importance of maintaining ecological balance, the use of such fertilisers could become a key component of sustainable agricultural development in Kyrgyzstan (Kurenkeev *et al.*, 2024). Furthermore, the development of local production of humate-enriched organomineral fertilisers can contribute to job creation and rural development. It can also reduce dependence on imports of chemical fertilisers, thereby increasing the country's economic sustainability (Mikos-Szymańska *et al.*, 2019; Vaschenko *et al.*, 2021).

S.B. Kenenbaev *et al.* (2023) also indicate that in the context of Kyrgyz agriculture, the introduction of humate-enriched organomineral fertilisers based on oxidised lignite contributes to the country's efficiency, sustainability, and competitiveness in the global market. Thus, despite the availability of sufficient information on the potential of humate-enriched organomineral fertilisers based on oxidised lignite, the gap that needs to be filled is related to a more detailed description of the process of obtaining humate-enriched organomineral fertilisers in agriculture, including technological aspects and production stages.

The study of the relevance of the introduction of humate-enriched organomineral fertilisers based on oxidised lignite into agriculture in Kyrgyzstan is important in the context of solving existing problems related to the sustainable development of the agricultural sector. Considering the specific climatic features and limited natural resources of the region, the search for effective methods to improve soil fertility and increase crop yields is an urgent task. The introduction of innovative technologies, such as humate-enriched lignite-based fertilisers, can significantly contribute to improving soil quality, preserving soil fertility and increasing crop productivity in the country. Thus, the study has the potential not only to improve the economic well-being of farmers, but also to reduce the negative impact on the environment by reducing the use of chemical fertilisers and maintaining the balance of ecosystems.

The purpose of this study was to determine the best methods of obtaining and processing humate-enriched organomineral fertilisers based on oxidised lignite to ensure the assimilation and effective use of important nutrient components by plants. To fulfil this purpose, the following tasks were set and implemented: study of characteristics and composition of humus produced by red wiggler worms of the *Eisenia foetida* species, evaluation of the effect of adding humus and glauconite containing natural mineral of Kyzifl-Tokoi deposit of the Kyrgyz Republic on the content of humic substances and nutrients in the soil material.

MATERIALS AND METHODS

To obtain an important component of humate-enriched organomineral fertiliser (HOMF) based on oxidised lignite, scientific experimental studies were carried out in the laboratory of the Osh Technological University of the Kyrgyz Republic. To improve the component composition of HOMF based on oxidised lignite, natural components were used: vermicompost and glauconite. Production of vermicompost (humus) was carried out using red wiggler worms (RWW) of the *Eisenia foetida* species, and production of mineral containing basic nutrients for plants in assimilable forms – by processing of natural glauconite containing mineral.

Before the vermicomposting process was organised, preparatory works were carried out:

1. Substrate preparation included the following steps: preparation of a wooden box 80 cm deep; preparation of over-digested cow dung and dry plant materials such as straw and leaves of fruit plants; preparation of necessary tools and accessories: thermometer, pH-meter F20-Standard (Mettler Toledo Switzerland), moisture meter testo 606-1 (Testo, Germany), shovel and water containers; filling the box with a substrate consisting of over-digested cow dung and dry plant materials in a 1:1 ratio; thoroughly mixing the substrate and moistening it to a moisture content of 70-80% of full capacity.

2. Substrate fermentation includes the following steps: setting the substrate for fermentation with maintaining constant humidity, moistening it with warm water and periodic stirring every 2-3 days; regular measurement of temperature and pH of the medium; at the end of the fermentation process of the components, the indicators should stay stable: pH at 7.1 and substrate temperature at 26-27°C.

3. Introduction of the worms. After the fermentation process was completed, the red wiggler worms *Eisenia foetida* were introduced. At the beginning, a small number of worms (50 individuals) were introduced to test the readiness of the environment for their activity. Then, an introduction of 1,000 specimen of red wiggler worms into the box was organised. Air oxygenation of the substrate was carried out daily by gentle stirring.

To carry out the composting process in laboratory conditions, the following technological scheme was established (Table 1).

Table 1*. Technological scheme of organic materials composting process (vermicompost production)*

No. 1 initial substrate			
	No. 2 ready-made substrate		
		No. 3 RWW in substrate	
			Ready-made vermicompost
RWW separated from vermicompost			
	No. 2 ready-made substrate		
		No. 3 RWW in substrate	
			Ready-made vermicompost

Source: *compiled by the authors of this study*

For enrichment of important micro- and macroelements of HOMF, glauconite containing sandstone from Kyzyl-Tokoya deposit was used, prepared to concentrated solution-suspension of glauconite, by adding 1 kg of glauconite for every 10 kg of substrate. Potassium, iron, aluminium, and silicon contents were determined using PAZH-2 device (Altavir, Ukraine), phosphorus content was determined based on spectral analysis using ULAB 101 spectrophotometer (China). The presence of minerals such as arogonite, graphite, calcite, goethite, and peaks of unknown minerals were determined by X-ray diffraction (XRD) analysis (Shimadzu XRD-7000, Japan). The mineralisation rate was determined by measuring the change in organic matter mass per month, the number of microorganisms was determined by culturing microbes from the sample on nutrient medium and then counting colonies, and air and water-air permeability was determined using a PZh 2-100-10-10/19 pycnometer (Altavir, Ukraine). The content of humic substances was determined according to the chromatography method, while X-ray fluorescence analysis was carried out on Thermo Fisher Scientific Inc. apparatus (USA) to determine the elemental composition of the samples.

The control sample was a substrate sample that was not enriched, not treated with worms, and did not contain glauconite, and represented the baseline condition. In addition, a comparative study of the effect of humate-enriched organomineral fertiliser on the growth and development of different plant species was carried out under laboratory conditions. During the study, the effects of this fertiliser on the following plant species were investigated: raw cotton variety Kyrgyz-6, rice (variety: six-line F1), Turkish tomato variety Shahti and Elpida, spice plants, particularly dill.

RESULTS

Red wiggler worms, or *Eisenia foetida*, are generally similar to common earthworms, but have several features that make them preferable for use in vermiculture. This species is characterised by rapid growth, short life cycle, and high fecundity. These worms are also more suitable for vermiculture breeding due to their ability to adapt quickly to changing conditions and reproduce rapidly. Using *Eisenia foetida* earthworms to create vermicompost and then incorporating this vermicompost into a humate-enriched organo-mineral fertiliser based on oxidised lignite will result in increased availability of micronutrients (such as iron, copper, manganese, zinc), vitamins (A and B), enzymes, antibiotics, and other beneficial factors to plants. This contributes to the activation of physiological processes in plants, improving their tolerance to diseases and pests. Furthermore, the use of such fertiliser will help in restoring soil fertility and increasing nutrient elements, which will be beneficial to plant growth and development (Al-Tawarah *et al.*, 2024).

Glauconite is used for enrichment of important trace elements as part of humate-enriched organic mineral fertilisers because of its unique properties and abilities. Glauconite is a valuable source of trace elements such as iron, manganese, potassium, phosphorus, copper, due to its chemical nature and exchange adsorption ability. Once glauconite is processed, nutrients are released and made available to plants in a digestible form. This mineral has high surface activity and a great ability to hold and release nutritional elements to plants, making it an ideal component for creating fertilisers to improve soil fertility and increase crop yields (Omarov *et al.*, 2024).

During the study, X-ray fluorescence analysis of vermicompost was carried out to determine its chemical composition and content of various elements. This allows the quality and composition of the fertiliser to be assessed and the presence of essential nutrients such as nitrogen, phosphorus, potassium, and trace elements to be verified. The results of such an analysis can be useful in optimising fertiliser application, as well as providing plants with the necessary nutrients for their health and growth. The analysis of vermicompost showed that the nutrients contained in it are presented in a form that is most favourable for assimilation by plants, thus contributing to their optimum and efficient nutrition. Vermicompost contains many organic compounds such as humus, amino acids, and trace elements that provide plants with the resources they need for healthy growth and development. This type of fertiliser can increase soil fertility and improve soil structure, contributing to crop yields and plant health.

The diffraction pattern graph represents the result of X-ray diffraction on the crystal structure of the sample. It displays the dependence of the diffracted X-ray intensity on the angle of diffraction or wavelength shift. Diffraction patterns are used to analyse the crystal structure of materials, identify crystal phases, determine the distances between atoms in the crystal lattice and other characteristics of crystalline materials. The magnitude and shape of diffraction peaks on the graph contain information about the internal structure of the sample and its crystal lattice (Fig. 1).

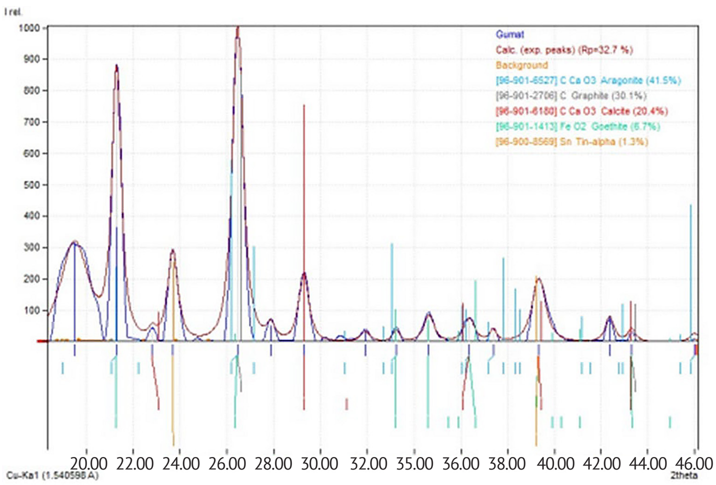

Figure 1*. Graph of diffraction pattern of vermicompost*

Source: *compiled by the authors of this study*

The results of the study show that HOMF containing humic substances, vermicompost, and glauconite in its composition has a positive effect on the growth and development of the plant species under study. This can manifest itself in increased plant growth rate, improved plant health, increased yields, and increased resistance to stressful conditions such as drought or disease. Such results indicate the potential effectiveness of HOMF in agricultural practices to improve the quality and quantity of agricultural products (Fig. 2).

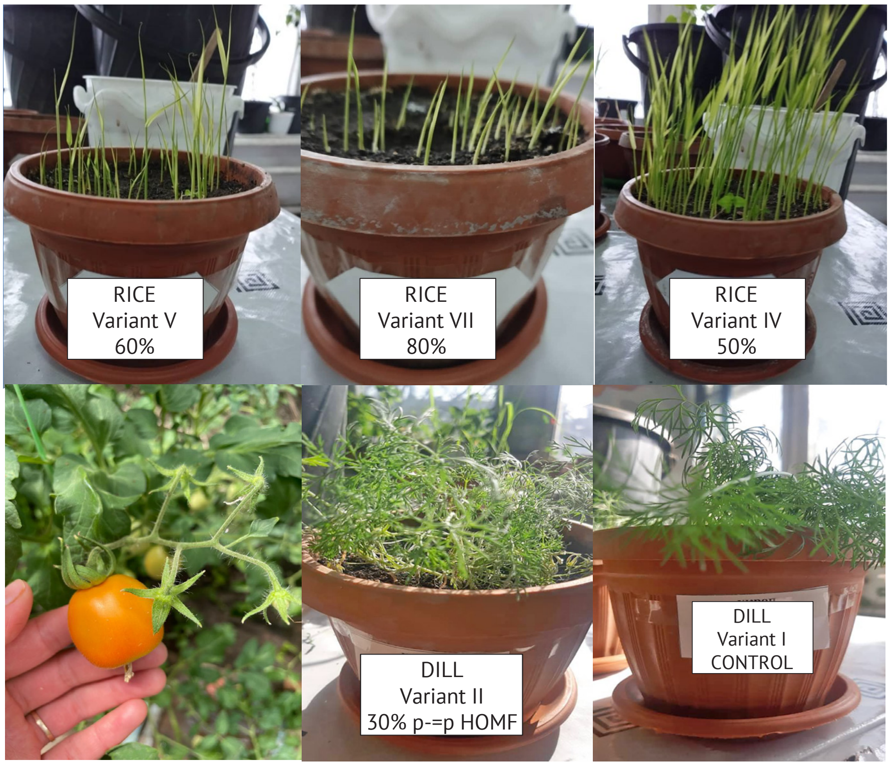

***Figure 2**. Crops under study with HOMF added to the soil*
***Source:** compiled by the authors of this study*

Glauconite available as a natural mineral was used for enrichment of HOMF, obtained by the technology of the authors of the study, considering that it contains important elements of plant nutrition (K.P.N) and micro- and macroelements necessary for physiological processes of plant organism. According to the results of analysis comparing the content of elements and minerals in control and vermicompost, it can be stated that the content of potassium in vermicompost is significantly higher (by 40%) compared to the control sample. This may indicate a higher nutrient content in vermicompost, which is favourable for plants. The iron and aluminium content in vermicompost is almost the same as in the control sample. This may indicate a retention or slight change in iron content during the vermicomposting process (Table 2).

***Table 2**. Comparison of elements and minerals content in control and vermicompost, %*

Parameter	Control	Vermicompost
Potassium	5.2	7.3
Iron	3.6	4
Aluminium	2.8	3.2
Silicon	6.1	8.5
Phosphorus	4.9	6.3
Arogonite	0.2	0.1
Graphite	0.3	0.2
Calcite	0.1	0.05
Goethit	0.15	0.08
Peaks of unknown minerals	0.05	0.03

***Source:** compiled by the authors of this study*

The silicon and phosphorus contents are also higher in vermicompost, by 39% and 28.5%, respectively, which is a positive factor for improving soil fertility. The vermicompost shows a decrease in the content of arogonite, graphite, calcite, goethite, and peaks of unknown minerals compared to the control sample. This may indicate the transformation or decomposition processes of these minerals during vermicomposting. Furthermore, the study conducted compares the characteristics of control and vermicomposted soil material. The results show that vermicomposted material has several advantages over the control. Specifically, soil pH increases after vermicomposting, which may contribute to more favourable conditions for plant growth. There is also an increase in moisture content and organic matter, which can enrich soil nutrients and improve soil fertility. Furthermore, the C/N ratio decreases, which may increase the availability of nitrogen to plants. The rate of mineralisation in vermicomposted material is also higher, indicating a more active conversion of organic matter into mineral forms. The number of microorganisms in the soil increases after vermicomposting, indicating increased biological activity of the soil. Finally, vermicomposted material has higher air and water-air permeability, which favours better air-water regime of soil and more active gas exchange. These results emphasise the benefit of vermicompost for improving soil properties and yield (Table 3).

***Table 3**. Characteristics of control and vermicomposted soil material*

Parameter	Control	Vermicompost
pH	6.5-7	7-7.5
Humidity (%)	30-40	40-50
Organic matter content (%)	20-30	35-45
C/N ratio	12-15	10-12
Mineralisation rate (g/kg/month)	15-25	30-40
Number of microorganisms (colonies/g)	4×10^6-6×10^6	7×10^6-9×10^6
Air permeability (%)	50-70	70-80
Water-air permeability (%)	40-60	60-70
Structure and texture	Loose	Crumb

***Source:** compiled by the authors of this study*

Overall, the study found that more intensive organic waste composting processes occur when red wiggler worms *Eisenia foetida* are used. Because of this process, an active mineralisation of organic matter occurs, which leads to the release of biologically active components into the soil. The resulting product, or humus, which is added to the soil, contributes to the formation of a special soil structure. Furthermore, the results of laboratory experimental studies indicate that vermicomposting using red wiggler worms *Eisenia foetida*, results in effective decomposition of organic material, resulting in a quality vermicompost. This process accelerates composting and converts organic waste into a more digestible form of plant nutrients. The resulting vermicompost contains nutrients in the form most available to plants, which improves soil fertility and stimulates plant growth.

Glauconites, whose structure is usually colloidal, are formed by complex syntheses involving many intermediate structures. Potassium plays a significant role in strengthening the structure of glauconite by facilitating the transformation of its intermediate forms into more stable ones. Humatised organomineral fertiliser enriched with glauconite and humus is superior to industrial mineral fertilisers in its effectiveness. Humic substances in HOMF improve the assimilability of basic and micronutrients for both plants and soil. Properties of the natural mineral glauconite, including its adsorption properties and structure features, contribute to the conversion of basic nutrition elements and trace elements necessary for physiological processes of plants into assimilable forms. This allows plants to utilise nutrients efficiently, which improves their growth and development. A humate-enriched organomineral fertiliser produced based on oxidised lignite has a full range of essential nutritional elements, including important micro- and macroelements. Due to enrichment with glauconite extracted from the natural mineral of Kyzyl-Tokoi deposit and humus substances of vermicompost, such fertiliser has an advantage over industrially produced mineral fertilisers.

Based on the data obtained during the study, it can be stated that the content of potassium oxide increased by 0.6%, from 7.4% in the control sample to 8% after the addition of glauconite, also increased the content of iron (III) oxide from 24.51% in the control sample to 26.85%, the content of aluminium oxide – by 0.41%, and the content of silicon oxide – from 41.57% in the control sample to 46.47% after the addition of glauconite. Notably, the humic content also increased by 1.1% after the addition of glauconite. Increasing humic content has many positive implications for soils, ecosystems, and agriculture. This includes improving soil structure and fertility, reducing erosion, improving fertiliser use efficiency, and maintaining biodiversity. Such changes contribute to sustainable agriculture, environmental protection, and healthy ecosystems (Table 4).

***Table 4**. Element content in control sample and with added glauconite, wt. %*

Parameter	Control	Glauconite
K_2O	7.4	8
Fe_2O_3	24.51	26.85
Al_2O_3	2.75	3.16
SiO_2	41.57	46.47
Humic substances content, wt. %	2.5	3.6

***Source:** compiled by the authors of this study*

The findings obtained, which show an increase in the content of all measured parameters after the addition of glauconite, emphasise its importance as an effective means of improving soil quality and stimulating plant growth. This is important not only for agriculture but also for environmental conservation. Improved soil quality provides more favourable conditions for plant development, which can lead to higher yields and reduced need for crop protection products. Plant growth stimulation, especially using natural and environmentally friendly materials such as glauconite, contributes to sustainable and ecologically balanced farming systems. This can reduce the negative environmental impacts of agricultural production, such as soil and water pollution, soil erosion and reduced biodiversity, and reduce the need for chemical fertilisers and pesticides by improving natural plant defences. Thus, the addition of glauconite to soil represents a promising solution to improve its quality and increase yields, considering the principles of sustainable agriculture and environmental sustainability.

Based on the presented data, the use of vermicompost (humus) produced by red wiggler worms can be recommended for enrichment of oxidised lignite to increase their humic content. This enhances the transformation of element compounds into forms available for plant uptake. It is also recommended to use glauconite isolated from a natural mineral, e.g., glauconite from Kyzyl-Tokoya deposit, for soil enrichment in combination with vermicompost (humus). This allows the fertiliser to contain the main nutritional elements and the necessary micro- and macronutrients for plants. The developed humate-enriched organic-mineral fertiliser containing all necessary nutrients, as well as micro- and macroelements for plants, can become a full-fledged alternative to chemical fertilisers, unlike which, it contributes to the preservation of soil fertility during the following years without depleting its structural content. Furthermore, the use of vermicompost and the enrichment of glauconite make it possible to create a fertiliser that provides plants with essential nutrients in an assimilable form, which contributes to their healthy growth and physiological development.

The findings of the study demonstrate that both vermicompost and the addition of glauconite to soil have considerably positive effects on soil quality and fertility. Vermicompost enriches the soil with organic compounds and nutrients, which contributes to effective plant nutrition and improved plant growth. The addition of glauconite increases the content of basic nutritional elements and humic substances, which also has a favourable effect on soil characteristics, highlighting the importance of using such techniques for sustainable agriculture and maintaining ecological balance.

DISCUSSION

Humified organomineral fertilisers based on oxidised lignite represent a vital component in modern agriculture, ensuring efficient and sustainable crop production. The use of such fertilisers is based on the use of lignite, which is subjected to an oxidation process that promotes the development of organic components with a high content of humic acids. Humate-enriched oxidised lignite contains a range of bioactive substances such as humus substances, humates, amino acids, and trace elements essential for healthy plant growth and development (Koković *et al.*, 2021).

The studies carried out by scientists and their findings also reveal significant aspects concerning the production of a vital component of humate-enriched organomineral fertiliser based on oxidised lignite. Specifically, Y. Bouhia *et al.* (2022) and C. Amoah-Antwi *et al.* (2021) found that vermicompost has a significant content of organic compounds, amino acids, and trace elements, which contributes to optimum plant nutrition. The conducted study agrees with the findings of other scientists, particularly M. Berca *et al.* (2017) and M.N. Ashraf *et al.* (2020), which confirm the increase of potassium, silicon, and phosphorus content in vermicompost. These elements play a key role in improving the nutrient composition of the soil and promote healthy plant growth. Moreover, H.S. Jat *et al.* (2019) also observed an increase in nutrient elements in vermicompost, which confirms the similarity of results.

The study on the use of red wiggle worms in organic waste composting is consistent with previous research including T. Keller *et al.* (2021) and A. Mustafa *et al.* (2020), which confirm the activity of organic matter mineralisation involving worms of *Eisenia foetida* species, as well as the positive effect of vermicompost on soil structure and plant growth. L. Joos *et al.* (2020)

aimed at investigating the effect of worms and minerals on improving soil carbon retention proved that the addition of worms changed the concentrations of organic carbon and nitrogen in certain density fractions and increased the thermal stability of organic matter in heavy fractions. These fractions contained higher proportions of aromatic and proteinaceous materials. Consequently, worms under composting conditions can effectively stabilise organic matter by forming aggregates and/or organo-mineral compounds containing more material originating from microorganisms (Domaratskiy *et al.*, 2023).

B. Symanowicz and R. Toczko (2023) confirm the improvement of soil characteristics under the influence of vermicompost, including increase in pH, moisture content, and organic matter. These changes create favourable conditions for plant growth and promote soil fertility, which is also reflected in the findings of the present study. Furthermore, confirmation of the obtained results can be found in the studies of S. Li *et al.* (2023) and G. Wang *et al.* (2020), which indicate the positive effect of vermicompost on soil biological activity. This indicates that vermicompost helps to improve microbiological processes in the soil, which can improve soil fertility. Comparable results were obtained by B. Al-Tawarah *et al.* (2024), who noted that the use of vermicompost improves soil structure by activating biological processes and enriching the soil with organic matter. This results in increased water-holding capacity of the soil and increased availability of nutrients to plants. The researchers also note that vermicompost is an effective tool in controlling soil erosion and preserving soil fertility for the long term.

S. Pot *et al.* (2022), in their studies on the microbiological characteristics of composts and management wastes compared to peat substrates, highlight that the composition of microbial communities in composts based on different raw materials can be more variable compared to peat substrates. In addition, I. Oyege and M.S. Balaji Bhaskar (2023) confirm that classification of management wastes based on parameters such as pH and hemicellulose content can be important for characterisation of bacterial and fungal communities, respectively.

Findings from many studies indicate the potential of various types of composts to improve plant growth or suppress pathogens, depending on their composition (Vinyukov *et al.*, 2022). Thus, green composts and vegetable composts may be most effective for non-acidophilic plants, while grass clippings and woody compost fractions may be beneficial for calcifuging plants (Lutz *et al.*, 2020; Le Mer *et al.*, 2020). Thus, the findings of the present study are in agreement with previous studies which also found the positive effect of vermicompost on soil properties and plant growth. Confirmation of these results under different conditions and using different techniques demonstrates the wide potential of vermicompost in improving agricultural sustainability and environmental conservation (Chimdessa & Sori, 2020; Ibrahim *et al.*, 2021).

The study confirms the positive effect of glauconite on soil characteristics, which agrees with the findings of I. Asghar *et al.* (2023), which shows an increase in the content of major nutritional elements and humic substances in the soil. This indicates that the addition of glauconite does improve soil fertility and stimulate plant growth. L. Liang *et al.* (2021) observed that the application of lignite-based humified organomineral fertiliser affects soil structure, making it more friable and improving water-holding capacity. This promotes more efficient penetration of moisture and nutrients to the plant roots. Humified fertilisers also help improve soil resistance to drought and erosion. Improved soil structure enriched with organic components helps to conserve moisture and prevent soil layers from being washed away by intense rainfall or irrigation (Tandy *et al.*, 2021; Ros *et al.*, 2020). These results demonstrate the potential of using local resources, such as lignite, to develop sustainable and effective organomineral fertilisers that can contribute to improved agriculture and environmental conservation in Kyrgyzstan (Sun *et al.*, 2020).

M. Berca *et al.* (2017) note the potential of using humate-enriched fertilisers as a tool to improve the economic efficiency of agriculture in Kyrgyzstan. Increasing yields and reducing fertiliser and tillage costs can lead to improved profitability and sustainability of agricultural enterprises. Consequently, the development of humate-enriched fertilisers based on lignite from Kyrgyzstan opens new prospects for sustainable agricultural development and environmental conservation in this region. It is also important to emphasise that the findings of Q. Wu *et al.* (2020) suggest that the use of lignite-based humate-enriched fertiliser can reduce the dependence of agriculture on chemical fertilisers. This can lead to reduced negative environmental impacts and lower costs of agricultural production. The use of humate-enriched fertiliser enhances plant immunity and resistance to stressful conditions such as drought, severe temperature fluctuations and diseases, which can improve yield and quality of produce (Vandecasteele *et al.*, 2021).

Considering the cited studies, as well as the findings of the present study, it can be stated that the use of humate-enriched fertilisers based on oxidised lignite is an effective way to improve soil fertility and stimulate plant growth. Thus, the agreement with the results of other studies confirms the reliability and importance of the obtained findings and emphasises the significance of obtaining a vital component of the humate-enriched organomineral fertiliser based on oxidised lignite of Kyrgyzstan as a fertiliser to improve soil properties and ensure healthy plant growth. The similarity of the results of various studies conducted by different groups of scientists in different regions confirms the consensus on the positive effects of humate-enriched fertilisers on soil properties and crop yields. These fertilisers help to improve soil structure, increase nutrient content, and activate biological processes necessary for healthy plant growth and development (Smetanska *et al.*, 2023).

Thus, based on the agreed results of various studies, it can be concluded that the use of humate-enriched fertilisers based on oxidised lignite in agriculture is promising to achieve a more sustainable and productive agriculture. Consequently, the findings of this study reflect the results of other researchers, confirming the positive effect of vermicompost and glauconite on soil properties and plant growth. This emphasises the importance of using these materials in agriculture to improve crop yields and soil quality. The combination of such studies allows for a full assessment of the efficiency and potential of the component of the humate-enriched fertiliser based on oxidised lignite.

CONCLUSIONS

The study provided significant data on vermicompost and its effect on soil characteristics. The analysis of vermicompost showed its richness in organic compounds and nutrient elements, which are presented in the form most assimilated by plants. The study found that the potassium content of vermicompost increases by 40% and silicon and phosphorus content is higher by 39% and 28.5%, respectively. Improvement in soil characteristics after vermicomposting was also observed: soil pH increased to 7-7.5, organic matter content increased to 35-45% and C/N ratio decreased to 10-12. This indicates more favourable conditions for plant growth and more efficient use of nitrogen.

The study also found that the addition of glauconite increased potassium oxide content by 0.6%, iron (III) oxide content increased by 2.34%, and aluminium oxide content increased by 0.41%. In addition, silicon oxide content increased by 4.9% and humic substances content increased by 1.1% after the addition of glauconite. Increasing humic substances brings many positive changes for the soil, including improving soil structure and fertility, reducing erosion, increasing fertiliser efficiency and maintaining biodiversity. Thus, the study found that the use of red wiggler worms of the species *Eisenia foetida* in the composting of organic waste promotes intensive composting processes and active mineralisation of organic matter. The resulting product, vermicompost enriched with glauconite and humus, helps improve soil structure and fertility, which stimulates plant growth. Hence, the addition of glauconite can be an effective way to improve soil quality, which is important for sustainable agriculture and environmental conservation.

A limitation of the study is that laboratory conditions may not fully reflect the complex interactions that can occur in a real soil environment. For instance, factors such as climatic conditions, biological activity of soil microorganisms, and soil chemical composition can substantially influence the effectiveness of vermicompost and glauconite as fertilisers. The prospect for further research is to evaluate the synergistic effects of vermicompost and glauconite with other fertilisers, soil adjustments, and agronomic practices to determine the best combinations of their application.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Отримання важливого компонента гуматизованого органомінерального добрива на основі окисленого бурого вугілля Киргизстану

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Анотація. Дослідження методів отримання та обробки гуматизованих органомінеральних добрив на основі окисленого бурого вугілля є ключовим аспектом для сучасного сільського господарства, з огляду на необхідність підвищення ефективності використання ресурсів, поліпшення якості ґрунту та забезпечення стійкості виробництва. Мета роботи – визначити оптимальні способи отримання та обробки гуматизованих органомінеральних добрив на основі окисленого бурого вугілля. Для досягнення поставленої мети проведено експериментальні дослідження в лабораторії інституту Природних ресурсів південного відділення Національної академії Киргизької республіки та навчально-науковій лабораторії кафедри Екологія та охорона довкілля Ошського технологічного університету імені М. М. Адишева в Киргизстані. Результати дослідження свідчать про значні зміни в ґрунтових характеристиках після застосування вермикомпосту та глауконіту. Аналіз вермикомпосту виявив, що він має значний вміст поживних елементів і органічних сполук. Вміст калію у вермикомпості збільшився на 40 %, а вміст кремнію і фосфору відповідно зріс на 39 % і 28,5 %. У результаті вермикомпостування спостерігається поліпшення характеристик ґрунту: pH підвищується до 7-7,5, вміст органічної речовини збільшується до 35-45 %, а C/N-відношення знижується до 10-12, що створює сприятливіші умови для росту рослин і підвищує ефективність використання азоту. Після додавання глауконіту відмічено збільшення вмісту оксиду калію на 0,6%, оксиду заліза (III) на 2,34%, та оксиду алюмінію на 0,41 %. Вміст оксиду кремнію зріс на 4,9 %, а гумінових речовин – на 1,1 %. Ці зміни в ґрунтових характеристиках сприяють підвищенню врожайності та поліпшенню якості ґрунту. Результати дослідження мають практичну значущість для сільського господарства в рамках поліпшення ґрунтових характеристик, підвищення врожайності та якості ґрунту, а також у зниженні залежності від хімічних добрив

Ключові слова: поживні речовини; ґрунт; екологічна стійкість; макроелементи; глауконіт; *Eisenia foetida*
