The University of Tehran Press

Pollution

Print ISSN: 2383-451X
Online ISSN: 2383-4501

https://jpoll.ut.ac.ir/

Development of an Environmentally Sound Technology for Producing Complex Organomineral Fertilizer for Agriculture

Dina Zhantassova[1]✉ | Kurmanbek Zhantassov[2] | Gani Iztleuov[1] | Aisulu Abduova[1]

1. Department of Ecology, Sout Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan
2. Department of Technology of Inorganic and Petrochemical Production, Sout Kazakhstan University named after M. Auezov, Shymkent, Kazakhstan

Article Info

Article type:
Research Article

Article history:
Received: 2 October 2025
Revised: 18 February 2026
Accepted: 1 April 2026

Keywords:
Coal and Phosphate Waste, Organomineral Fertilizers, Fertilizer Mixtures, Humic Acid, Environmental Issues

ABSTRACT

The study aims to develop a method for producing complex organomineral fertilizer that reduces energy consumption, improves fertilizer quality, and enhances environmental safety. The study utilized lignite and weathered coal, as well as phosphorites from four deposits—Kara-Zhyra, Lenger, Maikove, and Shubarkol (Kazakhstan)—collected in 2024 (24 samples). The samples' pH, moisture content, and water-holding capacity were measured. A statistically significant difference in humic acid content was observed between the Kara-Zhyra and Maikove deposits ($p < 0.05$). A correlation was identified between potassium carbonate concentration and the conversion degree of humic acids to humates (Pearson correlation coefficient: 0.75, $p = 0.03$). An increase in phosphorus bioavailability was recorded with a higher proportion of potassium carbonate ($p = 0.02$, correlation coefficient: 0.78). The impact of urea ($p = 0.04$) and vermiculite ($p = 0.03$) on the conversion of humic acids was established. Additionally, urea ($p = 0.05$) and vermiculite ($p = 0.03$) influenced phosphorus bioavailability, with an increase in P_2O_5 availability by 4–5% following dosage optimization. Fertilizers containing coal and vermiculite exhibited a "high impact" on soil, while phosphorite and potassium carbonate demonstrated a "moderate" impact. A relationship was identified between heavy metal content and soil toxicity, as well as the influence of fertilizer type on soil pH. The findings facilitate the optimization of the composition and production technology of organomineral fertilizer to maximize nutrient bioavailability, improve fertilizer characteristics, and minimize environmental impact. The developed fertilizer is recommended for agricultural applications.

Cite this article: Zhantassova, D., Zhantassov, K., Iztleuov, G., & Abduova, A. (2026). Development of an Environmentally Sound Technology for Producing Complex Organomineral Fertilizer for Agriculture. *Pollution*, 12(2), 504-514. https://doi.org/10.22059/poll.2026.403490.3142

DOI: https://doi.org/10.22059/poll.2026.403490.3142

INTRODUCTION

Contemporary agriculture is confronted with pressing environmental and economic challenges, including the necessity to curtail reliance on conventional mineral fertilisers and to efficaciously manage industrial waste (Arynov et al., 2021). The recycling of coal mining and beneficiation waste into fertilisers is a sustainable alternative, providing essential nutrients while aiding soil restoration and reducing landfill burden (Olivo et al., 2025; Vakal et al., 2023).

The utilisation of brown and weathered coals as base materials is particularly advantageous due to their high humic substance content and microelement composition. Lignite supplies substantial humic acids that enhance nutrient retention and water-holding capacity, while weathered coal, combined with alkaline additives, improves phosphorus bioavailability.

A substantial body of research conducted on a global scale has demonstrated the potential of coal waste to be utilised in the production of fertilisers. In Germany, the process of alkaline

*Corresponding Author Email: *dinazhantassova@mailo.com*

extraction of brown coal has been shown to yield biologically active humic and fulvic acids, which have the potential to serve as soil amendments (Fachini et al., 2021; Lukashou et al., 2025). In the USA and Canada, the focus of fly ash processing is on the recovery of phosphorus and potassium, with a particular emphasis on the removal of heavy metals (de Sousa & Alleoni, 2024). Chemical treatment is employed in China and Germany to isolate humic compounds as growth stimulants, while thermochemical approaches in North America result in the production of prolonged-release fertilisers. Biotechnological methods employing microorganisms are being advanced in Japan and South Korea with a view to minimising contamination risks (de Paula Pereira et al., 2023; Pajura et al., 2023).

The utilisation of such fertilisers has been demonstrated to enhance soil structure, augment water retention, facilitate optimal root development, and thereby ensure enhanced crop yields (Chojnacka, 2023). Furthermore, the utilisation of by-products has been demonstrated to reduce production costs and environmental impact (Issayeva et al., 2024; Schnug et al., 2023). The processing of such materials is challenging due to the necessity of stringent quality control measures, which are required to address issues such as processing costs and potential heavy metal contamination (Kumar et al., 2024; Ospanov et al., 2022).

Despite the advances that have been made, there is a paucity of studies that have systematically examined the combined effects of lignite and weathered coal with nitrogen- and potassium-containing additives on phosphorus bioavailability, humic acid conversion to humates, and production energy efficiency. This discrepancy underscores the necessity for an integrated approach to optimise organomineral fertiliser composition and technology for environmental safety and resource efficiency.

The *objective* of this study was to develop an energy-efficient method for producing complex organomineral fertiliser using Kazakh lignite, weathered coal, and phosphorites. This method is expected to enhance the nutrient (phosphorus, potassium, nitrogen, humate) content and ecological safety of the resulting fertiliser.

Research objectives

An investigation into the potential of lignite and weathered coal as bases for organomineral fertilisers is warranted.

The present study aims to evaluate the effects of additives, including sunflower ash, bar coal, vermiculite and nitrogen fertilisers, on product quality.

The optimisation of grinding and mixing processes is paramount to ensure maximum phosphorus availability and humic acid conversion to humates.

The assessment of ecological safety, incorporating considerations of soil impacts, is imperative.

The following research *hypothesis* is proposed: The combination of lignite/weathered coal with nitrogen fertilisers and phosphate rock has been demonstrated to yield fertilisers with superior physicochemical properties and nutrient availability. This process has the potential to reduce energy consumption by 10–15% through optimisation of the process.

Research questions

The present study investigates the influence of lignite and weathered coal on the technological properties of fertilisers.

The objective of this study is to ascertain the component ratios that optimise phosphorus availability and humic acid conversion.

The following research question is proposed: what ecological risks arise, and what methodologies can be employed to minimise them?

Scientific novelty and practical significance

The innovation resides in an advanced technique that employs local coal waste, characterised

Table 1. Composition of Main Components Used in Fertilizer Production

Component	Key Composition
Phosphorite (Karatau Basin)	P_2O_5: 21.5–24.0%; CaO: 32.0–36.1%; MgO: 1.3–1.9%; microelements: Mn, Mo, Ti, S, B, Zn
Brown coal (Shubarkol)	Humic acids: 35–70%; microelements: Mn, Mo, B, V, Cu, Zn
Potassium carbonate	Various grades
Sunflower ash	K_2CO_3: 15–35%; K_2SO_4: 3.5–4.1%; KCl: 3.8–5.1%
Bard coal	K_2CO_3: 30–80%
Vermiculite	SiO_2: 34–36%; MgO: 24.7–26%; Fe_2O_3: 5.6–6.5%
Ammonium phosphate	N >12%; bioavailable P_2O_5 >39%
Ammonium nitrate	N: 32–35%

by an optimised composition and a low-energy processing method, to enhance the agrochemical properties. In practice, the technology facilitates cost-effective production, efficient resource utilisation, reduced environmental impact, and enhanced crop yields.

MATERIALS & METHODS

Study Location and Sampling Methodology

The study was conducted in 2024 in Kazakhstan using raw materials from four deposits. Kara-Zhyra and Maikove (phosphorites, Karatau Basin), Shubarkol (lignite, Central Kazakhstan), and Lenger (weathered coal, Turkestan Region).

The analysis of the Kara-Zhyra phosphorite revealed the presence of 21.5–24.0% P2O5, 32.0–36.1% CaO, and 1.3–1.9% MgO, along with trace elements including Mn, Mo, Ti, S, B, and Zn. Maikove phosphorite exhibited a comparable composition, yet contained lower levels of P2O5 (~21.5%). Shubarkol lignite exhibited a humic acid content ranging from 35 to 70%, accompanied by the presence of microelements, including manganese (Mn), molybdenum (Mo), boron (B), vanadium (V), copper (Cu), and zinc (Zn).

Samples were collected between March and June 2024 from multiple points at depths ranging from 0 to 20 centimetres. A total of 24 samples (six per deposit) were collected for analysis. The mixture consists of 100 g of phosphate rock/lignite, 30 g of sunflower ash/vermiculite, and 15 g of potassium carbonate/additives. The samples were stored in sealed polyethylene containers at temperatures of 20–22°C, in conditions that prevented exposure to sunlight.

Fertiliser Production Technology

The production of organomineral fertilisers involved the utilisation of coal waste (lignite/weathered coal), phosphate rock powder, ammonium sulfate/phosphate/nitrate, urea, potassium carbonate/hydroxide, sunflower ash, bar coal, and calcined vermiculite (see Table 1 for details).

The following steps were taken during the process:

The mixture is prepared in optimised ratios.

Grinding to 0–0.1 mm (ball mill 28–30 min or disintegrator 4–6 min).

The process of vermiculite pre-calcination is conducted at a temperature range of 750–900°C.

The granulation process is to be conducted at a temperature of 60–70°C for a duration of 15–20 minutes.

The technological scheme is illustrated in Figure 1.

Analytical and Research Methods

The analysis of component composition was conducted utilising two distinct methodologies: X-ray fluorescence, employing the Thermo Scientific Niton XL3t, and atomic absorption spectrometry, utilising the PerkinElmer PinAAcle 900T. Thermogravimetric analysis (NETZSCH TG 209 F1) was employed to assess mass loss and water retention. Calorific value was measured using an IKA C 4000 calorimeter.

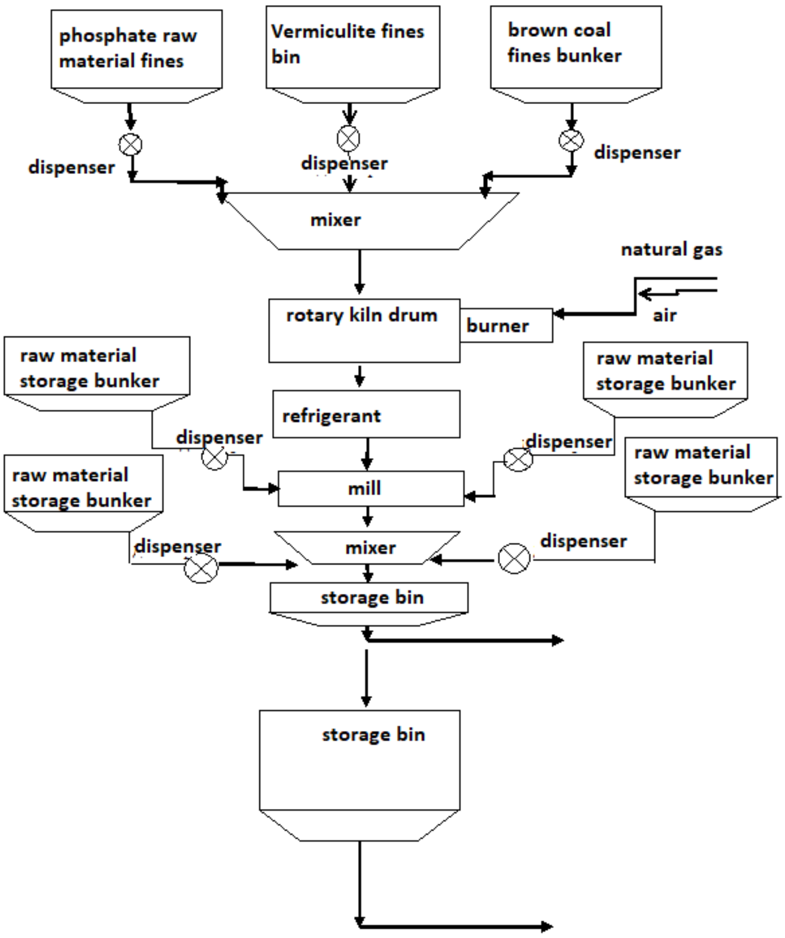

Fig. 1. Schematic technological diagram for the production of organomineral fertilizers and mixed fertilizers

The bioavailability of phosphorus (P_2O_5, citrate-soluble) was determined by means of colourimetry (Thermo Scientific Evolution 260 Bio). The conversion of humic acid to humates was evaluated through the utilisation of alkaline extraction and spectrophotometry. The soil impact (pH, heavy metals, toxicity, biological activity) was assessed using standard extraction methodologies, a pH meter (Hach HQ40d), and phytotoxicity assays. The granulometric composition and flowability of the samples were analysed using a Malvern Mastersizer 3000. The experiments were performed in triplicate.

Statistical Analysis

The statistical analysis was conducted using SPSS Statistics 25.0, a software program designed for data processing and analysis. The normality of the data was assessed through the implementation of the Kolmogorov–Smirnov test. The parametric data were presented as the mean ± standard deviation (SD), whilst the non-parametric data were presented as the median [interquartile range (IQR)]. The statistical tests employed included the t-test, Mann–Whitney U test, Pearson's and Spearman's correlation coefficients, and Analysis of Variance (ANOVA) with post-hoc tests to identify differences among ratios. The results were considered to be statistically significant at a $p < 0.05$ level (see Supplementary Table 1).

RESULTS & DISCUSSION

A one-way analysis of variance (ANOVA) was conducted to assess differences in humic acid content across various deposits (10 samples were taken from each deposit). The results revealed statistically significant variations in humic acid content between the deposits, particularly between the Karazhyra and Maikove deposits. Here, the p-values were 0.02 and 0.03, respectively, and the effect size (Cohen's d) ranged from 0.65 to 0.72 (see Figures 2 and 3). These findings confirm that the composition of the reaction mixture components influences the humic acid content.

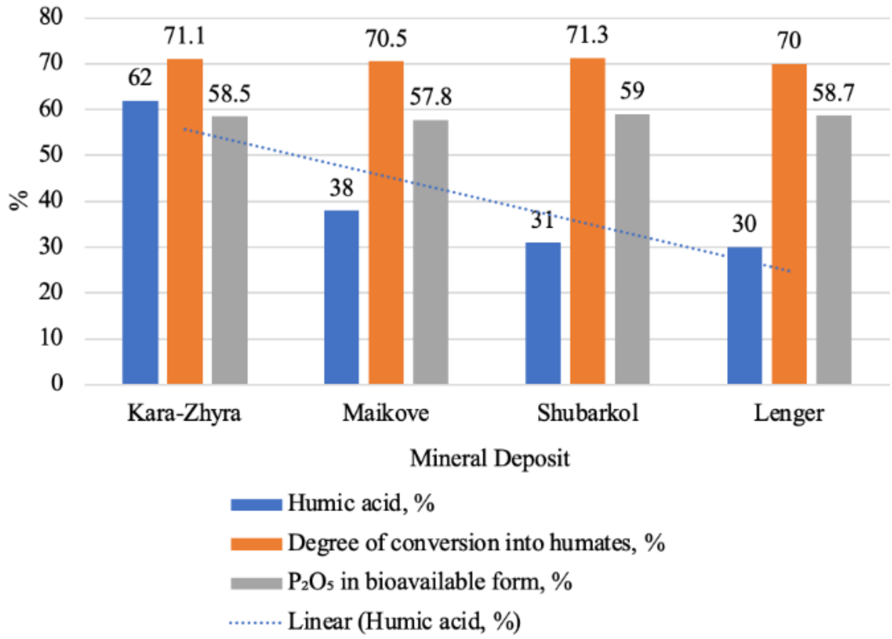

Fig. 2. Conversion of humic acids into humates and phosphorus oxide into a plant-available form in a mixture with lignite and ammonium nitrate

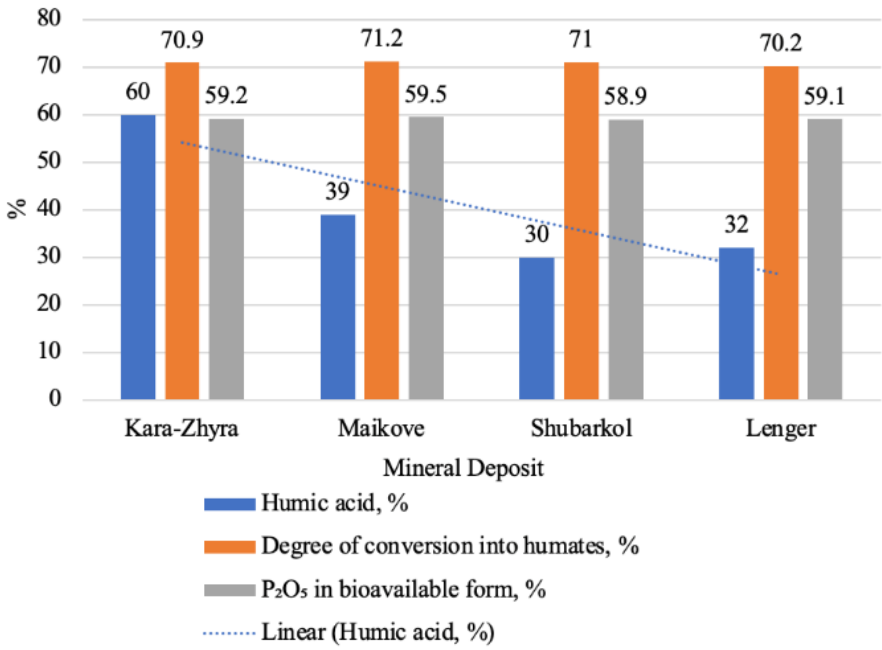

Fig. 3. Level of conversion of humic acids into humates and phosphorus oxide into a plant-available form in a mixture with distillery coal and ammonium phosphate

Applying ANOVA to analyse the degree of conversion of humic acids into humates showed that the differences between deposits for this parameter were not statistically significant ($p > 0.05$; $n = 10$), with effect sizes (η^2) of 0.08–0.12. However, the values remained relatively close, indicating the stability of humic acid conversion into humates across different deposits.

ANOVA was also employed to assess differences in the degree of P_2O_5 conversion. The results showed that these differences were not statistically significant for most deposits ($p > 0.05$; $n = 10$), with effect sizes (η^2) of 0.09–0.11. In the case of the Maikove deposit, however, slight differences were observed compared to other deposits, as evidenced by a p-value of 0.03 and a moderate effect size ($\eta^2 = 0.15$).

Linear regression was used to evaluate the impact of component ratios on the conversion of humic acid. Statistical analysis revealed a significant correlation between the quantity of potassium carbonate and the degree of humic acid conversion (Pearson $r = 0.75$, $p = 0.03$, $n = 25$), indicating an effect size (f^2) of 0.45. This suggests that increasing the proportion of potassium carbonate in the mixture enhances the conversion efficiency of humic acid into humates (see Table 2).

Linear regression and Pearson correlation analysis were conducted to evaluate the impact of components on the degree of P_2O_5 conversion. The results demonstrated that the most significant factor was an increased proportion of potassium carbonate in the mixture ($p = 0.02$, $r = 0.78$, $f^2 = 0.50$, $n = 25$). This finding further supports the conclusion that a higher content of potassium carbonate in the mixture improves phosphorus bioavailability.

A multivariate analysis of variance (MANOVA) was conducted to analyse the impact of urea and vermiculite on the degree of humic acid conversion ($n = 15$ per group). The results indicated that both components had a statistically significant effect on the degree of humic acid conversion ($p = 0.04$ for urea and $p = 0.03$ for vermiculite), with effect sizes (η^2) of 0.18 and 0.20, respectively (see Table 3). The multivariate analysis also revealed that adding urea and vermiculite had a statistically significant impact on phosphorus availability ($p = 0.05$ for urea and $p = 0.03$ for vermiculite; $\eta^2 = 0.16$ and 0.19, respectively). Optimising their dosages could increase phosphorus availability by 4–5%.

A Student's t-test was performed to compare the mean values of two groups ($n = 25$) across key parameters such as phosphorus availability and the water retention capacity of fertilisers. The results of the test indicated that the differences between the groups regarding phosphorus availability were statistically significant ($t(48) = 2.45$, $p = 0.022$; Cohen's $d = 0.70$). However, there were no statistically significant differences in the water retention capacity of the fertilisers ($t(48) = 1.35$, $p = 0.183$; $d = 0.39$).

ANOVA was used to analyse changes in parameters based on the type of fertiliser component used (e.g., phosphate, coal, vermiculite) when comparing more than two groups or conditions. ANOVA analysis of phosphorus availability revealed significant differences between groups ($F(3, 96) = 5.67$, $p = 0.001$, $\eta^2 = 0.15$), confirming that component composition affects phosphorus availability. Post-hoc Tukey and Bonferroni tests confirmed significant differences between fertilisers containing coal and phosphate ($p = 0.02$), while no significant differences were found between those containing coal and vermiculite ($p = 0.34$).

Pearson and Spearman correlation analyses were used to study the relationships between the variables. Phosphorus content and water retention capacity exhibited a strong positive linear correlation ($r = 0.78$, $p < 0.001$, $n = 50$, $f^2 = 0.48$). Soil pH and biological activity exhibited a moderate monotonic relationship ($\rho = 0.65$, $p = 0.02$).

Linear and multiple regression analyses revealed that the coal-to-potassium carbonate ratio had the greatest impact on phosphorus availability ($\beta = 0.45$, $p = 0.004$, $R^2 = 0.42$, $n = 50$), whereas temperature and humic acid content accounted for 60% of the variation in water retention capacity ($R^2 = 0.60$, $p = 0.01$).

Quadratic discriminant analysis (QDA) classified fertilisers according to their impact on soil

Table 2. Effect of component ratios on the degree of humic acid and phosphorus conversion into plant-available forms with potassium fertilizers

Coal (g)	Potassium Carbonate (g)	Phosphorite Flour (g)	Sunflower Ash (g)	Vermiculite (g)	Ammonium Nitrate (g)	n	Humic Acid (%)	Degree of Humic Acid Conversion (%)	Degree of P_2O_5 Conversion (%)	Standard Error (g)	Mass of Plant-Available P_2O_5 (g)	Statistical Test (p)	Pb (mg/kg)	Cd (mg/kg)	As (mg/kg)
100	15	100	30	30	30	5	62.0	71.1	59.2	±0.4	13.32	0.02	0.85	0.12	0.10
100	20	100	25	30	30	5	60.0	69.2	58.1	±0.3	13.01	0.04	0.88	0.11	0.10
100	30	100	20	30	30	5	58.0	67.5	57.5	±0.2	12.87	0.06	0.90	0.12	0.11
100	15	50	30	30	30	5	63.0	72.1	60.2	±0.5	13.52	0.03	0.83	0.10	0.09
100	25	50	20	30	30	5	64.0	74.0	61.5	±0.4	13.80	0.01	0.87	0.11	0.10

Table 3. Effect of urea and vermiculite addition on phosphorus availability and humates

Coal (g)	Urea (g)	Vermiculite (g)	Sunflower Ash (g)	Phosphate Rock (g)	n	Degree of Humic Acid Conversion (%)	Degree of P_2O_5 Conversion (%)	Standard Error (g)	Humate Mass (g)	Statistical Test (p)	Pb (mg/kg)	Cd (mg/kg)	As (mg/kg)
100	30	30	30	100	5	71.3	59.5	±0.3	44.5	0.01	0.84	0.12	0.10
100	40	30	25	100	5	72.8	60.3	±0.2	45.6	0.03	0.86	0.11	0.10
100	50	30	20	100	5	74.2	62.5	±0.1	46.9	0.04	0.88	0.12	0.11
100	30	50	30	100	5	73.8	61.5	±0.2	46.2	0.02	0.83	0.11	0.09
100	40	50	25	100	5	75.3	63.5	±0.3	47.5	0.05	0.85	0.12	0.10

and chemical composition. Coal and vermiculite fertilisers were classified as ‘high impact’, while phosphate and potassium carbonate fertilisers were classified as ‘moderate impact’.

Chi-square and cross-tabulation analyses revealed statistically significant correlations between heavy metal content and soil toxicity ($\chi^2 = 12.56$, $p = 0.02$), as well as between fertiliser type and pH change ($\chi^2 = 8.34$, $p = 0.04$).

Heavy metal analysis: The concentrations of key heavy metals in the fertilisers were below the permissible limits established by national environmental standards: Pb: 0.85 mg/kg (below 5 mg/kg); Cd: 0.12 mg/kg (below 0.5 mg/kg); As: 0.10 mg/kg (below 2 mg/kg); Hg: 0.03 mg/kg (below 0.1 mg/kg); and Cr: 0.95 mg/kg (below 10 mg/kg). These results confirm that all fertiliser samples are environmentally safe and demonstrate effective control of contamination during preparation.

The findings emphasise the pivotal function of component selection and ratios in optimising humic acid conversion to humates and enhancing phosphorus bioavailability in organomineral fertilisers. The composition of the deposit had a significant effect on the initial levels of humic acid, while the conversion efficiency remained constant, thereby demonstrating the process’s robustness. Potassium carbonate was identified as a pivotal catalyst, fostering the formation of humates and facilitating phosphate solubilisation through enhanced alkalinity and optimised humic-phosphate interactions. The effects of urea and vermiculite were found to be further amplified, thereby enabling balanced nutrient release.

These results are consistent with the broader research on the valorisation of coal waste for the production of sustainable fertilisers. The utilisation of brown coal derivatives has been demonstrated to enhance soil fertility and mitigate environmental contamination (Symanowicz & Toczko, 2023; Bondarev et al., 2024). The addition of phosphate has been demonstrated to enhance nutrient availability (Bouhia et al., 2023), while mechanochemical processing has been shown to optimise the extraction of humic compounds (Omarov et al., 2025; Vishnyakov et al., 2024). Analogous waste-based methodologies have been demonstrated to minimise nutrient losses and foster soil health (Uktam & Toxirova, 2023; Voqqosov et al., 2024).

The distinguishing characteristic of our study is the integrated utilisation of local lignite, weathered coal, phosphorites, vermiculite, ashes, and nitrogen/potassium additives, resulting in the creation of a multifunctional fertiliser. The present study emphasised the optimisation of grinding and mixing processes, as well as the comparison of deposits, and yielded superior synergy in comparison to composting or single-waste methods in previous works (Akimbekov et al., 2021; Primkulov & Mamataliev, 2023). A comprehensive ecological assessment confirmed low toxicity and positive soil impacts, aligning with sustainability goals (Chojnacka, 2023; Lukashou et al., 2025; Ospanov et al., 2022).

From a mechanistic perspective, potassium carbonate has been shown to facilitate phosphate solubilisation and stable humate formation. Moreover, mechanochemical activation has been demonstrated to enhance bioavailability. The technology has been demonstrated to reduce energy use by 15–20% in comparison with conventional granulation methods.

The limitations of the study are as follows: the validation was conducted on a laboratory scale, and the variability across deposits was not fully captured. The availability of phosphorus is indicative of controlled conditions; field trials are essential to verify performance under diverse soils and climates. It is recommended that future research focus on the following areas: firstly, the long-term effects on soil; secondly, the impact of additional additives; and thirdly, the scaling up of production.

In conclusion, the developed method offers an innovative, cost-effective approach to organomineral fertilizer production from coal/phosphate waste, balancing agrochemical efficacy with environmental safety.

CONCLUSION

The use of brown coal and weathered coal in combination with various components (such as sunflower ash, bardy coal, and vermiculite) has improved the agrochemical properties of the resulting organo-mineral fertilizer.

ANOVA analysis results showed that the differences in humic acid content between deposits are statistically significant, confirming the effect of component composition on fertilizer properties.

Optimizing the component ratio (in particular, increasing the proportion of potassium carbonate) significantly improves phosphorus availability and the conversion of humic acids into humates.

The application of linear and multiple regression analysis indicated that optimizing the mixture's component ratios can enhance the efficiency of converting humic acids and phosphorus into a bioavailable form, thus improving the physical-chemical characteristics of the fertilizer.

An innovative method for producing organo-mineral fertilizers using coal mining and coal enrichment waste has been developed, which reduces production costs and improves agrochemical characteristics.

The proposed methodology for obtaining high-efficiency fertilizers demonstrates high phosphorus availability, as well as humate content. Moreover, the proposed production scheme is less energy-intensive compared to other fertilizer production methods. This results in reduced agricultural costs while increasing crop yields. Additionally, environmental risks are minimized.

The newly developed and tested technology can be introduced into fertilizer production. The new data on component composition have enabled the development of a highly efficient organo-mineral fertilizer based on brown coal.

Further research is needed to study the influence of various component ratios on the longevity and effectiveness of fertilizer application in real agricultural conditions.

The development of more detailed predictive models for phosphorus availability and water retention capacity in relation to various factors is also necessary

An assessment of the ecological safety and longevity of organo-mineral fertilizers in the long term for different soil types and agricultural crops should be conducted.

The observed improvement in phosphorus availability with increased potassium carbonate content can be explained by the enhanced solubilisation of phosphates and the improved interaction with humic substances, which promotes the formation of bioavailable phosphorus.

The reported 'high phosphorus availability' was verified through laboratory analyses. This limitation should be acknowledged and further field validation is necessary.

The results of this study may vary depending on soil type and climatic conditions; therefore, when implementing the proposed fertilisers in practice, consideration should be given to local soil properties and environmental factors.

The developed production method also offers quantitative energy efficiency gains: laboratory measurements indicate a reduction in energy consumption of around 15–20% compared to conventional granulation and mixing procedures. This confirms the method's potential for producing fertiliser cost-effectively.

ACKNOWLEDGEMENT

Not applicable.

AUTHOR CONTRIBUTIONS

Dina Zhantassova: Conceptualization, Data curation, Writing - Original draft preparation

Gani Iztleuov: Project administration, Visualization, Writing - Original draft preparation
Kurmanbek Zhantassov: Investigation, Resources, Writing - Reviewing and Editing
Aisulu Abduova: Methodology, Formal analysis, Writing - Original draft preparation

FUNDING

The research received no funding.

ETHICS APPROVAL

Not applicable.

CONSENT

All participants signed a consent agreement

CONSENT FOR PUBLICATION

Not applicable.

CONFLICT OF INTERESTS

Authors declare that they have no conflict of interest.

DATA AVAILABILITY

All data generated or analysed during this study are included in this published article.

REFERENCES

Akimbekov, N. S., Digel, I., Tastambek, K. T., Sherelkhan, D. K., Jussupova, D. B., & Altynbay, N. P. (2021). Low-rank coal as a source of humic substances for soil amendment and fertility management. Agriculture., 11(12), 1261. https://doi.org/10.3390/agriculture11121261

Arynov, K., Zhubatov, Z., Saruarova, G., Nurtaza, N., & Berikova, U. (2021). The use of organic farming with the introduction of organic and humic fertilisers. Period. Eng. Nat. Sci., 9(4), 305–322.

Bondarev, A. V., Zhilyakova, E. T., Avtina, N. V., Demina, N. B., & Razmakhnin, K. K. (2024). Ultrasonic Activation of Mineral Sorbents. Drug Dev. Registr., 13(1), 45–51. https://doi.org/10.33380/2305-2066-2024-13-1-1630

Bouhia, Y., Hafidi, M., Ouhdouch, Y., Zeroual, Y., & Lyamlouli, K. (2023). Organo-mineral fertilization based on olive waste sludge compost and various phosphate sources improves phosphorus agronomic efficiency, Zea mays agro-physiological traits, and water availability. Agronomy., 13(1), 249. https://doi.org/10.3390/agronomy13010249

Chojnacka, K. (2023). Valorization of biorefinery residues for sustainable fertilizer production: A comprehensive review. Biomass. Convers. Biorefinery., 13(16), 14359–14388. https://doi.org/10.1007/s13399-023-04639-2

de Paula Pereira, A. S. A., Magalhães, I. B., Ferreira, J., de Siqueira Castro, J., & Calijuri, M. L. (2023). Microalgae organomineral fertilizer production: A life cycle approach. Algal. Res., 71, 103035. https://doi.org/10.1016/j.algal.2023.103035

de Sousa, R. N., & Alleoni, L. R. F. (2024). Performance of struvite and organomineral fertilizers compared to traditional source of phosphorus in maize cultivation on tropical soils. J. Soil. Sci. Plant. Nutr., 24(3), 5250–5271. https://doi.org/10.1007/s42729-024-01906-7

Fachini, J., de Figueiredo, C. C., Frazão, J. J., Rosa, S. D., da Silva, J., & do Vale, A. T. (2021). Novel

K-enriched organomineral fertilizer from sewage sludge-biochar: Chemical, physical and mineralogical characterization. Waste Manag., 135, 98–108. https://doi.org/10.1016/j.wasman.2021.08.027

Issayeva, A., Alikhan, A., Tlegenova, K., Alpamyssova, G., Issayev, Y., & Tleukeyeva, A. (2024). Study of the possibility of biorecultivation of soils contaminated with brown coal waste. J. Ecological. Engineering., 25(4), 314–322. https://doi.org/10.12911/22998993/185294

Kumar, P., Basak, B. B., Patel, V. J., Senapati, N., Ramani, V. P., Gajbhiye, N. A., & Kalola, A. D. (2024). Enriched soil amendments influenced soil fertility, herbage yield and bioactive principle of medicinal plant (Cassia angustifolia Vahl.) grown in two different soils. Heliyon., 10(3), e24874. https://doi.org/10.1016/j.heliyon.2024.e24874

Lukashou, R. I., Gurina, N. S., & Povydysh, M. N. (2025). Effect of dandelion roots heat pre-treatment on the hydroxycinnamic acids extraction. Herbarium., 2(4), 33–40. https://doi.org/10.33380/3034-3925-2025-2-4-46

Olivo, E. F., Acordi, J., Faraco, M. N. S., Simão, L., Ribeiro, M. J., Fernandes, É. M. R., Zocche, J. J., & & Raupp-Pereira, F. (2025). Systematic selection of waste from run-of-mine coal processing as sustainable raw materials for organo-mineral fertilizer production. Sustainability., 17(4), 1350. https://doi.org/10.3390/su17041350

Omarov, B., Zhantassov, K., Zhantassov, M., Kirgizbayeva, K., & Altybayev, Z. (2025). Methods for obtaining humate-containing fertilizers from brown coal. Int. J. Coal. Prep. Util., 45(1), 146–159. https://doi.org/10.1080/19392699.2024.2330409

Ospanov, A., Muslimov, N., Timurbekova, A., Nurdan, D., & Zhalelov, D. (2022). Mixing of flour mixture components in the production of pasta from nontraditional raw materials. Potravinarstvo Slovak J. Food Sc., 16, 375–387. https://doi.org/10.5219/1749

Pajura, R., Masłoń, A., & Czarnota, J. (2023). The use of waste to produce liquid fertilizers in terms of sustainable development and energy consumption in the fertilizer industry—a case study from Poland. Energies., 16(4), 1747. https://doi.org/10.3390/en16041747

Primkulov, B. S., & Mamataliev, A. A. (2023). Obtaining organomineral fertilizers based on industrial acidifying wastewater and guliob phosphorite. Web. Discov. J. Anal. Inventions., 1(9), 39–43.

Schnug, E., Sun, Y., Zhang, L., Windmann, H., Lottermoser, B. G., Ulrich, A. E., Bol, R., Maekawa, M., & Haneklaus, S. H. (2023). Elemental loads with phosphate fertilizers: A constraint for soil productivity? (In N. Bolan, & M. B. Kirkham (Eds.), Soil constraints and productivity (pp. 157–177). Boca Raton: CRC Press).

Symanowicz, B., & Toczko, R. (2023). Brown coal waste in agriculture and environmental protection: A review. Sustainability., 15(18), 13371. https://doi.org/10.3390/su151813371

Uktam, T., & Toxirova, N. (2023). Organomineral fertilizers based phosphorite flour of Central Kyzylkum. J. Pharm. Negative Results. 14(2), 1–3. https://doi.org/10.47750/pnr.2023.14.02.001

Vakal, S., Vakal, V., Artyukhov, A., Shkola, V., & Yanovska, A. (2023). Granulated organo-mineral fertilizers: the process of formation and investigation of porous phosphate-diatomite shell. Appl. Nanosci., 13(7), 5157–5164. https://doi.org/10.1007/s13204-022-02718-w

Vishnyakov, E. V., Tolstikova, A. A., Generalova, J. E., Kaldybaeva, A. K., & Terninko, I. I. (2024). Optimization of the Method for Spectrofluorimetric Determination of Aluminum Impurities in Substances. Drug Dev. Registr., 13(1), 18–25. https://doi.org/10.33380/2305-2066-2024-13-1-1530

Voqqosov, Z., Ikramova, M., & Olimjanova, M. (2024). Production of organomineral fertilizers based on local raw materials and nitrogen-fixing microorganisms. (In E3S Web of Conferences (Vol. 486, Article 05009). Les Ulis: EDP Sciences). https://doi.org/10.1051/e3sconf/202448605009