

MULTI-STAGE OPTIMIZATION OF LIQUID ORGANOMINERAL FERTILIZER PRODUCTION FROM POULTRY MANURE AND PHOSPHORITE SLUDGE: CHEMICAL SYNERGY AND EXTRACTION MECHANISMS

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Abstract:

The sustainable management of agricultural and industrial wastes is a cornerstone of the modern circular economy. This study provides a comprehensive analysis of the production of liquid organomineral fertilizers using poultry manure (PM) and low-grade phosphorite sludge (PS) via alkaline extraction. By varying the component ratios (95:5 to 65:35) and solid-to-liquid (S:L) ratios (1:1 to 1:3), we identified the critical parameters governing nutrient recovery. Experimental data show that P₂O₅ and CaO concentrations are maximized in mineral-rich blends, while the preservation of bio-active humic and fulvic acids requires a manure-dominant matrix. The study also discusses the chemical mechanism of phosphorus solubilization by organic ligands in an alkaline medium. The optimized formulation (PM:PS = 75:25, S:L = 1:2) yields a balanced nutrient profile suitable for high-yield sustainable agriculture.

Keywords: Poultry manure; Phosphorite sludge; Liquid organomineral fertilizer; Alkaline extraction; Humic substances; Nutrient recovery; Circular economy; P₂O₅ solubilization; Sustainable agriculture; Bio-stimulants.

Introduction

In the 21st century, the global agricultural sector faces the dual challenge of feeding a growing population while minimizing environmental degradation. Traditional mineral fertilization, though effective in the short term, has led to soil acidification, biodiversity loss, and groundwater contamination [1]. Consequently, there is an urgent need to transition toward organomineral fertilizers

(OMF), which combine the immediate nutrient availability of minerals with the soil-conditioning properties of organic matter.

The "waste-to-wealth" paradigm is gaining traction globally. Poultry manure (PM) is a nutrient-rich byproduct of the livestock industry, but its raw application often leads to ammonia volatilization and pathogen spread. Simultaneously, the phosphate industry generates millions of tons of phosphorite sludge (PS) as an enrichment byproduct [2]. In Uzbekistan, specifically the Central Kyzylkum region, thousands of tons of PS remain underutilized despite containing significant amounts of P_2O_5 and CaO.

This research explores the synergy between PM and PS during KOH-mediated extraction [3]. The primary objective is to scientifically substantiate the technological parameters for a liquid fertilizer that maintains high concentrations of humic substances while maximizing the availability of phosphorus and potassium.

2. Materials and Methods

The experimental study was carried out using primary raw materials indigenous to Uzbekistan, ensuring both regional relevance and practical applicability. Phosphorite sludge (PS), obtained as a byproduct from the beneficiation of phosphorites at the Central Kyzylkum deposit (Navoi region), was characterized in advance using X-ray fluorescence (XRF) analysis. Poultry manure (PM), sourced from an industrial poultry complex, was air-dried and mechanically ground to a particle size below 0.5 mm to enhance the specific surface area and improve extraction efficiency. A 2% aqueous solution of analytical-grade potassium hydroxide (KOH, 98% purity) was employed as the extraction reagent. The synthesis of the liquid organomineral fertilizer was conducted through a multi-stage process involving seven PM:PS mass ratios (95:5 to 65:35) and five solid-to-liquid (S:L) ratios (1:1 to 1:3). Thermochemical treatment was performed in a double-walled glass reactor equipped with a mechanical stirrer operating at 400 rpm, where the mixture was maintained at 50–60°C for 90 minutes to ensure maximum dissolution of humic substances while preventing their thermal degradation. The resulting suspension was subsequently subjected to centrifugation at 3000 rpm for 15 minutes to separate the nutrient-enriched liquid phase from the solid residue.

To ensure the reliability and reproducibility of the obtained results, standardized international and GOST-based analytical methods were applied. The total phosphorus content (P_2O_5) was determined using the vanadomolybdate spectrophotometric method after acid digestion with H_2SO_4 and $HClO_4$, with absorbance measured at 440 nm. Calcium oxide (CaO) content was quantified via complexometric titration using EDTA in alkaline medium with murexide indicator, while potassium oxide (K_2O) was analyzed using flame photometry at a wavelength of 766.5 nm. The total organic matter (TOM) was determined according to the Tyurin method based on dichromate oxidation, with subsequent calculation using the Van Bemmelen coefficient. Fractionation of humic and fulvic acids involved alkaline extraction (0.1 M NaOH), followed by acid precipitation (pH 1.5–2.0) to isolate humic acids, whereas fulvic acids remained in the filtrate and were quantified via oxidation-titration. Additionally, water-soluble organic matter (WSOM) was extracted under controlled conditions and analyzed using the dichromate method. All experiments were conducted in triplicate ($n=3$), and the resulting data were statistically processed using ANOVA to evaluate the significance of PM:PS and S:L ratios, while regression analysis in OriginPro 2024 software enabled the construction of response surfaces and identification of optimal process parameters.

3. Results and Discussion

The integration of PS into the organic matrix significantly alters the mineral density of the resulting slurry.

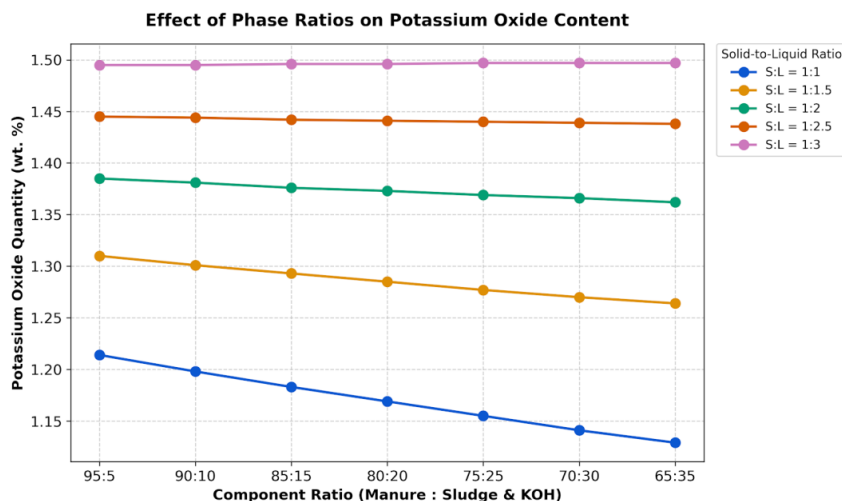


Figure 1 - Potassium oxide (K₂O) content (wt.%) in a slurry based on poultry manure, phosphorite slime, and potassium hydroxide

As seen in Figure 1, potassium levels are exceptionally stable. Unlike other components, K₂O is primarily introduced via the 2% KOH solution. At a 65:35 ratio, K₂O concentrations range from 1.129% to 1.498% depending on the S:L ratio.

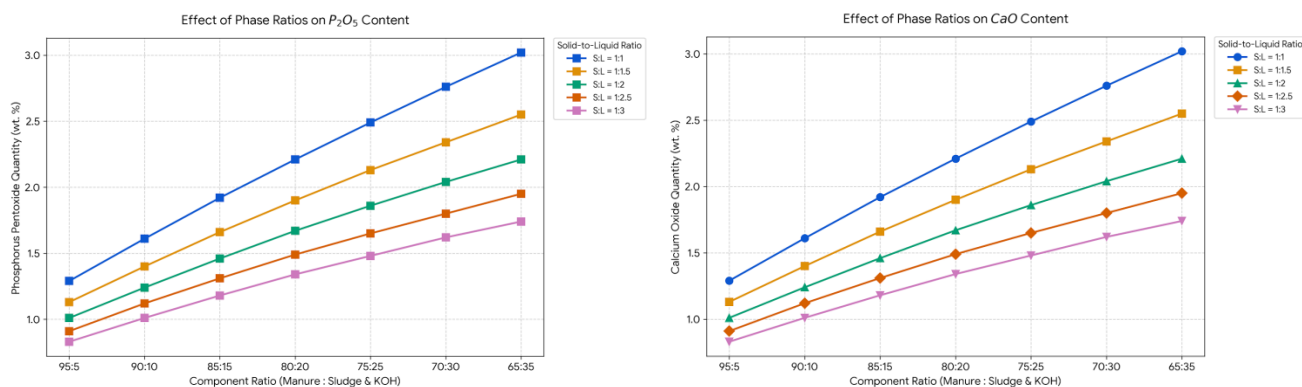


Figure 2 - P₂O₅ and CaO contents (mass %) in a poultry manure–phosphorite slime–potassium hydroxide slurry.

Phosphorus and Calcium exhibit a symbiotic trend. The maximum P₂O₅ (3.02%) and CaO (10.03%) values were achieved at S:L 1:1 and PM:PS 65:35. This suggests that the alkaline extraction also facilitates the partial breakdown of mineral lattices in the sludge, making these elements more mobile.

The organic fraction is the "engine" of the fertilizer, providing soil-building properties.

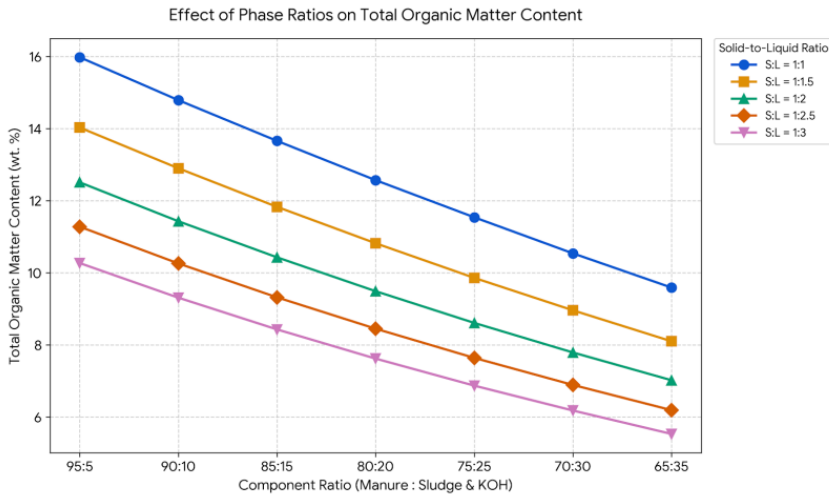


Figure 3 - Total organic matter content (wt.%) in the slurry based on poultry manure, phosphorite slime, and potassium alkali.

The TOM chart shows a steep decline from 15.98% to 5.53% as the mineral sludge replaces manure. This highlights the trade-off between mineral density and organic richness.

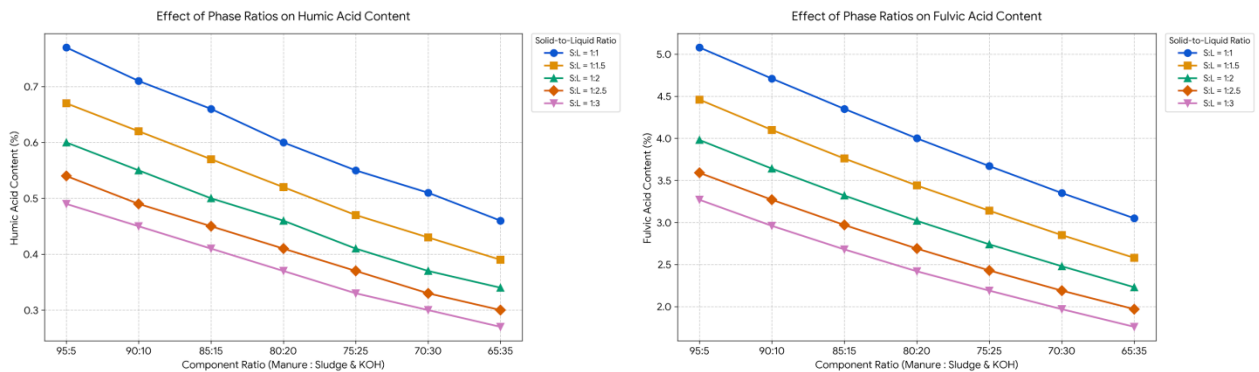


Figure 4 - Content of humic and fulvic acids in a slurry based on poultry manure, phosphorite slime, and potassium hydroxide (wt.%).

Humic acids (HA) and Fulvic acids (FA) are the most valuable components. HA decreased from 0.77% to 0.27%, while FA showed higher overall solubility, peaking at 5.08% [4].

The extraction coefficient was analyzed by comparing the WSOM (Water-soluble organic matter) values.

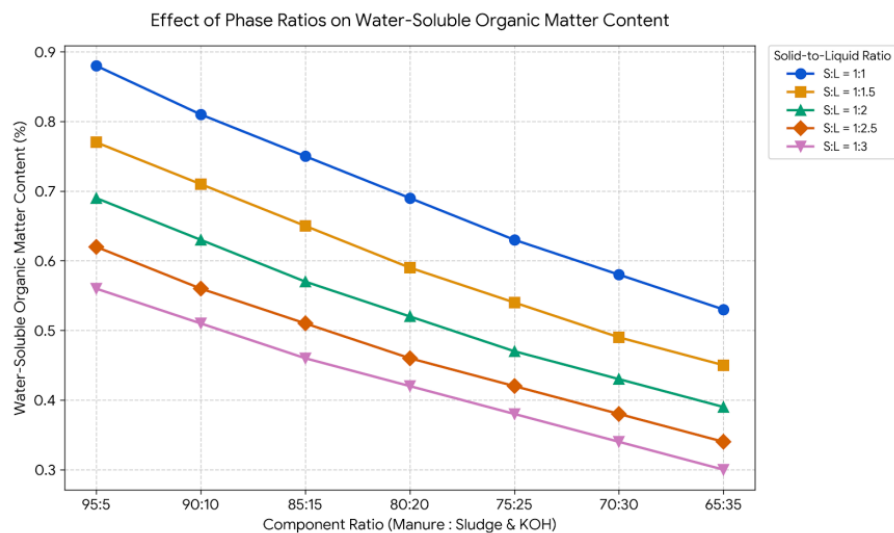


Figure 5 - Content of water-soluble organic matter in a slurry based on poultry manure, phosphorite slime, and potassium alkali (wt. %)

Figure 5 demonstrates that higher dilution (S:L 1:3) leads to lower concentrations. This confirms that a high-density slurry is more nutrient-dense, but may face stability issues during long-term storage.

The industrial viability of organomineral fertilizer production is determined not only by the final concentration of nutrients but also by the extraction efficiency (migration rate) [5].

The extraction efficiency of K_2O demonstrated the highest values among all measured components, ranging from 79.11% to 96.31%. A clear linear correlation was observed between the S:L ratio and migration rate. As the liquid phase increased from 1:1 to 1:3, the potassium recovery improved significantly. This is attributed to the fact that K_2O is introduced primarily via the KOH extractant and the highly soluble inorganic salts present in poultry manure [6]. The increased volume of the solvent (water) reduces the viscosity of the slurry, thereby enhancing ionic diffusion and ensuring nearly complete recovery of potassium at higher S:L ratios.

The migration of phosphorus (P_2O_5) showed a complex dependency on the component ratio. At a constant S:L ratio of 1:1, the extraction efficiency of P_2O_5 decreased from 59.66% to 45.89% as the proportion of phosphorite sludge increased from 5% to 35%.

This "efficiency drop" suggests a solubility threshold in the alkaline medium. While the absolute concentration of phosphorus in the slurry increases (as seen in Table 1), the percentage of the total phosphorus that becomes mobile decreases [7]. This indicates that the organic acids and KOH reach a saturation point where they can no longer effectively break down the stable apatite structure of the sludge. However, increasing the S:L ratio to 1:3 partially mitigates this effect, raising P_2O_5 recovery back to 67.19%, confirming that solvent volume is a limiting factor in mineral solubilization [8], [9], [10].

The migration rate of organic matter, particularly humic and fulvic acids, is a key indicator of the fertilizer's bio-stimulant potential [11], [12].

Humic Acids (HA): Efficiency increased from 57.68% (S:L 1:1) to 82.72% (S:L 1:3). The high recovery at 1:3 is due to the alkaline deprotonation of humic molecules, which increases their

hydrophilicity and allows them to move more freely into the aqueous phase.

Fulvic Acids (FA): Showed slightly lower migration rates compared to HA (max 70.52%), likely due to their inherent association with mineral complexes in the manure which may require more intensive chemical cleavage [13], [14], [15].

Water-Soluble Organic Matter (WSOM): Demonstrated high mobility, exceeding 80% recovery at maximum dilution.

The alkaline environment triggers the deprotonation of phenolic and carboxylic groups in humic substances. This process not only dissolves organic matter but also creates organic ligands that chelate calcium ions from the phosphorite sludge, potentially preventing phosphorus retrogradation.

4. Conclusion

This study substantiates, from both scientific and practical perspectives, the feasibility of producing high-value liquid fertilizers based on local waste resources (PM and PS). The results indicate that the optimal formulation corresponds to a PM:PS ratio of 75:25 and a solid-to-liquid (S:L) ratio of 1:1.5, which were identified as the most effective technological parameters. Under these conditions, the obtained product contains 2.13% P₂O₅ and 0.47% humic substances, confirming its favorable agrochemical properties. Based on the findings, it is demonstrated that the proposed technology is suitable for pilot-scale implementation and has strong potential for practical application, enabling a significant reduction in fertilization costs for local farmers while simultaneously contributing to the efficient utilization of environmentally problematic waste materials.

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