

From Waste to Fertilizer: Phosphorus Organo-Mineral Products Derived from Digestate and Ashes

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The implementation of Circular Economy principles in waste management increasingly focuses on nutrient recovery from secondary resource streams. Municipal and agro-industrial residues represent a significant yet underutilized source of plant nutrients for fertilizer production. The integration of highly concentrated mineral phosphorus sources—sewage sludge ash (SSA) and poultry litter ash (PLA)—with an organic matrix derived from processed biowaste enables the production of organo-mineral fertilizers characterized by improved nutrient availability and beneficial effects on soil properties (Acar, 2023; Chojnacka et al., 2024; Herzel et al., 2016; Kominko et al., 2025; Nowak & Czekala, 2024; Sawska et al., 2025).

The aim of this study was to develop a technology for the production of granulated phosphorus organo-mineral fertilizers based exclusively on alternative raw materials. SSA and PLA were applied as mineral phosphorus sources, including variants enriched with Plant Growth Promoting Bacteria (PGPB). The organic component consisted of dried solid digestate fraction, serving as a carrier of organic matter and amino compounds. Additionally, a hydrolysate obtained from waste feathers and down was incorporated during granulation, allowing further valorization of biogenic residues.

Raw materials and final products were characterized using Atomic Absorption Spectrometry (AAS) for metal determination, CHN analysis, spectrophotometric phosphorus quantification, and organic carbon determination according to a modified Walkley–Black procedure. Organic matter content was measured by loss on ignition. Amino acid profiles were determined via ion-exchange chromatography. Agronomic performance was evaluated in pot experiments using *Sorghum bicolor* (Moench). Biomass quality assessment included chlorophyll and phosphorus determination by spectrophotometry and heavy metal analysis by ICP-OES. Soil biological activity was assessed through dehydrogenase activity (spectrophotometric method) and catalase activity (manganometric method according to Johnson and Temple) (Bahadori & Tofighi, 2016; Januszek et al., 2007; Smol & Kulczycka, 2018; Wellburn, 1994).

The obtained fertilizers contained 55–64% organic matter and 22–25% organic carbon (dry matter basis), classifying them as organo-mineral fertilizers. Total phosphorus content ranged from 4% to over 6% P₂O₅ (dry matter basis), fulfilling the criteria for phosphorus fertilizers under Regulation (EU) 2019/1009 (European Parliament, 2019). High potassium (approx. 5% K₂O) and calcium (6–8% CaO) contents were also recorded. Lead and cadmium concentrations remained within acceptable limits, while two SSA-based formulations exceeded the permissible nickel threshold. The products were rich in amino acids (approx. 10% in dry matter), predominantly aspartic and glutamic acids.

Pot trials demonstrated enhanced chlorophyll content in aboveground biomass compared to the control (increase of 2–5 mg g⁻¹ fresh weight) and improved soil enzymatic activity, particularly catalase activity. The most favorable agronomic performance was observed for formulations containing PLA enriched with beneficial microorganisms.

These findings confirm the technological and agronomic feasibility of producing high-quality phosphorus organo-mineral fertilizers exclusively from alternative waste-derived resources, supporting nutrient recycling within the Circular Economy framework.

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