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Influence of Raw Material Ratios and S:L Parameters on Nutrient Migration in Liquid Organo-Mineral Fertilizer Production

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ABSTRACT: This study presents a comparative chemical analysis of the primary product (slurry) obtained by treating a mixture of chicken manure and phosphorite sludge with potassium hydroxide (KOH), and the resulting liquid fertilizer separated via centrifugation. The investigation focused on the influence of raw material ratios (ranging from 95:5 to 65:35) and dilution levels (solid-to-liquid ratios from 1:1 to 1:3) on the migration of nutrients (P_2O_5, K_2O, CaO) and organic matter from the insoluble solid phase to the soluble liquid phase. The results indicate that while increasing the dilution level reduces the concentration of substances in the liquid fertilizer, it significantly enhances their extraction coefficient (recovery rate) from the raw materials.

KEYWORDS: chicken manure; phosphorite sludge; alkaline extraction; potassium hydroxide (KOH); liquid mineral–organic fertilizer; nutrient recovery; phosphorus solubilization; humic acids; solid-to-liquid ratio; circular agriculture

I. INTRODUCTION.

Ensuring long-term soil fertility while cutting dependence on synthetic fertilizers motivates the move toward integrated organo-mineral systems that recycle wastes into high-efficiency fertilizers. Chicken manure is nutrient-rich (N, P, K, Ca, Mg) and improves soil physical and biological properties, but direct land application can cause nutrient losses, emissions, and pollution if unmanaged. Phosphatic by-products such as poultry-litter ash or phosphorite ore are concentrated in P and Ca but often poorly plant-available, requiring chemical conditioning for effective use.

Combining organic residues with mineral P sources to produce organo-mineral fertilizers (OMFs) has been shown to:

supply >20–30% NPK with added secondary nutrients and micronutrients,
improve soil organic matter, structure, and water retention,
match or surpass yields from conventional mineral fertilizers in maize, wheat, oat, and rapeseed,
reduce nitrate leaching and greenhouse-gas emissions when well formulated.

Existing poultry-manure valorization focuses on compost, biochar, ash, or struvite crystals, mostly yielding solid fertilizers with slow or constrained nutrient release and limited humic mobility. Less attention has been paid to direct production of homogeneous suspensions or liquid fertilizers that co-deliver soluble NPK and humic substances from chicken manure together with solubilized P and Ca from low-grade mineral sources. Optimization of extraction conditions (pH, S:L ratio, reactant proportions) is critical to maximize P recovery efficiencies that can reach ~75–95% under well-designed processes.

This study targets the creation of homogeneous suspensions and liquid fertilizers from chicken manure (CHM), phosphorite sludge (PS), and KOH. By varying CHM:PS mass ratios and solid-to-liquid (S:L) ratios, the work quantifies changes in nutrient concentrations and evaluates the migration (extraction) rates of macronutrients (N, P, K, Ca, Mg) and humic substances into the liquid phase, aiming to identify optimal process parameters for maximum nutrient solubility and recovery suitable for sustainable agricultural application.

II. MATERIALS AND METHODS

The primary raw materials utilized in this study were phosphorite sludge (PS), an industrial byproduct of the enrichment process of phosphorites from the Central Kyzylkum deposits (Navoiy region), and chicken manure (CHM)

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obtained from a local poultry farm. The chemical composition of the phosphorite sludge and chicken manure was determined using standard analytical methods and is presented as follows: Phosphorite Sludge (wt.%): P_2O_5 – 11.21; CaO – 42.28; CO_2 – 20.91; SiO_2 – 12.54; Al_2O_3 – 2.79; SO_3 – 1.46; Fe_2O_3 – 1.42; MgO – 0.61. Chicken manure (wt.%): Moisture – 64.82; organic matter – 23.29; ash – 11.89; CaO – 1.61; P_2O_5 – 1.29; N – 1.21; K_2O – 0.95. Fulvic acids – 7.41; humic acids – 1.12; water-soluble organic substances – 1.28. A 2% aqueous solution of potassium hydroxide (KOH) was employed as the extracting agent and activating reagent.

The experimental process was conducted under laboratory conditions in the following sequence: Chicken manure and phosphorite sludge were initially weighed at various mass ratios: 95:5, 90:10, 85:15, 80:20, 75:25, 70:30, and 65:35. The mixtures were ground and blended in a laboratory ball mill for 15 minutes until a homogeneous mass was achieved. A 2% KOH solution was added to the prepared dry mixture. The solid-to-liquid (S:L) ratios were studied at variants of 1:1, 1:1.5, 1:2, 1:2.5, and 1:3. The process was carried out in a water bath at a temperature of 50–60°C with mechanical stirring (stirring speed of 400 rpm) for 90 minutes. This resulted in a dark brown, thick suspension (slurry). The resulting suspension was allowed to settle and subsequently centrifuged at 3000 rpm to separate the solid and liquid phases. The isolated liquid phase (the final liquid fertilizer) was collected for chemical analysis.

The content of primary nutrients and organic substances in the obtained samples (slurry and liquid fertilizer) was determined using standard chemical analysis methods: Total Nitrogen determined via the Kjeldahl method. Phosphorus (P_2O_5) a nalyzed using the photoelectrocolorimetric method with a KFK-3 photometer. Potassium (K_2O) determined by flame photometry. Organic Matter (Humic and Fulvic Acids) assessed based on standard chemical analysis techniques (modified Tyurin method). Additionally, the degree of migration of beneficial components from the raw materials into the liquid phase (extraction coefficient) was calculated and subjected to statistical analysis.

III. RESULTS AND DISCUSSION

At the initial stage of the study, the chemical composition of the primary product—a homogeneous suspension (slurry) formed by the interaction of chicken manure (CHM), phosphorite sludge (PS), and potassium hydroxide (KOH) solution—was investigated. The results showed that the nutrient concentration in the slurry varied systematically with both the mass ratio of the raw materials and the solid-to-liquid (S:L) ratio.

Increasing the share of the mineral component (phosphorite sludge) in the mixture led to a marked increase in phosphorus (P_2O_5) and calcium (CaO) content. At an S:L ratio of 1:1, changing the CHM:PS ratio from 95:5 to 65:35 raised the total phosphorus content in the slurry from 1.29% to 3.02%, while calcium increased from 2.63% to 10.03%. This trend is consistent with the high intrinsic contents of P_2O_5 (11.21%) and CaO (42.28%) in the phosphorite sludge.

The potassium (K_2O) content in the slurry remained relatively high across all studied compositions, ranging from 1.129% to 1.498%. Although a slight decrease in the relative share of potassium was observed with increasing PS content—due to the reduction in organic mass—the use of KOH as an extracting and activating agent ensured sufficient potassium enrichment of the product.

Pronounced effects were also observed when varying the S:L ratio, a key technological parameter. Increasing the liquid phase from 1:1 to 1:3 caused a dilution effect and consequently reduced the concentration of all nutrients. For example, at a CHM:PS ratio of 65:35, increasing the S:L ratio from 1:1 to 1:3 decreased phosphorus from 3.02% to 1.74% and calcium from 10.03% to 5.79%.

Overall, the process conducted at 50–60 °C in an alkaline medium produced a stable suspension enriched with essential macronutrients, including nitrogen, phosphorus, potassium, and calcium. This primary slurry can thus be considered a concentrated raw material for the subsequent extraction of liquid fertilizers.

The composition of the liquid fertilizer obtained after separation of the solid phase was then evaluated. At an S:L ratio of 1:1, increasing the phosphorite sludge content in the initial slurry up to 35% raised total phosphorus in the slurry to 3.02% and calcium to 10.03%. These elevated values are linked to the presence of undissolved phosphorite particles and residual manure solids remaining in the suspension at this stage.

The liquid fertilizer produced by centrifuging the slurry represents the fraction of nutrients in soluble form, directly available for plant uptake. The extent to which nutrients are transferred from the complex organic–mineral matrix into this liquid phase is therefore a key indicator of extraction efficiency.

Analysis of the liquid phase (Pic 1) revealed a characteristic chemical pattern: at a CHM:PS ratio of 65:35 and S:L = 1:1, increasing the proportion of phosphorite sludge raised the concentration of soluble phosphorus in the liquid phase to 5.02%. This provides clear experimental evidence for the activation of initially poorly soluble phosphorites under alkaline conditions created by KOH.

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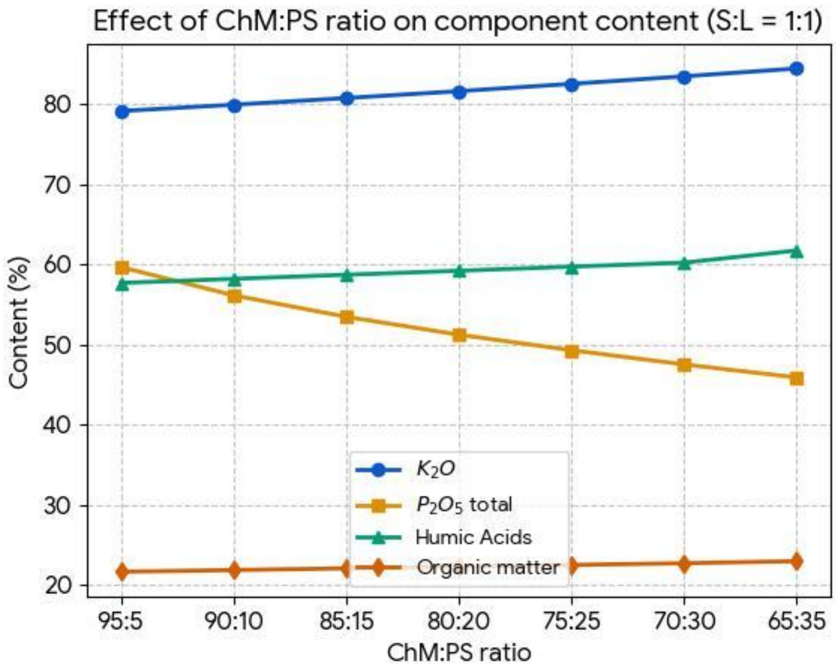
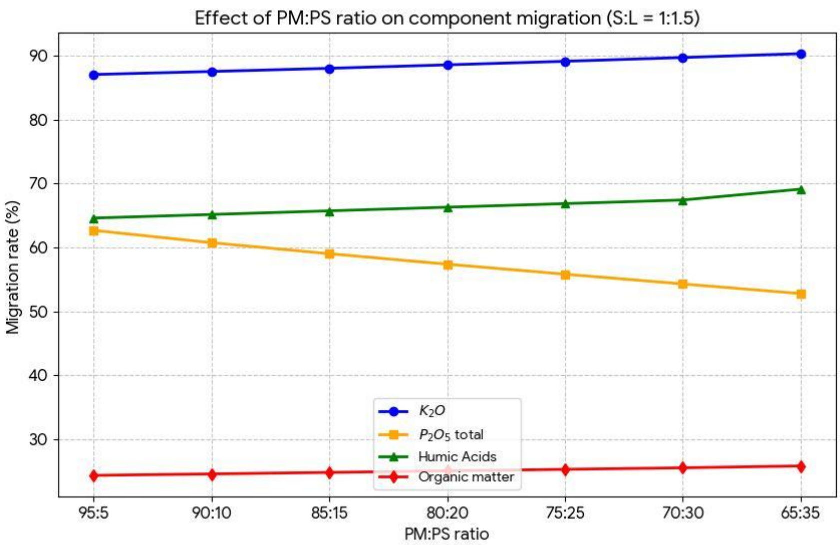


Pic 1. Effect of ChM:PS ratio on component (S:L=1:1)

However, increasing the liquid volume (S:L = 1:3) led to a pronounced dilution of all components. For instance, the content of organic matter decreased from 12.78% to 5.10%.

The most informative parameter for evaluating process performance was the migration rate, defined as the percentage of each element transferred from the raw slurry into the liquid fertilizer. The data presented in Pic 2 highlight several important trends:



Pic 2. Effect of ChM:PS ratio on component (S:L=1:1,5)

Although increasing the liquid phase volume (S:L = 1:3) lowered the absolute concentration of nutrients in the liquid fertilizer, it substantially improved the migration rate of beneficial components. At a CHM:PS ratio of 65:35, the migration of humic acids rose from 61.73% at S:L = 1:1 to 82.72% at S:L = 1:3.

Potassium showed an almost complete transition into the liquid phase, reaching up to 96.31% migration efficiency. This is consistent with its introduction in the form of highly soluble KOH.

The recovery of phosphorus also improved with higher water content, attaining a maximum migration rate of 67.19%.

These results indicate that there is a trade-off between nutrient concentration and migration efficiency. While higher dilution (S:L = 1:3) reduces the nutrient content in the liquid fertilizer, it enhances the overall extraction and solubilization of key components, particularly humic substances, potassium, and phosphorus. This balance should be considered when optimizing process parameters for the production of liquid fertilizers from chicken manure and phosphorite sludge.

IV. CONCLUSION

While the primary slurry contains a higher total amount of substances, the liquid fertilizer obtained after centrifugation retains P_2O_5 (up to 5.02%) and humic substances (up to 1.64%) in highly bioavailable forms, which are readily accessible for plant uptake. To obtain a highly concentrated fertilizer, an S:L ratio of 1:1 is recommended. Specifically, a CHM:PS ratio of 65:35 is optimal for mineral-rich products, while 95:5 is best for organic-focused fertilizers.

To achieve maximum nutrient recovery from waste materials and minimize loss, an S:L ratio of 1:3 is more efficient, as it allows over 82% of humic acids to transition into the liquid phase.

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