STUDY OF THE CHEMICAL AND MINERALOGICAL COMPOSITION OF COMPLEX-MIXED FERTILIZERS OBTAINED ON THE BASIS OF VERMICULITE AND SELECTION OF THE OPTIMAL COMPOSITION

Ochilov Siroj Urozboy ugli[1]
Allaniyazov Davran Orazimbetovich[1],
Karimboyeva Mohira baxtiyor qizi[2],
[1]**Karakalpak Research Institute of Natural Sciences of the Karakalpak Branch of the Academy of Sciences of the Republic of Uzbekistan**
[2]**Karakalpak State University**
https://doi.org/10.5281/zenodo.20726465

Keywords: *vermiculite, phosphogypsum, biohumus, organomineral fertilizer, granulation, P_2O_5, SEM-EDS, TGA/DSC, Aral Sea region.*

The growing demand for multifunctional fertilizers that combine plant nutrition with soil-improving properties has stimulated interest in organomineral compositions based on local raw materials. In the Aral Sea region of Karakalpakstan, large tonnages of phosphogypsum — a by-product of phosphoric-acid production — and deposits of vermiculite, a hydrated Mg–Al–Fe layered silicate, provide a basis for producing complex fertilizer-ameliorants. In such systems biohumus supplies organic matter, ammophos and urea provide phosphorus and nitrogen, phosphogypsum contributes calcium and sulfur, and vermiculite acts as a structure-forming, nutrient-retaining and prolonging matrix. The present work studies the chemical and mineralogical composition of granulated organomineral fertilizers as a function of the phosphogypsum and vermiculite content and selects the optimal composition.

Granulated organomineral fertilizers were prepared from biohumus, phosphogypsum, vermiculite, ammophos and urea in the proportions listed in Table 1. The components were homogenized, moistened and granulated. The granules were characterized for pH, total and citric-acid-soluble P_2O_5, total CaO, K_2O, total SO_3, organic-matter content, total nitrogen, granulometric composition and compressive strength. The microstructure and elemental composition of the selected optimal samples were examined by scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), and their thermal behavior by combined thermogravimetric and differential-scanning-calorimetric (TGA/DSC) analysis.

The composition and the main physico-chemical and commercial characteristics of the obtained organomineral fertilizers are summarized in Table 1.

Table 1. *Effect of the phosphogypsum and vermiculite content on the properties of the organomineral fertilizers*

No.	Bio-humus	Phos pho-	Verm i-culite	Amm ophos	Urea	pH	P_2O_5 total, %	P_2O_5 citric-sol.,	CaO total, %	K_2O, %	SO_3 total, %	Orga nic, %	N total, %	<2 mm, %	2–4 mm, %	>4 mm, %	Stren gth, MPa
	2.5	2.5		.4	.6	.1	.75	6.68	1.35	.12	1.8	9	.4	1	3	6	.3
	8.12	9.38		.6	.9	.3	.6	4.88	0.32	.35	1.32	5	.0	8	0	2	.2
	2.5	2.5	4	4.94	.06	.8	.9	5.35	3.25	.41	9.32	5	.0	2	5	3	.4
	1.25	3.75	8	9.2	.8	.3	.6	7.56	.2	.01	8.35	1	.6	1	3	6	.3

	4.25	2.75	7.2	8.34	.46	.1	.7	8.98	8.4	.02	2.8		.4	8	8	4	.9
	0	0	4	5.6	0.4	.6	1.2	7.76	2.52	.42	5.32		4.3		0	1	.6
	2.5	.5	8	9.88	2.12	.5	2.3	8.84	.2	.75	5.2	1	0.2		8	4	.4

With increasing vermiculite content from 6 to 28%, the total P_2O_5 rose from 2.75 to 12.3%, K_2O increased from 0.12 to 2.75%, total nitrogen increased, and the compressive strength of the granules grew from 1.3 to 2.6 MPa. Owing to its layered structure, vermiculite improves granule structure-formation, enhances water-retention, retains ammonium and potassium ions and acts as a prolonging (slow-release) matrix for the nutrients.

An increase in the phosphogypsum content raised the CaO and SO_3 levels and stabilized the pH within 4.1–5.5. Phosphogypsum thus serves as a source of calcium and sulfur, lowers alkalinity and promotes aggregation of soil particles; the highest sulfur supply is provided by compositions No. 6 and No. 7. For all compositions the degree of citric-acid-soluble P_2O_5 was high (94.88–98.98%), indicating good bioavailability of the phosphate phase and the efficiency of ammophos as a phosphorus source. The organic-matter content decreased from 31.8 to 15.2% as the biohumus fraction was reduced, while the bulk of the granules fell within the commercially demanded 2–4 mm fraction (up to 78–80% for No. 6 and No. 7).

A comparative evaluation of the whole series (Table 1) shows that compositions No. 6 and No. 7 provide the most favorable combination of agrochemical and physico-mechanical properties. Composition No. 6 (24% vermiculite; biohumus : phosphogypsum = 20 : 20) exhibits the highest compressive strength (2.6 MPa), a high total P_2O_5 content (11.2%) with 97.76% of it in citric-soluble form, a high K_2O content (2.42%) and the highest yield of the commercial 2–4 mm fraction (80%). Composition No. 7 (28% vermiculite) provides the highest total P_2O_5 (12.3%) and K_2O (2.75%), the highest citric-soluble P_2O_5 (98.84%), a favorable pH (5.5) and high granule strength (2.4 MPa). Together, these two compositions combine the highest contents of available phosphorus, potassium and sulfur with maximum mechanical strength and a high commercial-fraction yield, and were therefore selected as the optimal variants for detailed mineralogical and thermal characterization.

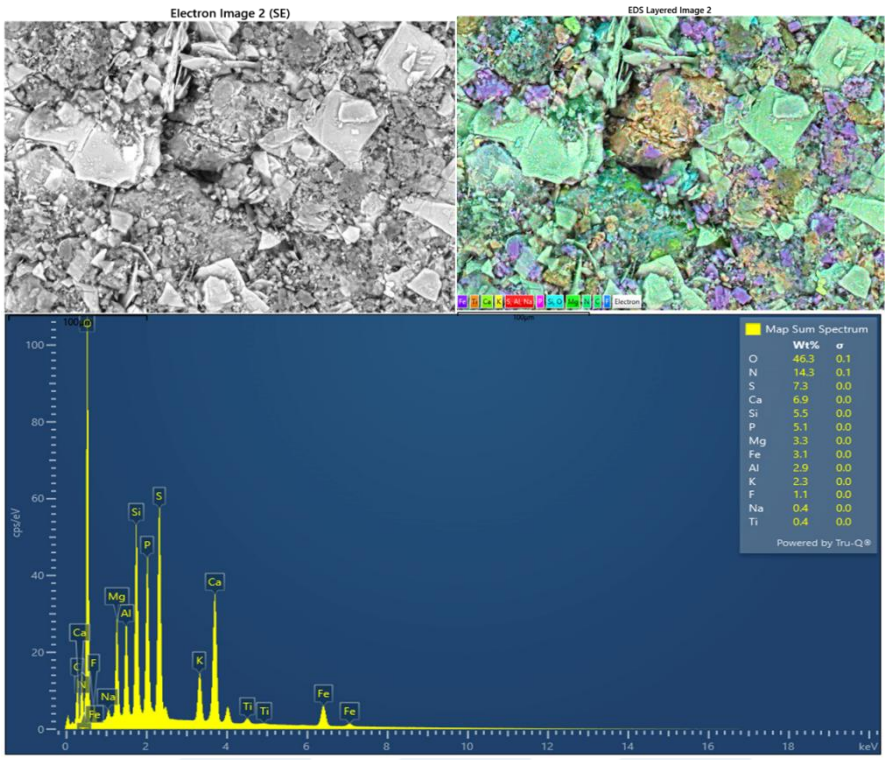

Fig. 1. SEM-EDS analysis of the vermiculite-containing fertilizer (Table 1, sample No. 6): secondary-electron image, EDS layered map and map-sum spectrum.

SEM-EDS confirms that both optimal samples have an aluminosilicate (vermiculite-type) nature. The principal elements are oxygen, silicon, magnesium and aluminum, whose association (Mg–Al–Si) is characteristic of layered hydromicaceous silicates of the vermiculite group, while the elevated contents of phosphorus, sulfur, calcium and potassium confirm enrichment of the mineral matrix with agronomically valuable nutrients. Such a material can simultaneously act as a loosening and water-retaining substrate, a source of macro- and micro-elements and an ion-exchange component of the soil environment; trace amounts of F, Ti, Na and Ba correspond to natural mineral impurities of the raw material and do not affect its properties.

Combined TGA/DSC analysis revealed a multistage thermal decomposition for both optimal samples. For sample No. 6, successive mass losses of 22.88% (145–266 °C), 20.69% (266–531 °C) and 10.03% (560–810 °C) correspond, respectively, to the removal of adsorbed and interlayer water, decomposition of the organic matrix and high-temperature dehydroxylation, with a residual mass at 1000 °C of about 46%. Sample No. 7 behaves analogously (mass losses of 25.88%, 13.15% and 12.03% in the corresponding intervals), showing endothermic effects at ≈141, 245, 382 and 652 °C and an exothermic peak near 801 °C associated with crystallization of new silicate phases. Both samples retain structural stability up to ≈550–600 °C and leave a high thermostable residue, which confirms the robustness of the vermiculite matrix.

Granulated organomineral fertilizers combining biohumus, phosphogypsum, vermiculite, ammophos and urea were obtained and characterized. An increase in the vermiculite and mineral content raises the contents of available phosphorus, potassium and sulfur as well as the mechanical strength of the granules, while the share of citric-soluble P_2O_5 remains high (≈95–99%) for all compositions. On the basis of a comprehensive comparison of the

agrochemical and physico-mechanical properties, compositions No. 6 and No. 7 were selected as optimal. SEM-EDS and TGA/DSC analyses confirmed that these samples retain the vermiculite Mg–Al–Si matrix enriched with P, S, Ca and K and possess high thermal stability, which makes them promising multifunctional, slow-release fertilizer-ameliorants for the saline soils of the Aral Sea region.

Adabiyotlar, References, Литературы:

1. Allaniyazov D.O. Development of the scientific basis of the technology and processes for obtaining complex fertilizers from glauconites and phosphorites of Karakalpakstan. - Tashkent: IONKh AS RUz, 2019.
2. Asanov A.M., Erkaev A.U., Allanyazov D.O., Ochilov S.U., // Analysis of the adsorption and desorption properties of the heat-treated vermiculite mineral // International Scientific and Practical Conference "Current Problems, Solutions, and Development Prospects of Modern Chemistry" May 15, 2025 238-239.
3. Allaniyazov D.O., Reymov A.M., Erkayev A.U., Tazhibaev T.A., Kurbiazov D.K. // Sorption capacity of glauconite and vermiculite of Karakalpakstan // Science, technology and global challenges Proceedings of I International Scientific and Practical Conference Tokyo, Japan 11-13 September 2025.
4. Allaniyazov D. O. Kalandarova F., Aymuratov D., Aymuratova N. // Physicochemical properties and mineralogical characteristics of vermiculite from the Tebinbulak deposit // Universum: Technical Sciences Issue: 12 (141) December 2025 Part 7. Moscow 2025. 59-63.