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CONSERVATION OF NATURAL RESOURCES THROUGH SUSTAINABLE FERTILIZED SOIL FROM ALUM SLUDGE BY TAKAKURA COMPOSTING

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Abstract

The management of alum sludge produced by water treatment plants has become a significant environmental issue. Improper handling of this sludge can lead to various environmental problems. Effective sludge management is crucial to mitigate or eliminate negative impacts on land, air, soil and water quality. Utilization of alum sludge, a byproduct of water treatment, promotes waste reduction and conservation of landfill space. At the same time, Takakura composting is proven to conserve nutrients in organic waste, returning them to the soil and reducing reliance on chemical fertilizers. This study aimed to evaluate the performance of Takakura composting methods (TCM) using alum sludge from a water treatment plant in Jenderam Hilir, Sepang. Four different TCM set-up were prepared with varying ratios of vegetable waste, sludg and seed compost. The composts were allowed to stabilize for up to four weeks and the final product was analyzed to assess the level of decomposition and quality of the final compost. The physical analysis revealed a maximum temperature of 46°C. After four weeks of composting, the nutrient content analysis showed that available phosphorus ranged from 23.71 to 33.75mg/kg, potassium from 0.36meq/100g soil to 0.53meq/100g soil and total nitrogen from 0.21 to 0.45%. The study concludes that the compost developed is appropriate for use in farming. Notably, Compost B, consisting of a 0.4:0.1:0.5 ratio of vegetable waste, sludge and seed compost respectively (measured in grams), yielded the best results.

***Keywords**: Takakura composting; Alum sludge; NPK*

Introduction

The global demand for potable water continues to rise, driven by its essential role in sustaining life and fostering human development. The world's population is expanding by approximately 80 million individuals annually, while changes in lifestyle and dietary habits have led to increase per capita water consumption. Consequently, the demand for freshwater has surged, with an annual increase of 64 billion cubic meters [1]. Water quality parameters are crucial in determining the suitability of water for various applications. In this context, drinking water treatment processes generate substantial quantities of alum sludge worldwide, necessitating the implementation of economically iable and environmentally responsible management practices. Researchers suggest that sludge production from water treatment facilities typically accounts for 1-3% of the raw water volume processed. Furthermore,

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thickened sludge typically contains 2-4% solids, while mechanically dewatered sludge (via centrifuge) comprises 17-23% solids [2].

Notably, comprehensive data on alum sludge production and disposal remains limited both globally and nationally. Recent literature provides sparse statistics on sludge production, associated costs and related information. For instance, the Czech Republic reported a production of 34,494 tons of water treatment sludge (dry mass) in 2006. In Portugal, annual alum sludge production is estimated at 66,000 tons [3], while the Netherlands incurs significant disposal costs of £30-£40 million per year [4]. Ireland's alum sludge disposal costs are projected to double by the end of the next decade, from the current 15,000-18,000 tons of dried solids annually [4].

A persistent challenge in sludge management is identifying cost-effective and efficient disposal methods. This issue is particularly acute due to the substantial quantities of sludge produced and its adverse environmental impacts on water utilities globally, in both urban and rural settings. In Australia, the volume of sludge generated by various water authorities varies significantly on an annual basis, influenced by the number of treatment plants operated by each organization [2]. A study by Maiden et al. (2015) revealed that sludge disposal in the Victorian water industry costs approximately $130 per ton, amounting to an annual expenditure exceeding $6.2 million. A significant portion of this sludge is typically classified as waste and disposed of in sewers or landfills, resulting in both financial and environmental consequences.

Consequently, it is imperative to explore sludge recycling and reuse options, while evaluating the potential benefits and cost savings associated with these alternatives. Historically, storage, sewer disposal and landfilling have been prevalent methods [5,6]). However, escalating costs and environmental concerns are compelling the industry to consider alternative strategies such as recycling, reuse and resource recovery. Concerns have been raised regarding the viability, long-term potential and sustainability of certain alternatives [5,7]. It is crucial to thoroughly investigate and assess practical management solutions for alum sludge reuse, particularly options that can effectively utilize substantial quantities of the material and alleviate the burden on the water treatment industry.

The utilization of alum sludge in producing fertilized soil through Takakura composting contributes significantly to environmental conservation by transforming an industrial byproduct into a valuable resource. This process reduces the amount of sludge disposed in landfills, thereby preventing potential soil and water contamination from pollutants present in the sludge. By converting alum sludge into a nutrient-rich soil amendment, the need for synthetic fertilizers, which are energy-intensive and can lead to environmental degradation, is diminished. Additionally, the composting process promotes the recycling of organic waste, supporting a circular economy approach. This not only improves soil health and fertility, leading to better crop yields with less environmental impact, but also mitigates the release of greenhouse gases by capturing carbon within the soil. Ultimately, the sustainable use of alum sludge conserves natural resources, reduces pollution and supports long-term ecosystem health, demonstrating a viable strategy for waste management and environmental preservation.

Materials and Methods

Preparation of fermentation solution

This fermentation solution is formulated using brown sugar in combination with various fermented food substrates, including yogurt, yeast, tapai, tempe and mushrooms. For this study, tempe exhibiting approximately 50% yellowish coloration and sourced from a local market was selected as the substrate for isolating native microorganisms in the preparation of seed compost. The fermentation solution preparation protocol utilizing tempe was as follows: A sugar solution was prepared by dissolving 200 grams of brown sugar (molasses) in three liters of water. Subsequently, 200 grams of tempe were fragmented and introduced into a five-liter vessel containing the sugar solution. The mixture was then subjected to static fermentation conditions at ambient temperature for a duration of 3-5 days. To mitigate pressure buildup from gaseous byproducts, the vessel's closure was temporarily loosened daily.

Preparation of Alum Sludge

Water treatment sludge constituted a primary component in the compost preparation. The sludge was sourced from a water treatment facility located in Jenderam Hilir, Sepang. Specifically, untreated sludge was collected immediately following sedimentation process, prior to its transfer to the drying bed. To eliminate excess moisture content, the sludge underwent oven-drying at 105°C before utilization. The resultant semi-dried sludge was subsequently stored in a sealed plastic container.

Preparation of Vegetable Waste

Vegetable waste and banana peels, procured from Pasar Awam Salak, Sepang together with the sludge were mechanically reduced in size (<1inch) to enhance the composting rate, as particle dimensions significantly influence microbial decomposition efficiency.

Preparation of Seed Compost

The process of creating the seed compost requires 4kg of dried sludge, 2kg of chicken feed, the fermentation solutio and a suitable container to house the bed. The dried sludge and chicken feed were mixed in a thorough manner and the fermentation solution was meticulously incorporated into the mixture. The careful blending process ensured a thorough and uniform combination of the ingredients. Afterward, the mixture was transferred into a container and sealed for a few days. At this stage, a layer of white mold will be developed on the surface of the fermented bed, signifying the successful advancement of the fermentation process. The combination of ingredients that results is known as seed compost. Preparing seed compost is an essential part of the composting process, which involves using alum sludge and chicken feed along with the fermentation solution. This seed compost is a valuable resource of beneficial microorganisms that are crucial for the effective breakdown of organic matter in later stages of composting.

Composting Set-up

To ascertain the optimal composting material ratio, four distinct set-ups were meticulously prepared and designated as A, B, C and D. Each sample comprised a unique combination of sludge, green waste and seed compost, while maintaining a uniform total mass of one kilogram across all samples. The precise compositional breakdown of these samples is delineated in Table 1 below.

Table 1. Composting material ratio of various composting set-up

Compost	Percent ratio (%)	Weight (kg)
A	50% VW : 50% SC	0.5 : 0.5
B	40% VW : 10% SL : 50% SC	0.4 : 0.1 : 0.5
C	30% VW : 20% SL : 50% SC	0.3 : 0.2 :0.5
D	50% SL : 50% SC	0.5 : 0.5

SL: Sludge, VW: Vegetable waste, SC: Seed Compost

Physico-chemical analysis of Compost

To maintain ideal conditions for the composting process, several critical parameters were meticulously monitored and regulated. Maintaining these factors within optimal ranges is essential for promoting the growth and metabolic activity of microorganisms responsible for organic matter decomposition during the composting process. To comprehensively evaluate the quality of the final compost product, samples of the four set-up were submitted to the Department of Agriculture for soil quality analysis. This analysis yielded significant data regarding nutrient conten and the overall suitability of the compost for agricultural or horticultural applications. The methodologies employed for analyzing the parameters are delineated in Table 2. These methods were selected and implemented with precision to ensure the acquisition of accurate and reliable data throughout the composting process.

Table 2. In-house method for physico-chemical analysis (Department of Agriculture)

Parameter	Standard Operation Procedure (SOP)	Equipment
pH	Glosolan-SOP-06	pH meter
Total Nitrogen	Glosolan-SOP-13	ICP-OES
Phosphorus	Bray-Kurtz II	UV-VIS spectrophotometer
Pottasium	MS 678: Part IV: 1980	ICP-OES

Results and discussion

Physical Observation

Figure 1 illustrate the physical condiction of the four-composting set up by the end of Week 1 and Week 4. Within the first two days, the presence of mold was detected on the surface of the compost, indicating active microbial activity. The detection of mold or white filaments on the surface of compost, often associated with actinomycetes, is a widely observed phenomenon in composting. Actinomycetes, which are a group of filamentous bacteria, play a crucial role in breaking down complex organic matter such as lignin and cellulose. This microbial activity is particularly active during the thermophilic phase of composting when temperatures rise and actinomycetes thrive in environments with less moisture and high organic content [8].

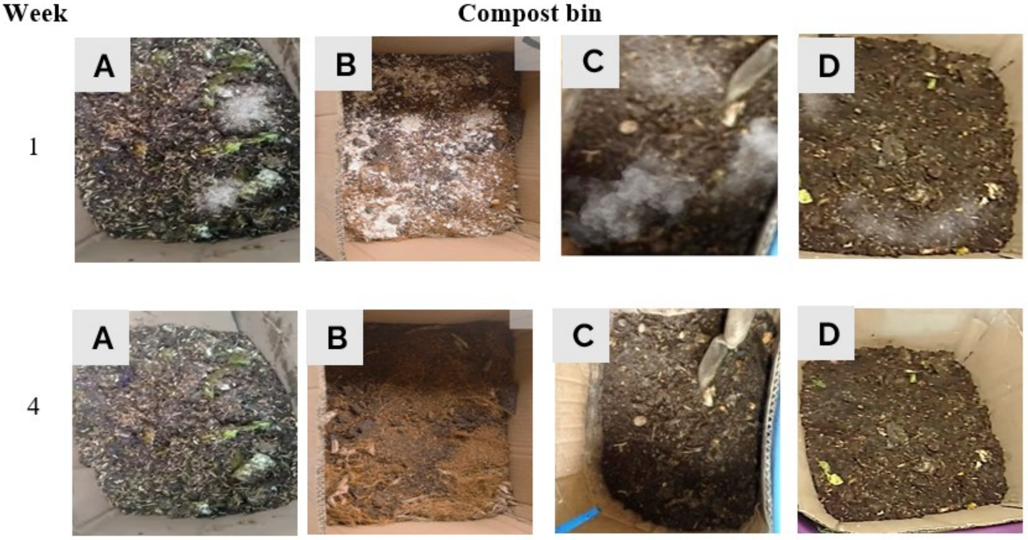

Fig. 1. Physical observation of compost set-up A, B, C and D.

Temperature

Temperature serves as the primary indicator for assessing composting process efficacy. Fluctuations in temperature throughout the composting process signify microbial activity, with temperature increases indicative of established microbial degradation processes. Figure 2 depicts the temperature profiles of four distinct compost formulations.

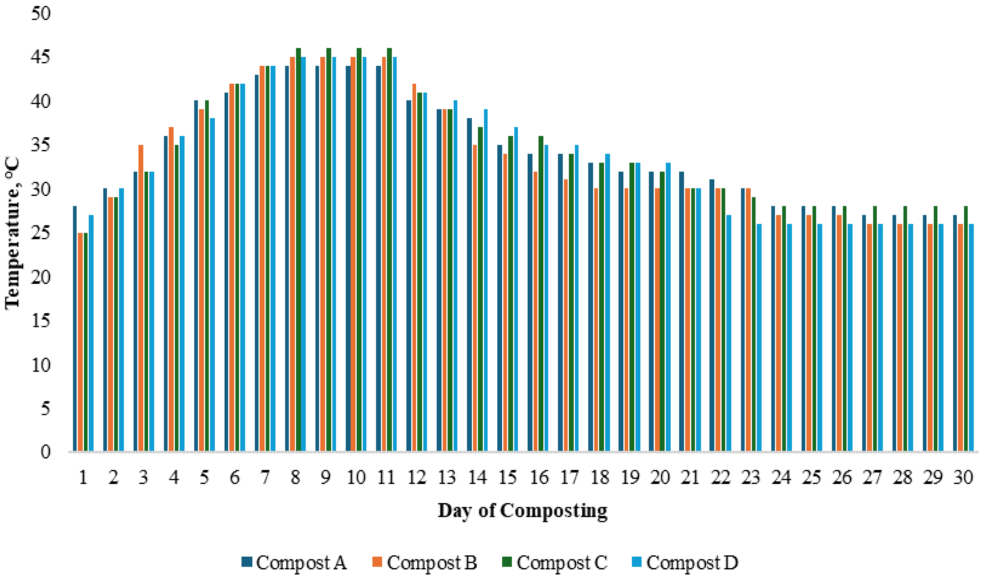

Fig. 2. Changes in temperature of compost.

Throughout the composting period, temperatures exhibited a gradual initial increase. By the second week, all compost types surpassed 40°C, maintaining this elevated temperature for approximately 72 hours before gradually declining to 39°C at the process conclusion. This data demonstrates that the compost reactors achieved thermophilic temperatures followed by a gradual temperature reduction. The observed thermal variations can be attributed to the differential quantities of food waste incorporated into each compost formulation.

The combinations of organic compounds, including proteins, fats and substantial quantities of readily degradable organic nitrogen, significantly influence temperature dynamics [9]. Furthermore, it was reported optimal microbial activity during composting occurs within the temperature range of 35 to 40°C [10].

The data presented in figure 2 clearly indicates a transition to the curing phase after the second week of composting. This transition marks the initiation of compost maturation, which continues until the compost temperature equilibrates with ambient conditions, typically ranging from 26 to 28°C. This observation is consistent with Tin Lee's (2016) findings, which reported ambient temperature ranges of 24 to 31°C during the final stages of composting [11].

pH

The pH value serves as a critical indicator of compost acidity or alkalinity, significantly influencing the growth and metabolic activity of microorganism's integral to the composting process. As evidenced in table 3, pH measurements remained relatively stable throughout the study period.

The observed pH values exhibited variations contingent upon the decomposition medium and the specific composition of food waste introduced into each reactor. These findings corroborate the research of *M. Rastogi et al.* [12], which demonstrated that microbial degradation of organic matter results in the production of acids, carbon dioxide and heat.

Table 3. pH of compost

Type of compost	pH
Compost A	6.4
Compost B	7.2
Compost C	7.4
Compost D	6.8

Numerous studies have emphasized the importance of maintaining an appropriate pH range to optimize microbial activity. It is generally accepted that microorganisms and bacteria exhibit optimal functionality within a pH range of 6.0 to 7.5 [13]. Throughout the decomposition process, the pH values of all compost samples consistently remained within the favorable range of 6.4 to 7.4. This pH stability ensured the maintenance of optimal conditions for microbial activity and efficient composting processes.

NPK Analysis

A critical parameter in evaluating compost efficacy as a fertilizer is the analysis of its NPK (nitrogen, phosphorus and potassium) content. To ensure optimal fertilizer performance, it is imperative that the nutrient content falls within a specific range. The NPK content analysis of the research compost yielded significant results across all three primary nutrients.

A comprehensive summary of the NPK analysis results for the compost samples is presented in Table 4 below.

Table 4. Results and interpretation of soil analysis

Sample	Total Nitrogen, N (%)	Phosphorus, P (mg/kg)	Potassium, K (meq/100g soil)
Compost A	0.21	23.71	0.36
Compost B	0.34	33.75	0.53
Compost C	0.31	26.84	0.45
Compost D	0.45	28.43	0.41
Optimum range (Department of Agriculture)	0.27 – 0.40	25 – 45	0.45 – 0.80

Total Nitrogen

Figure 3 illustrates the total nitrogen values for the research ranged from 0.27 to 0.40%. Result revealed that the nitrogen content in Compost A is recorded to be below the recommended range. Nitrogen loss occurs through volatilization, leaching and incomplete denitrification. Volatilization is the primary route, leading to emissions of N_2O, N_2 and NH_3, which constitute 47%–77% of the total nitrogen loss during the composting process [14]. Composts B and C exhibited nitrogen levels within the ideal range, indicative of a well-balanced nutrient profile conducive to optimal plant health and growth. The range reported for Compost B is somehow higher than findings which is in the range of 0.9-3 % [15].

Phosphorus

Figure 4 demonstrates phosphorus concentrations exhibited variation between 25 and 45mg/kg. The Department of Agriculture's report stipulates that high-quality compost should contain phosphorus within the range of 25 to 45mg/kg. Analysis of test results indicates that all compost variations, except for Compost A, meet these quality standards. Notably, Compost B exhibited the highest available phosphorus content at 33.75mg/kg which demonstrate that phosphorus content typically increases during organic matter decomposition. During the compost maturation phase, microbial mortality results in the release of phosphorus from microbial biomass into the compost matrix, thereby enhancing its overall phosphorus content. This finding is consistent with previous research, which indicates that the phosphorus content typically rises during the process of organic matter decomposition. Throughout the maturation phase of composting, microorganisms perish, leading to the release of phosphorus from these microorganisms into the compost. This process ultimately enhances the compost's phosphorus content [16].

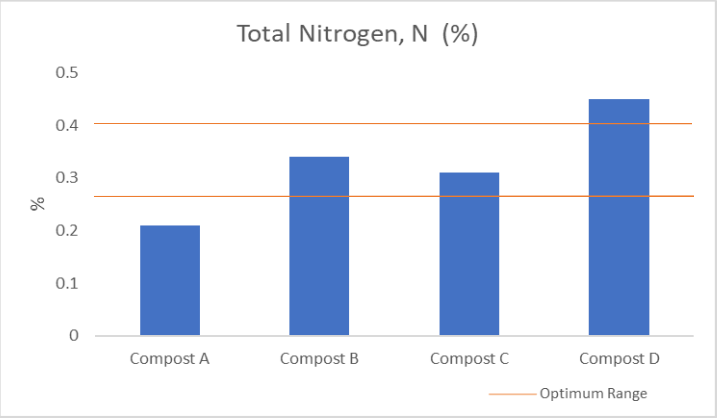

Fig. 3. Total Nitrogen in Compost

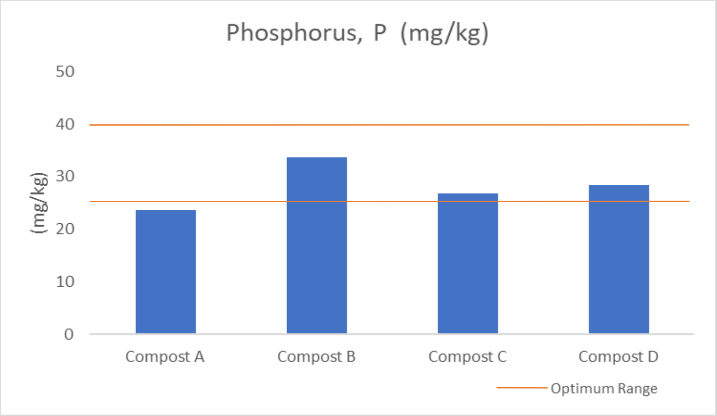

Fig 4. Phosphorus in Compost

Potassium

Figure 5 illustrates Potassium levels ranging from 0.45 meq/100g soil to 0.80meq/100g soil. According to the compost quality standards established by the Department of Agriculture, high-quality compost should have a potassium (K) content ranging from 0.45 to 0.80meq/100g soil.

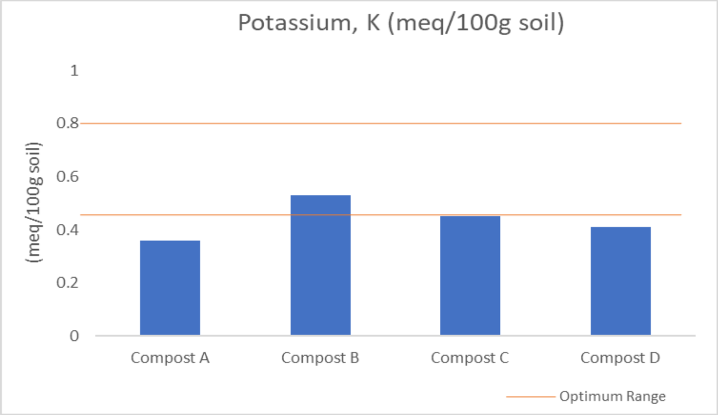

Fig. 5. Potassium in Compost

However, analysis of the compost samples revealed that Composts A and D did not meet this criterion. Compost B exhibited the highest potassium content at 0.53meq/100g soil, whereas Compost A had the lowest at 0.36meq/100g soil. The potassium content in compost can be affected by the inclusion of different activators, which are important in promoting the breakdown of raw materials by microorganisms. This process is dependent on certain environmental conditions, such as the presence of necessary nutrients, proper aeration and appropriate moisture levels [17].

Conclusions

This study provides valuable insights into the composting process and the nutrient composition of the resultant compost. Temperature and pH values remained within recommended ranges (42 to 46°C and 6.4 to 7.4, respectively), indicating effective management of the process and the maintenance of optimal conditions for microbial activity and organic matter decomposition. Nutrient analysis of the compost yielded promising results. aligned with the standards established by the Department of Agriculture, confirming the compost's suitability as an ideal product. Compost B, comprising 40% vegetable waste, 10% sludge and 50% seed compost, demonstrated superior effectiveness in the composting process compared to other tested mixtures.

This research emphasizes the conservation aspect in terms of waste minimization (alum sludge and organic waste) and promoting sustainable practices for soil improvement. It enhances our understanding of the composting process and provides valuable data on the nutrient content of compost derived from various organic waste materials. The findings support the potential utilization of this compost in agricultural settings, offering a sustainable solution for organic waste management while producing a valuable soil amendment. `Future research directions may include extended field trials to evaluate the effects of this compost on crop yields and soil health. Additionally, investigating the economic viability of large-scale production and application of this compost could provide valuable insights for practical implementation.

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