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# Production of Calcium-Ammonium-Phosphate (CAP) Multinutrient Fertilizer from Acetylene Gas Industry Waste and Phosphoric Acid

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**ABSTRACT**

The increasing global demand for food has raised the need for effective fertilizers, while the depletion of conventional raw materials and industrial waste accumulation have become pressing issues. Acetylene gas industries generate large amounts of semi-solid lime waste containing calcium hydroxide, which is often disposed of without treatment, causing environmental problems. This study aims to utilize acetylene waste as a raw material for producing Calcium-Ammonium-Phosphate (CAP) multinutrient fertilizer through a precipitation method using phosphoric acid ($H_3PO_4$) and ammonium hydroxide ($NH_4OH$). The variables investigated include pH values (6,7,8,9,10) and waste mass (30,35,40,45,50 g). The resulting products were analyzed using Scanning Electron Microscopy–Energy Dispersive X-ray (SEM-EDX). The results indicate that the optimum pH to obtain the highest nutrient content of calcium (Ca), phosphorus (P), and nitrogen (N) is pH 10. In addition, variations in the mass of acetylene industry solid waste were found the optimum condition was achieved at 30 g of waste, which provided the highest concentrations of calcium, phosphorus, and nitrogen. This research demonstrates the potential of acetylene industry waste as an alternative raw material for sustainable fertilizer production.

## INTRODUCTION

The global challenge of food security remains critical, as the agricultural sector continues to face problems such as climate change, soil degradation, and pest attacks that reduce productivity (Salasa, 2021). Fertilizers play a central role in sustaining soil fertility and supporting crop growth (Fidiansyah et al., 2021). However, fertilizer scarcity has emerged as a serious problem in Indonesia, where production declines have triggered a fertilizer crisis, requiring innovation in alternative raw materials and production technologies (Sarwani, 2023).

Fertilizers are materials applied to soil or plant tissues to provide essential nutrients for plant growth, either in natural or synthetic forms (Lewu, 2020). Fertilizers can generally be classified based on their raw material sources and nutrient content. From the perspective of raw material sources, fertilizers are divided into inorganic and organic types. Inorganic fertilizers are produced through chemical, physical, or biological processes and are generally manufactured by the fertilizer industry. Organic fertilizers, on the other hand, are composed predominantly or entirely of organic matter derived from plant or animal residues, which are processed into solid or liquid forms. These fertilizers function to improve the physical, chemical, and biological properties of soil by supplying nutrients.

In terms of nutrient content, fertilizers can be classified as single or compound fertilizers. Single fertilizers contain only one primary nutrient, such as nitrogen (N), phosphorus (P), or potassium (K). The degree of solubility is defined as the maximum amount of solute that can dissolve until a saturated state is reached (Apsari, 2020). Compound fertilizers, in contrast, contain more than one plant nutrient, such as combinations of N-P, P-K, N-K, or the complete N-P-K formulation (Purba, 2021).

Healthy plant growth depends on an adequate balance of macro- and micronutrients. Macronutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S) are needed in large quantities for structural formation and metabolism. Nitrogen enhances leaf and protein formation, phosphorus aids root and energy processes, while potassium regulates water and enzymes. Calcium strengthens cell walls, magnesium forms chlorophyll, and sulfur builds amino acids. Micronutrients like Fe, Zn, Mn, Cu, B, Mo, and Cl, though required in trace amounts, are crucial for enzyme activity and reproduction (Sufardi, 2020). Deficiency lowers yield. Thus, multi-nutrient fertilizers like Calcium-Ammonium-Phosphate (CAP) support sustainable farming.

The acetylene industry generates large amounts of solid waste from the reaction between calcium carbide ($CaC_2$) and water, producing acetylene gas and lime sludge containing high calcium hydroxide ($Ca(OH)_2$). Improper disposal of this waste causes soil alkalinity and water pollution. In East Java, over 1,500 tons are produced annually. Its high calcium content offers potential for conversion into value-added fertilizers, reducing environmental impact and supporting sustainable fertilizer production (Sani, 2021).

Utilization of acetylene industry waste as fertilizer raw material is a promising approach. With its abundant $Ca(OH)_2$ content, the waste can be processed into Calcium-Ammonium-Phosphate (CAP) fertilizer. CAP is produced through a precipitation process involving $Ca^{2+}$, $NH_4^+$, and $PO_4^{3-}$ ions (Rosikah, 2024). This makes CAP not only an effective fertilizer but also a sustainable innovation by converting industrial by-products into valuable agricultural inputs.

Several factors influence the synthesis of CAP fertilizer. The raw material weight strongly affects the product yield, as excessive mass can lead to supersaturation during dissolution with phosphoric acid (Rosikah, 2024). The concentration of phosphoric acid also plays a vital role, where 30% $H_3PO_4$ is commonly used. Too low a concentration results in incomplete precipitation, while too high leads to excessive acidity that reduces product quality (Haekal, 2008). Particle size determines surface area, with smaller particles providing larger reactive surfaces and enhancing precipitation efficiency (Auliah, 2019). pH conditions during precipitation are equally important, as product purity and recovery are highly dependent on maintaining optimal pH values (Haruda, 2016). Furthermore, the concentration of ammonium hydroxide solution is crucial to achieve targeted pH levels without forming unwanted by-products; typically, 1 N $NH_4OH$ is selected for stability and control (Rosikah, 2024). Aging time after precipitation also affects crystallization, with an optimal period of 10 minutes allowing stable CAP crystal formation, while shorter times yield amorphous products and longer times cause crystal fragility (Li, 2012). Finally, stirring time influences reaction completion, where 40 minutes has been reported sufficient to ensure thorough mixing without disrupting crystal growth (Rosikah, 2024).

Several previous studies have highlighted the potential of alternative resources for phosphate-based fertilizer synthesis. Sumada (2011) reported that geothermal wastewater can serve as a source of valuable nutrients for multinutrient fertilizer production. Asri et al. (2022) investigated brine from salt industries and demonstrated its feasibility as a raw material for CAP synthesis. Rosikah (2024) examined the use of marine shell waste and found that its high calcium content was well suited for phosphate precipitation. Other research has also explored the influence of operating conditions, such as pH, concentration, and mixing ratio, on product yield and nutrient availability (Alhaq, 2024). Collectively, these studies emphasize that precipitation-based processes can be tailored to maximize nutrient recovery and enhance fertilizer efficiency.

In this study, Scanning Electron Microscopy–Energy Dispersive X-ray (SEM-EDX) was used to analyze the products. This technique provides information regarding surface topography and atomic concentration of materials and is widely applied in material characterization (Setyaningsih & Septiano, 2019). SEM-EDX serves as an instrument for both qualitative and quantitative elemental analysis, generating input from electron signals produced by the interaction of the electron beam with atoms in the sample, which are subsequently detected and processed by the SEM system (Julinawati, 2015). The characterization results reveal the elements present in the sample along with their chemical composition (Hamriani, 2016).

However, most previous studies have not specifically examined acetylene industry waste as a raw material for CAP fertilizer production. While other calcium sources have been extensively investigated, acetylene waste which contains a high concentration of $Ca(OH)_2$ remains underutilized. Furthermore, prior research primarily focused on reaction yield and solubility, without thoroughly studying the influence of pH and waste mass variation on the quality and nutrient composition of CAP fertilizer. This research addresses that gap by analyzing the effect of pH and acetylene waste mass on the quality of CAP fertilizer produced through precipitation using phosphoric acid and ammonium hydroxide.

Based on these considerations, this study focuses on synthesizing multinutrient CAP fertilizer from acetylene industry solid waste through precipitation using phosphoric acid ($H_3PO_4$) and ammonium hydroxide ($NH_4OH$). The objectives of this research are to analyze the effect of pH on the precipitation process and quality of CAP fertilizer and to analyze the effect of acetylene industry waste mass on the quality of CAP fertilizer.

## RESEARCH METHODS

### Materials and Equipment

The raw material used in this study was solid waste from the acetylene gas industry, which mainly contained calcium hydroxide ($Ca(OH)_2$). Additional chemicals included phosphoric acid ($H_3PO_4$) with a concentration of 30%, ammonium hydroxide ($NH_4OH$) with a concentration of 1 N, and distilled water. The main equipment employed consisted of a beaker glass, magnetic stirrer, analytical balance, oven, 100-mesh sieve, burette, pH meter, and a Scanning Electron Microscopy–Energy Dispersive X-ray (SEM-EDX) instrument for product characterization.

### Procedure Experimental

The waste was first prepared by crushing and sieving it to a particle size of 100 mesh. Different weights of the sieved waste (30, 35, 40, 45, and 50 g) were measured and then dissolved in 200 mL of 30% phosphoric acid. The dissolution process was conducted using a magnetic stirrer at 300 rpm for 40 minutes. The resulting mixture was filtered, and the filtrate obtained was titrated dropwise with 1 N ammonium hydroxide until the pH reached predetermined values of 6, 7, 8, 9, or 10. After the desired pH was reached, the solution was allowed to stand for 10 minutes to complete precipitation. The precipitate was then separated by filtration, oven-dried at 120°C for four hours, and sieved through a 100-mesh sieve to obtain a uniform product.

This study applied a 5×5 factorial experimental design, involving two independent variables: waste mass (30, 35, 40, 45, and 50 g) and pH of precipitation (6, 7, 8, 9, and 10). Each experimental combination was conducted to determine its effect on the amount and quality of the resulting product.

The solubility of the synthesized CAP fertilizer was evaluated by dissolving 5 g of the product in 100 mL of water and stirring it for 30 minutes. The suspension was filtered, and the remaining solid was dried at 100°C for one hour, weighed, and then redissolved in another 100 mL of water. This cycle was repeated three times to assess cumulative solubility.

## Data Analysis

Statistical data analysis in this study was performed by calculating the percentage yield (%), defined as the ratio between the final mass of the dried product and the initial mass of the raw material, multiplied by 100. The calculation formula is as follows:

$$Yield(\%) = \frac{m_{final}}{m_{initial}} \times 100\% \quad (1)$$

The yield values obtained from each experimental condition were compared to identify the optimal synthesis parameters. Finally, the chemical composition and morphology of both the raw waste and the CAP product were analyzed using SEM-EDX to determine the content of calcium, nitrogen, and phosphorus, as well as to observe the crystal structure of the fertilizer.

# RESULTS AND DISCUSSION

## Analysis of SEM-EDX of Acetylene Industry Waste

The raw material used in this research was solid waste from the acetylene industry. Table 1 shows the SEM-EDX analysis, which indicates that calcium (Ca) was the dominant element with a concentration of 40.44%. This high calcium content confirms the potential of acetylene waste as a precursor for the synthesis of Calcium-Ammonium-Phosphate (CAP) fertilizer. The presence of oxygen (O) and carbon (C) also suggests carbonate and hydroxide species in the waste matrix, which are typical by-products of acetylene production.

**Tabel 1.** SEM-EDX Analysis of Acetylene Industry Solid Waste

| Element | Weight(%) |
|---|---|
| Ca K | 40.44 |
| C K | 8.60 |
| O K | 45.80 |
| Fe K | 0.66 |
| Al K | 0.55 |
| Si K | 0.59 |
| P K | 0.23 |
| N K | 3.12 |

(Laboratorium Mechanical Engineering, ITS 2025)

The dominance of calcium and oxygen indicates that the waste is mainly composed of $Ca(OH)_2$ and carbonate species. Similar compositions have been reported in studies of acetylene industry by-products (Sani, 2021).

## Yield of Calcium-Ammonium-Phosphate (CAP) Fertilizer

The effect of pH and waste mass variation on the yield of CAP fertilizer after drying, as shown in Table 2 :

**Tabel 2.** Yield of CAP Fertilizer under Different Conditions

| Waste Mass (g) | pH | | | | |
|---|---|---|---|---|---|
| | 6 | 7 | 8 | 9 | 10 |
| 30 | 23.6003% | 91.6423% | 88.5877% | 64.2377% | 55.1518% |
| 35 | 63.2461% | 75.2194% | 52.2616% | 54.4844% | 46.3543% |
| 40 | 71.5415% | 78.5605% | 41.3110% | 39.6095% | 45.8643% |
| 45 | 45.0643% | 26.8339% | 29.6597% | 26.6762% | 25.4738% |
| 50 | 36.9750% | 21.2175% | 13.2817% | 18,5497% | 27.1583% |

The yield of the synthesized CAP fertilizer under different pH conditions and waste masses is presented with the trend shown in Figure 1.

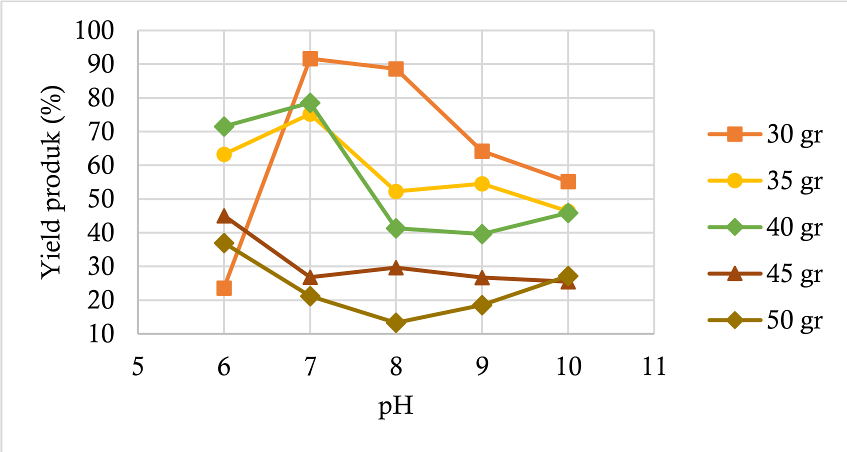
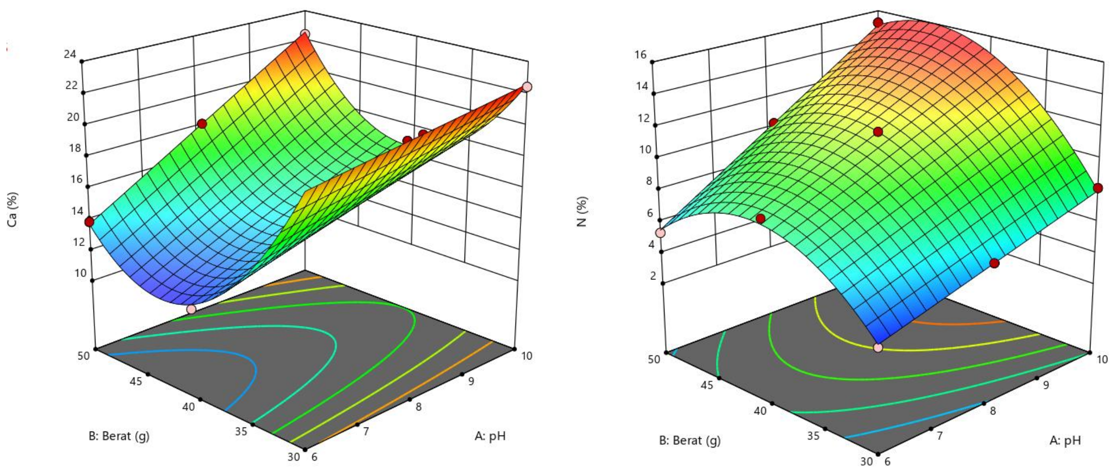



**Figure 1.** Effect of pH on Yield of CAP Fertilizer

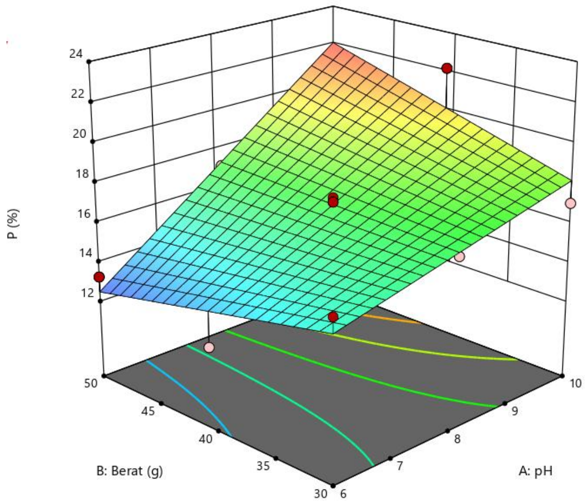
The results revealed that the yield was strongly influenced by both variables. The highest yield, 91.64%, was achieved when 30 g of waste was reacted at pH 7. At this condition, the neutral pH facilitated effective precipitation of CAP without excessive formation of secondary products. In contrast, increasing the waste mass to 45 g or 50 g reduced the yield significantly, particularly at alkaline pH values. This reduction is likely due to the formation of tricalcium phosphate ($Ca_3(PO_4)_2$), an insoluble compound that limited the availability of phosphorus for CAP formation (Van Der Houwen, 2001). The overall trend demonstrated that the optimum yield is obtained at lower waste mass and near-neutral pH.

## SEM-EDX Analysis Results of CAP Fertilizer

To further understand the effect of pH and waste mass on the nutrient composition of the CAP fertilizer, three-dimensional surface plots were generated to illustrate the variation of calcium, nitrogen, and phosphorus contents under different experimental conditions. The surface plots were created using Design Expert software with the aim of visualizing, in three dimensions, the magnitude of the response for each different treatment condition. These plots provide a clearer visualization of how both parameters simultaneously influence the incorporation of nutrients into the CAP structure.




(a) (b)




(c)

**Figure 2.** (a) Effect of pH and waste mass (gram) on calcium content (%), (b) Effect of pH and waste mass (gram) on nitrogen content (%), (c) Effect of pH and waste mass (gram) on phosphorus content (%)

The nutrient composition of the CAP products, namely calcium, nitrogen, and phosphorus is illustrated by the three-dimensional surface plots in Figures 2. The data showed that calcium content consistently increased with higher pH, reaching up to 22.45% at pH 10 with 30 g of waste. Similarly, nitrogen content rose with both pH and waste mass, from 3.75% at pH 6 to as high as 15.20% at pH 10 with 50 g of waste. At acidic conditions (pH 6–7), the nitrogen content in the product remained low because ammonium ions ($NH_4^+$) were more prone to volatilization as $NH_3$ gas, thereby reducing their incorporation into the precipitate. As the pH increased toward alkaline conditions (pH 8–10), the volatilization effect decreased and more ammonium ions were retained in the solid phase, resulting in higher nitrogen content in the CAP product (Nurjanah, 2025). Phosphorus content also followed a positive trend, with the highest value of 22.17% at 40 g of waste and pH 10.

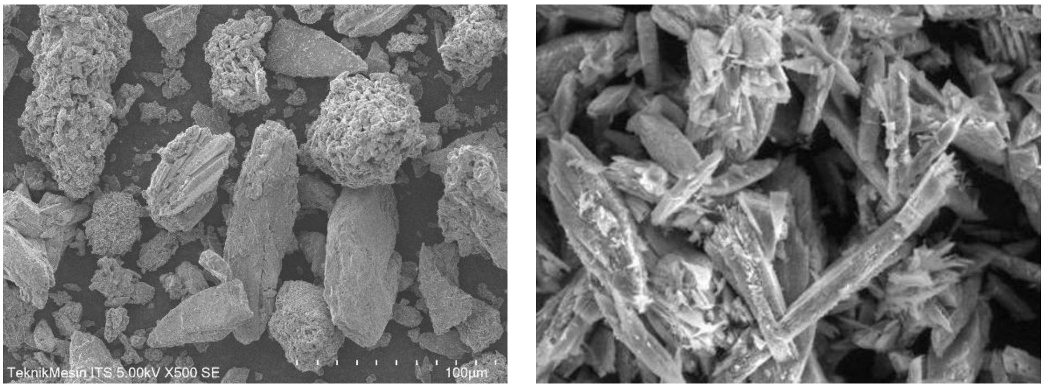
When compared with the study conducted by Rosikah et al. (2024), who synthesized CAP from marine shell waste, the obtained Ca and P contents were significantly higher, with Ca reaching 76.63% and P 22.2% at pH 3 and 20 g of raw material. The present study, using acetylene industry waste as the calcium source, yielded comparatively lower calcium and phosphorus percentages (22.45% Ca and 22.17% P at optimal conditions). This discrepancy can be attributed to differences in the raw material composition marine shell waste primarily contain $CaCO_3$ (>97%), whereas acetylene waste mainly contains $Ca(OH)_2$ with possible impurities that reduce the calcium availability for precipitation.

In both studies, pH played a crucial role in determining product quality and composition. Rosikah et al. reported that $CaHPO_4$ solubility decreased with increasing pH, resulting in higher product yield at neutral conditions (pH 7), consistent with the principles of precipitation reactions in phosphate systems. In the current research, a similar pattern was observed, where higher pH favored solid phase formation and nutrient incorporation. This behavior aligns with the equilibrium of the precipitation reaction:

$$CaHPO_{4(l)} + NH_4OH_{(l)} \rightarrow CaNH_4PO_{4(s)} + H_2O_{(l)}$$

At higher pH, ion concentration rises, driving equilibrium toward solid CAP formation. In acidic conditions, greater $CaHPO_4$ solubility and $NH_3$ release inhibit precipitation, resulting in reduced yield and nutrient content.

Overall, the comparison indicates that although different calcium sources lead to variations in product composition, the general precipitation mechanism and pH dependency remain consistent. The results reinforce that alkaline environments enhance CAP formation efficiency, while excess reactant mass can disturb stoichiometric ratios and cause impurity co-precipitation (Le Corre, 2009).




(a) (b)

**Figure 3.** (a) SEM morphology of CAP fertilizer synthesized from acetylene waste, (b) SEM morphology of CAP fertilizer synthesized from marine shell waste (Source : Rosikah, 2024)

Morphological analysis using SEM, shown in Figure 3, revealed that the CAP crystals formed from acetylene waste exhibited hexagonal structures with relatively well-defined edges. This morphology was comparable to CAP synthesized from other calcium-rich waste materials such as marine shell waste (Rosikah, 2024). In addition to regular crystals, some irregular morphologies were observed, suggesting the presence of impurities or incomplete incorporation of ions during crystallization. The crystal structure is critical because it influences both nutrient release behavior and solubility (Mu, 2019).

## Solubility Test of CAP Fertilizer

The solubility of CAP fertilizer was evaluated through three successive dissolution steps in 100 mL of water (Table 3). The average solubility was 0.3364 g/100 mL, indicating that CAP is a slow-release fertilizer. This property is desirable in agriculture, as nutrients such as phosphorus and nitrogen are released gradually, improving fertilizer efficiency and reducing leaching losses.

**Tabel 3.** Solubility of CAP Fertilizer in Water

| Trial | Initial Weight (g) | Dissolved (g) | Solubility (g/100ml) |
|---|---|---|---|
| 1 | 5.00 | 0.4525 | 0.4525 |
| 2 | 4.55 | 0.2710 | 0.2710 |
| 3 | 4.28 | 0.2857 | 0.2857 |
| | **Average** | | 0.3364 |

The SEM-EDX analysis of the remaining solids after the dissolution process showed that nitrogen and phosphorus contents decreased, while calcium content increased. This indicates that nitrogen and phosphorus were more readily dissolved compared to calcium. Ammonium and phosphate compounds, such as DAP or MAP, are highly soluble in water (Margenot, 2023). In contrast, crystalline calcium phosphate exhibits very low solubility, particularly when its crystal structure is well-ordered, making it difficult to dissolve. Crystal form also plays a significant role in solubility: dense crystalline structures are less soluble, whereas irregular structures dissolve more easily (Sakhno, 2025). The CAP fertilizer tested in this study is categorized as a slow-release fertilizer, in which the dissolution occurs gradually, as most of the calcium remains in the solid residue and does not dissolve immediately.

# CONCLUSION

Based on the research entitled "*Production of Calcium-Ammonium-Phosphate (CAP) Multinutrient Fertilizer from Acetylene Gas Industry Waste and Phosphoric Acid*", it can be concluded that pH plays a crucial role in determining the quality of the fertilizer produced. The results revealed that the optimal pH for achieving the highest nutrient concentrations of calcium (Ca), phosphorus (P), and nitrogen (N) was pH 10. Moreover, variation in the mass of acetylene industry solid waste significantly affected the final nutrient content, with the best result obtained using 30 grams of waste. This indicates that appropriate pH adjustment combined with the right amount of raw material is essential for producing high-quality CAP fertilizer.

Practically, this research demonstrates that acetylene industry waste containing abundant $Ca(OH)_2$ can be effectively converted into value-added CAP fertilizer. Such utilization enhances resource efficiency, minimizes waste disposal issues, and supports environmental sustainability. Large-scale application of this process could decrease dependence on non-renewable phosphate rock and reduce fertilizer production costs. Additionally, CAP's characteristic as a slow-release fertilizer helps maintain soil nutrient availability, reduces leaching losses, and promotes long-term soil fertility, particularly in tropical regions.

Future research is recommended to investigate the effect of temperature during the dissolution of waste with $H_3PO_4$ to optimize reaction kinetics and yield, as well as to test CAP's performance on crop growth under real agricultural conditions.

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