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Study of Anaerobic and Aerobic Fertilizers of Organic Waste Treatment

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Abstract—Phosphorus is a critical nutrient for plant growth, significantly enhancing agricultural productivity and ecosystem sustainability. Organic waste-based fertilizers offer a sustainable solution to boost soil phosphorus levels while addressing waste management challenges. This study evaluated the phosphorus content of anaerobic and aerobic fertilizers derived from organic waste, focusing on factors that influence phosphorus dynamics during composting. Composting methods and feedstock composition affected phosphorus transformation and availability, with temperature, moisture, aeration, and microbial activity playing pivotal roles in mineralization, immobilization, and solubilization. The experiment used market waste, pineapple peel, dry leaves, sawdust, water, sugar, manure, and EM4. The composting process involved weekly monitoring of pH, temperature, and compost height. The results showed that the pH of the anaerobic compost ranged from 7.2 to 7.4, meeting the SNI 19-7030-2004 standard. The mature compost color was brownish-black, which also complied with the standard. Phosphorus contents as P_2O_5 were 1712 mg/kg in aerobic fertilizer and 2653 mg/kg in anaerobic fertilizer. Phosphorus is crucial for root development, water, and nutrient absorption, and enhances plant tolerance to drought. It also affects flower and fruit formation, affecting crop yield quality and quantity. This study highlighted the importance of understanding phosphorus dynamics to optimize nutrient management and improve organic waste utilization in agriculture. Future research should explore the phosphorus transformation mechanisms and innovative composting techniques to enhance phosphorus availability for plant uptake.

Keywords—*Aerobic; Anaerobic; Compost; Organic waste fertilizers; Phosporus*

1. INTRODUCTION

In the modern world, food waste is an inevitable result. The report's findings indicate that roughly one-third of food meant for human consumption is lost or wasted in the food supply chain; this has a production value of $750 billion and accounts for 6.8% of annual greenhouse gas emissions worldwide, even though the precise amount of food waste worldwide is unknown. This waste includes fertilizer, copious amounts of water, and vast areas of land used to cultivate food that will never be eaten in huge numbers. This condition occurs at a time when 821 million people do not have access to enough food, and initiatives are being made to increase food supplies to meet the needs of an expanding population [1].

Food waste occurs at every point in the supply chain, including harvest rejection, losses during production and processing, unsold food at retail stores, and consumer disposal. Poor countries usually suffer huge losses connected to the consuming stage, while developed countries often suffer major post-harvest losses due to inadequate storage and limited access to refrigeration [2].

Most food waste is gathered with other garbage from the city and either burned or dumped in landfills. However, today, more than ever, there could be significant environmental harm from it. Burning garbage releases no methane into the atmosphere and makes it possible to use heat to produce power [3]. However, because home food waste contains much water, many fruits, and vegetables have low or negative calorific value. In addition, food waste contains nutrients that are not recoverable by burning or landfilling; these nutrients can support the development of new plants. As a result, to extract long-term value from food waste streams, other processing techniques must be used instead of incineration and landfilling [4].

The utilization of organic waste or food waste-based fertilizers has gained considerable attention as a

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sustainable approach to replenishing soil phosphorus levels while addressing waste management challenges. Anaerobic and aerobic composting processes are commonly employed to convert organic waste into nutrient-rich fertilizers. Phosphorus, an essential nutrient for plant growth, plays a pivotal role in agricultural productivity and ecosystem sustainability [5,6,7]. However, the phosphorus content in these fertilizers may vary depending on the composting method used [8,9].

Despite the increasing interest in organic waste-based fertilizers, there is a lack of comprehensive comparative studies examining the phosphorus dynamics in anaerobic versus aerobic composting processes under similar conditions. Previous studies have mainly focused on either one or the other method, without directly comparing the two. This study aims to fill this gap by systematically comparing the phosphorus content and dynamics in fertilizers produced through anaerobic and aerobic composting methods utilizing the same types of organic waste [10,11].

One of the key factors affecting phosphorus dynamics during composting is the feedstock composition [10]. Different organic materials have varying phosphorus contents and compositions, which can affect the transformation and availability of phosphorus during the composting process. Additionally, process conditions, such as temperature, moisture, and aeration play critical roles in phosphorus transformation and bioavailability in composted materials [12,13,14].

Microbial activities also significantly impact phosphorus dynamics during composting [15]. Microorganisms involved in decomposition and nutrient cycling processes can affect phosphorus mineralization, immobilization, and solubilization, ultimately affecting the availability of phosphorus to plants [16]. Furthermore, the interaction between phosphorus and other nutrients in the composted materials may further complicate phosphorus dynamics and availability [17].

This study provides a detailed comparative analysis of phosphorus levels in anaerobic and aerobic fertilizers derived from organic waste. By addressing the existing gap in the literature, this study offers novel insights into the factors affecting phosphorus availability in different composting conditions. The findings are expected to contribute to more effective nutrient management strategies and enhance the application of organic waste in sustainable agriculture.

2. EXPERIMENTAL SECTION

2.1. Materials

The materials used in this experiment were market waste, pineapple peel waste, dry leaves, sawdust, water, sugar, manure, EM4, phosphate standar solution 1000 mL, HNO_3, and ammonium molybdovanadate from Merck®.

2.2. Instrumentation

The pH of anaerobic and aerobic pH were measured using a pH meter (Trans Instrumen BP3001).

2.3. Preparation of Anaerobic Fertilization

To begin the test, 5 kg of organic waste was prepared, such as leaf debris, and slice it finely into 1-2 cm pieces. Subsequently, a starting solution that had been diluted five to ten times was added using a 1% sugar solution into the garbage. The starter and organic waste were then added to the composter, and the compost's initial temperature and height were noted. After that, the composter was covered and placed in a location protected from sunlight and rain. The project used six composters in total.

2.4. Preparation of Aerobic Fertilization

The fruit peel waste was cut into small pieces, approximately 1-2 cm, and then homogenized for a more uniform consistency. Next, the empty weight of the aerobic composter was measured (only the blue-colored drums were used). After that, the small-cut fruit peel waste was added to the aerobic composter until it reached nearly full capacity. At this stage, the compost height, initial compost temperature, and total composter weight after adding the fruit peel waste were recorded to determine the amount of waste added to the composter. The composter was then covered and placed in an area protected from direct sunlight and rain. Monitoring of temperature, pH, and compost height was conducted every three days to ensure optimal conditions during the composting process.

2.5. pH Monitoring

The fertilizer sample was taken 10 g and then placed into a 250 mL beaker glass. Next, distilled water was added as needed. Then, a pH meter was used to measure and record the obtained pH. This was done periodically three times a day.

2.6. Phosphorus Content Testing

The first step in the phosphorus testing procedure was to transfer 0.0; 1.0; 2.0; 3.0; 4.0; and 5.0 mL of a 100 mg/L phosphate working solution into each 100 mL measuring flask. Next, 5 mL of an ammonium molybdovanadate solution was added to each flask, which was then measured with distilled water and homogenized. Next, a 250 mL beaker was filled with 1 g of the weighed fertilizer sample. Next, 25 mL of 1:3 nitric acid was added. The mixture was then heated, and swirled on a hotplate, stirring until the volume was reduced by half. Finally, 50 mL of distilled water was added to the beaker.

After the date's volume was reduced by half, the sample was quantitatively transferred into a 100 mL volumetric flask, measured with distilled water, and homogenized. It was then cooled to room temperature. After filtering the sample solution, 5 and 25 mL of the filtrate were added to each 100 mL volumetric flask, followed by the addition of 5 mL of ammonium molybdovanadate solution. Finally, the solution's volume was measured and homogenized with distilled water. P levels (mg/Kg) was count by **Eq. (1)** where *Mf* = Multiplying Factor, *V* = Volume of Measuring Flask (L), C = Measurable Concentration (mg/L), and *W* = Weight (gram).

$$P\ Levels\ \left({}^{mg}/_{Kg}\right) = \frac{(C \times Mf \times V)}{(W)} \quad (1)$$

3. RESULT AND DISCUSSION

3.1. Physical Characteristics of Fertilizer

Composting is a process where organic materials undergo biological decomposition by specific microbes, transforming organic waste into compost through biological activity under controlled conditions. During the decomposition process, compost fertilizer changes its physical form (color, odor, and texture). These changes occur due to the addition of materials mixed into the compost and the activity of microorganisms present in the organic materials and the starter used in compost production. Monitoring was conducted four times a month.

Monitoring data of pH on fertilizer sample results can be seen in **Fig. 1**. The pH value indicates the concentration of H^+ ions in a solution, expressed as -log [H^+]. An increase in H^+ concentration raises the solution's potential, which is measured by an instrument and converted to the pH scale. A glass electrode is selective for H^+, allowing the measurement of the potential caused by the increase in H^+ concentration. The potential measured is based on the reference electrode potential (calomel or AgCl). Typically, a single electrode comprising both the reference and glass electrodes (a combination electrode) is used.

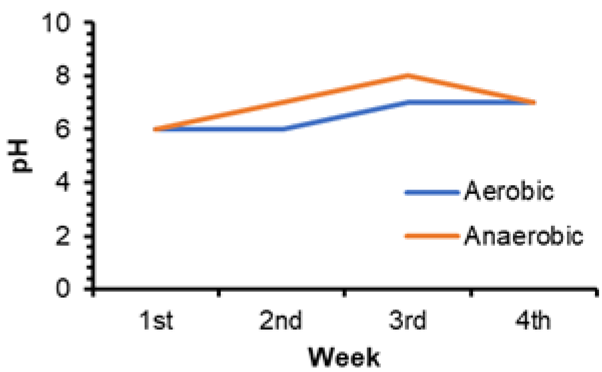

Fig. 1. Monitoring data of pH on fertilizer sample results on November 2023

Table 1. Monitoring data of color on fertilizer sample

Time	Aerobic	Anaerobic
1st week	Brown	Brown
2nd week	Brown	Brown
3rd week	Dark Brown	Dark Brown
4th week	Dark Brown	Dark Brown

According to the results obtained, the composting process could occur within a pH range of 6 to 8, with fungi thriving in slightly acidic conditions. Figure 1 shows that the pH of all anaerobic compost samples was in line with SNI 19-7030-2004, where the pH of compost after one month ranged between 7.2 and 7.4. This is likely due to the temporary or localized release of acids causing a pH drop, while ammonia production from nitrogen compounds increases the pH in the early composting phase. Mature compost typically has a near-neutral pH. Based on the pH values obtained, the pH of the samples meets the quality standards according to SNI number 7763 of 2018, which is 4-9.

Fine and mature compost is typically brown to black, and the color change is highly dependent on the base materials used in compost production. Mature compost will feel soft when crushed because, during the composting process, organic materials undergo decomposition and changes in fresh materials, forming microbial cell substances and transforming into an amorphous, dark-colored form. This substance is referred to as soil-like material. Compost maturity is influenced by several factors during the composting process. After composting was complete, the raw materials turned brownish-black. The color change (**Table 1**) can be attributed to the activity of microorganisms during decomposition. The color produced in this study meets the standard (SNI 19-7030-2004) for brownish-black compost.

The physical characteristics of the composting process of organic materials are marked by changes in the texture of the compost base materials during decomposition. Organic materials added during composting could decompose evenly and blend with the base materials, no longer resembling the initial composition. During composting, the added materials undergo decomposition, indicating that the decomposition process and microbial activity are functioning well, signifying mature compost. Mature compost smells like soil and is fragrant. Compost that is fully matured will have a humus-like or earthy smell; if it smells foul. This indicates that the decomposition process is not complete and is still ongoing [26]. These results comply with the standard (SNI 19-7030-2004) that mature compost smells earthy.

From **Table 2**, it is noted that the temperature was very high on the first day and then decreased after the second day and onwards. This condition occurs due to the decomposition process by decomposer microorganisms that can inhibit bacterial growth. The composting temperature has a beneficial effect as it can reduce pathogenic bacteria (microbes or weeds). If the temperature during composting is less than 20˚C, the compost is considered failed and needs to be repeated. In aerobic and anaerobic samples, the temperature meets the requirements for compost maturity.

Table 2. Monitoring data of temperature on fertilizer sample

Time	Aerobic (°C)	Anaerobic (°C)
1st week	29	30
2nd week	27	30
3rd week	26	28
4th week	25	26

3.2. Phosporus Levels Testing

Phosphorus is an essential nutrient for plants, playing a crucial role in various metabolic processes and growth. Plants absorb phosphorus from the soil in the form of soluble phosphate ions available in the soil solutions. In addition, phosphorus can also be taken up in more complex forms, like nucleic acids, phytate, and phosphohumate, albeit in smaller amounts.

Organic fertilizers serve as an important source of phosphorus for plants because phosphorus in organic fertilizers is slowly but continuously available. This helps provide a stable supply of phosphorus for plants during their growth periods. Phosphorus in plants plays a crucial role in cellular respiration, photosynthesis, and energy metabolism. As a key component in nucleic acid (DNA and RNA) formation, phosphorus is also vital for storing and transmitting genetic information crucial for plant development [18].

Based on the test results, the phosphorus content as P_2O_5 was found at 1712 mg/kg for aerobic fertilizer and 2653 mg/kg for anaerobic fertilizer. The importance of phosphorus in root development cannot be overstated. Phosphorus stimulates the growth of strong and deep roots, which in turn enhances a plant's ability to absorb water and nutrients from the soil. This makes plants more tolerant of dry environmental conditions and improves harvest yields in shorter periods [18,19].

The relationship between phosphorus content and other physical characteristics of compost, such as pH, color, smell, and temperature. The compost pH plays a direct role in phosphorus availability. Phosphorus is most available to plants in soils with a pH range of 6-7.5, with its availability decreasing under more acidic or alkaline conditions. The anaerobic compost exhibited a higher phosphorus content (2653 mg/kg) and higher pH at week 3 (alkaline), indicating that phosphorus might be more concentrated or preserved under these conditions. This is because, at higher pH levels, phosphorus exists predominantly in the HPO_4^{2-} form, which is more stable and less prone to leaching compared to $H_2PO_4^-$ found in more acidic environments. However, extremely alkaline conditions can precipitate phosphorus into insoluble compounds, reducing its availability over time.

The compost color can often reflect its nutrient richness and organic matter content. Darker compost, typically seen in nutrient-rich organic matter, suggests a higher concentration of essential elements like phosphorus. In this study, the anaerobic compost, with its higher phosphorus content, may have exhibited a darker color due to the increased decomposition and microbial activity that helps release nutrients from organic matter.

The smell of compost, particularly in anaerobic conditions, is often due to the breakdown of organic matter, releasing gases, such as ammonia or sulfur compounds. Although phosphorus itself does not directly contribute to the odor, its role in microbial metabolism during decomposition can enhance the overall process. Anaerobic compost with higher phosphorus levels might produce stronger odors due to more active microbial degradation.

Temperature fluctuations during composting significantly affect microbial activity, which in turn affects phosphorus mineralization. Higher temperatures during the thermophilic stage facilitate the breakdown of organic matter, releasing phosphorus, which is accessible to plants. The anaerobic sample, with its higher phosphorus levels, indicates prolonged microbial activity, which can correlate with higher composting temperatures and a longer thermophilic phase, resulting in greater phosphorus release.

As plants reach the reproductive stage, phosphorus becomes increasingly critical. It aids in flower and fruit formation and influences the size, quality, and quantity of crop yields. Moreover, phosphorus also plays a crucial role in carbohydrate metabolism and protein synthesis. Overall, phosphorus not only supports plant growth physically but also significantly impacts the final yields obtained by farmers [19,20,21].

CONCLUSION

Based on the test results, weekly monitoring of the fertilizer yielded a pH range of 7.2-7.4; a height of 18-19.5 cm; and a temperature of 26-28°C, with a dark brown color. Furthermore, phosphorus levels at 1712 mg/kg for aerobic fertilizer and 2653 mg/kg for anaerobic fertilizer indicated that it contained phosphorus at varying concentrations, but it was still within a range that could provide adequate support for plant growth. Phosphorus in organic fertilizer was crucial for stimulating the development of strong roots, enhancing the plant's ability to absorb water and nutrients, and influencing harvest yields with optimal quality.

SUPPORTING INFORMATION

There is no supporting information in this paper. The data supporting this research's findings are available on request from the corresponding author (DMF).

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CONFLICT OF INTEREST

There was no conflict of interest in this study

AUTHOR CONTRIBUTIONS

DMF, AZ, and ARP conducted the experiment and calculation. DMF wrote and revised the manuscript. All authors agreed to the final version of this manuscript.

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