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Sustainability Analysis of the Vertical Composter as an Innovative Approach for Organic Waste Management and Space-Efficient Urban Food

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Abstract: The waste problem is a never-ending problem, so it is everyone's responsibility to find solutions to the existing waste problem. According to data from the Ministry of Environment and Forestry in 2022, waste in Indonesia is predominantly composed of organic waste, accounting for 41.27% of the total waste. The purpose of this study was to determine plant growth by utilizing used barrels as a vertical composter for organic waste, which is useful for providing small-land farming, and to determine the quality of liquid and solid fertilizers. The method used was a laboratory experiment. The results of the study were as follows: the number of mustard green leaves was 15 cm, and the bok choy leaves were 13 cm. The total height of the mustard greens was 40 cm, and the bok choy was 20 cm. The length and area of the leaves continue to increase by around 0.2 cm or more per day. The highest nutrient content in both compost and liquid fertilizer is P2O5 in Gegelengan Village, 4.223% in compost, and 5.4% in Kediri Village in liquid fertiliser, while the lowest is the N-Total content of 0.5% (compost) and 1.2% (liquid fertilizer). The research results obtained from the initial soil, solid organic fertilizer and liquid organic fertilizer met the quality standards based on the Decree of the Minister of Agriculture No. 261/KPTS/SR.320/M/04/2019.

Keywords: Composting; Liquid Organic Fertilizer; Organic Waste; Vertical Composter.

Introduction

Rapid population growth and urbanization have led to the reduction of productive land, particularly in urban areas. This trend has simultaneously increased the volume of household waste, which is predominantly organic, while reducing the available space for agriculture and food cultivation. Organic waste, primarily derived from food residues, garden waste, and other biodegradable materials, contributes significantly to environmental pollution and greenhouse gas emissions when not properly managed [1].

According to KLHK (2022), organic waste accounts for 41.27% of the total waste in Indonesia, with households contributing 38.2% [2]. Data from the West Nusa Tenggara Provincial Environmental Service further indicate that West Lombok Regency produces approximately 211 tons of organic waste daily, of which only 60 tons are processed through TPST facilities. This gap between waste generation and processing capacity underscores the urgent need for localized waste management solutions [3].

Several studies have demonstrated that household compost contains essential macronutrients within acceptable limits, as specified in the Indonesian National Standard (SNI 19-7030-2004), including total nitrogen (0.92–1.14%) and phosphorus (0.18–1.30%) [4], which are sufficient for supporting plant growth. However, utilization of such compost remains limited due to a lack of awareness and accessible small-scale technology for waste conversion [5].

The urban farming system for pak choy (also known as bok choy) revealed that the polybag method yielded the highest income, while the wall planter bag method yielded the highest profit per area. All cultivation methods were efficient, with the R/C ratio exceeding 1, and the production and income of pak choy for each method surpassed the break-even point (BEP). However, if the B/C ratio is less than 1, all pak choy cultivation methods in the urban farming system are considered unfeasible and require further review [6].

An innovative solution to these issues is the vertical composter, a compact vertical composting system that integrates waste decomposition and plant cultivation within a single structure. This technology enables households to produce and use compost independently, even in confined spaces such as balconies, small yards, or narrow alleys. The vertical composter embodies the principles of the Sustainable Development Goals (SDGs), particularly environmental sustainability, economic efficiency, and community empowerment.

This research, therefore, focuses on analyzing the sustainability and effectiveness of the vertical composter as a dual-function tool for organic waste management and space-efficient urban agriculture, contributing toward food self-sufficiency in limited land areas.

Research Methods

This study employs an experimental laboratory design to evaluate the efficiency of the *vertical composter* in producing organic fertilizers and its potential for urban food cultivation.

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The primary materials used include household organic waste (vegetable scraps, fruit residues, and leftover food), soil as a planting medium, and seedlings of mustard greens (Brassica juncea) and pak choi (*Brassica rapa*). Hydrochloric acid (HCl) and sodium hydroxide (NaOH) were used for laboratory chemical analyses. The *vertical composter* unit was constructed from recycled plastic drums (230 L capacity, 90 cm height, 57 cm diameter) equipped with PVC pipes and liquid collection trays. Laboratory instruments included glassware (beakers, test tubes, and flasks), an analytical balance, hot plate, pH meter, UV–Vis spectrophotometer, furnace, and vortex mixer.

Composting Process

Organic waste was placed inside the composter, layered with soil to initiate anaerobic fermentation. The process was monitored over a 45-day period with sampling every five days (Day 0–45). Observations included the formation of solid compost and liquid organic fertilizer, as well as temperature and moisture fluctuations.

Nutrient Analysis

Nutrient analyses were conducted on both solid and liquid fertilizers using standard methods:

1. Nitrogen (N): Kjeldahl method
   Organic nitrogen in the sample is converted to ammonium sulfate through a digestion process using concentrated H_2SO_4 and a catalyst. The ammonium is then released as ammonia through distillation with a strong base (NaOH), then captured in an acidic solution and titrated
2. Phosphorus (P): Bray method
   Available phosphorus is extracted from the soil using a weak acid solution (HCl + NH_4F). The extracted phosphate is then reacted with ammonium molybdate to form molybdenum blue, which is measured using a spectrophotometer (UV-Vis).
   Used for:
   Acid soils (pH < 7). For alkaline soils, Olsen is typically used. Result: Available phosphorus (ppm or mg/kg).
3. Carbon (C): Walkley and Black method [7] Oxidation of organic carbon in the sample by a solution of $K_2Cr_2O_7$ (dichromate) in acidic conditions (H_2SO_4). Chromium is reduced by organic carbon. The remaining dichromate is titrated with $FeSO_4$ to calculate the amount of oxidized organic carbon. Note: This method measures approximately 70–80% of the total organic carbon because not all C is completely oxidized. Result: Organic carbon content (% organic carbon) [8].
4. Soil and compost destruction method (solid organic fertilizer): Weigh 0.5 g of dry sample into a digestion tube. Add 8 mL of concentrated HNO_3. Allow the initial reaction to proceed for 15–30 minutes (in a fume hood). Gradually add 2 mL of H_2O_2 (30%) to aid in the oxidation of the remaining organic matter; add it slowly to avoid splashing. Heat the solution on a hot plate until it boils gently for 1–2 hours, until it becomes clear or nearly dry (do not allow it to dry completely, as this will form a hard precipitate). Cool. Transfer the sample to a 50 mL volumetric flask, wash the residue with distilled water, and adjust the final volume to 50 mL.
5. Fe test using AAS method: The sample was digested by adding a 65% HNO3 solution, heating it, then diluting it with distilled water and mixing it until homogeneous. The solution was filtered using filter paper until a clear liquid was obtained, and then transferred to a vial. Fe(NO3)3 Calibration Curve: 5 mL of 1000 mg/L Fe(NO3)3 stock solution was transferred to a volumetric flask and eluted with 0.5 M HNO3 to the mark, resulting in a 50 mg/L Fe standard solution. Next, standard Fe solutions were prepared with concentrations of 5, 10, 20, 30, 40, and 50 mg/L [9].
6. *Escherichia coli* Test Method: Solid organic fertilizer samples were stored at room temperature (20–25°C) and tested a maximum of 7 days after receipt. 5 grams of solid organic fertilizer samples were then ground and weighed and put into 45 mL of Buffered Peptone Water (BPW), to produce an initial dilution of 1x. The sample was then homogenized until evenly distributed by inverting. Next, serial dilutions were carried out to archive a dilution level of up to 10-3, by transferring 1 mL of solution from each dilution level into a test tube containing 9 mL of sterile BPW, thus obtaining three dilution levels, namely 10^{-1}, 10^{-2}, 10^{-3}. The entire dilution process was carried out aseptically. Next, a Presumptive Test was carried out: A total of 1 mL was pipetted from each dilution level and put into Lactose Broth (LB) media equipped with a Durham tube, in triplicate. The tubes were incubated at 36°C for 24 hours. Tubes showing gas formation and turbidity are considered presumptive positive [10].

pH values were determined using a calibrated pH meter. The optimal pH is crucial for nutrient availability and efficient plant absorption.

Plant Growth Assessment

Plant growth trials were conducted by cultivating mustard greens and pakchoy in *vertical composter* media compared to polybag controls. Growth parameters observed included shoot height, leaf count, and emergence rate over time.

Physical Parameter Monitoring

Environmental factors, including ambient temperature, soil temperature, and humidity, were measured across three reactors situated in different environmental settings to assess the impact of spatial variation on composting performance.

Results and Discussion

Construction of the Vertical Composter

The vertical composter developed in this study serves not only as a composting device but also as a vertical planting medium, providing an innovative solution for vegetable cultivation in limited spaces. The construction process required approximately 17 days under normal working conditions; however, the duration could be shortened if performed continuously without interruption.

Laboratory Analysis of Liquid Organic Fertilizer (LOF)

This research was conducted at the Environmental Laboratory of Sekolah Tinggi Teknik Lingkungan Mataram. Liquid fertilizer samples were collected from three different villages in West Lombok Regency: Sandik Village (Gunung Sari District), Kediri Village (Kediri District), and Gegelang Village (Narmada District).

The isolated liquid fertilizer samples were analyzed for chemical and microbiological parameters, and the results are summarized in Table 1.

Table 1. Laboratory Results of Liquid Organic Fertilizer Analysis

Parameter	Sandik	Kediri	Gegelang	Unit	Standard (Min–Max, Kepmentan No.261/2019)
pH	8	8	9	–	4.0 – 9.0
Temperature	25	26	28	°C	–
C-Organic	2.30	2.33	2.32	%	≥10
N-Organic	0.772	1.787	1.220	%	2 – 6
P_2O_5	4.739	5.449	5.111	%	2 – 6
Fe Total	51.205	53.106	64.350	ppm	90 – 900
E. coli	98	95	99	CFU/mL	$<1\times10^2$

Initial Soil Quality and Solid Organic Fertilizer

The solid compost was produced using cow manure, rice husks, vegetable and fruit residues, and local soil as the primary raw materials. The composting process lasted 30 days. Prior to composting, baseline soil quality was analyzed from the same three villages to serve as a comparison, as shown in Table 2.

Table 2. Initial Soil Quality and Solid Organic Fertilizer Laboratory Results

Parameter	Initial Soil	Solid Organic Fertilizer	SNI (2004) Standard
Temperature (°C)	25–27	24.9–29.8	27–30
pH	5.3–5.8	6.6–7.0	6.0–9.0
Moisture (%)	70–80	68–89	50
C-Organic (%)	4.5–5.53	2.35–3.53	9.8–32
N-Total (%)	0.131–0.367	0.595–0.831	≥0.40
P_2O_5 (%)	0.773–1.13	1.14–2.93	≥0.10
C/N Ratio	–	17–20	20–25

Plant Growth Observation (Biological Parameters)

Morphological observations were conducted on mustard greens (*Brassica juncea*) grown on the vertical composter. Growth parameters included leaf length and number of leaves, as presented in Table 3.

Table 3. Observation Results of Plant Growth on Vertical Composter

Day	Growth Stage	Leaf Length (cm)	Number of Leaves
1–4	Germination phase; early seedling emergence	0.3	2
5–6	Cotyledon emergence (seed leaves)	0.4	2
7–10	True leaf formation begins; 1–2 leaves emerge	2.0	3
11–15	Increased height and leaf number	3.5	5
16–20	Rapid leaf elongation and new shoot development	5.5	6

Quantity of Solid and Liquid Organic Fertilizer

The vertical composter unit (height: 109.5 cm) effectively produced both solid and liquid organic fertilizers during the composting process. The vertical design allows continuous nutrient recycling and efficient decomposition.

Quality of Fertilizers and Soil

pH

pH is a key parameter in assessing fertilizer quality. The results (Figure 1) show that initial soil pH increased from acidic (5.6) to neutral after composting, while the liquid fertilizer exhibited an alkaline pH. Both values meet the standards of SNI 2004 (solid compost) and KEPMENTAN 2019 (liquid fertilizer). This shift in pH indicates microbial activity in decomposing organic materials into simpler compounds beneficial for plants [11].

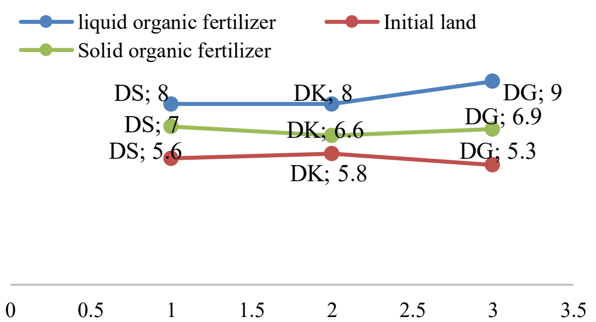

Figure 1. Results of pH measurements

Temperature

The composting process occurred under mesophilic temperature conditions (24.9–29.8°C), as shown in Tables 1–2 and Figure 2. The temperature remained moderate due to the geographical location of Sandik and Gegelang Villages near Mount Rinjani, where the ambient temperature is naturally lower. This range supports the growth of mustard and pakcoy plants, which thrive between 15–30°C with 10–13 hours of sunlight per day [12].

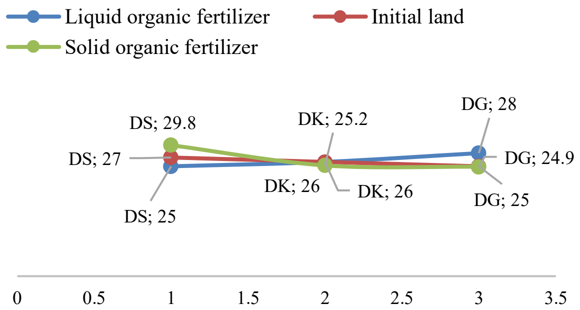

Figure 2. Temperature measurement results

Organic Carbon (C-Organic)

Organic carbon serves as an energy source for microorganisms during the process of decomposition. The composting process enhanced soil fertility by increasing the availability of essential nutrients (N, P, K) and supporting sustainable soil productivity. Elevated C-organic levels also contribute to maintaining soil and water quality, playing an essential role in nutrient cycling [13].

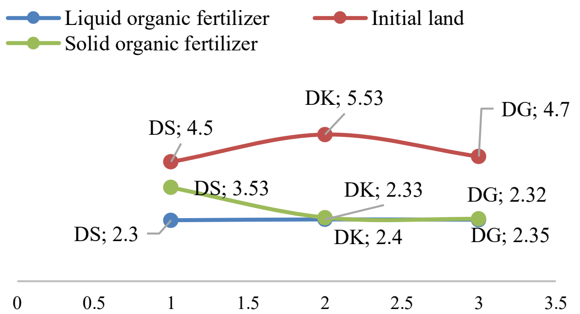

Figure 3. Carbon Organic Content

Total Nitrogen (N-Total)

Nitrogen is a major macronutrient essential for vegetative growth, particularly leaf and stem formation, which are vital for photosynthesis [14]. Although the total nitrogen levels obtained were below government standards, continuous leaf development was still observed every two days. According to Safei et al. (2014) in Likabu et al. (2025), nitrogen plays a crucial role in vegetative growth, particularly in promoting leaf expansion [15].

Total nitrogen describes the total amount of nitrogen available in fertilizer, which plays a vital role in plant growth through the formation of proteins, enzymes, and chlorophyll. Furthermore, nitrogen plays a key role in stimulating overall growth, particularly stem growth, which can boost plant height [16].

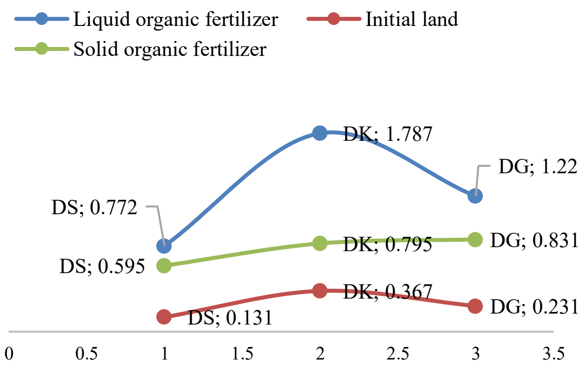

Figure 4. N-Total test results

Available Phosphorus (P_2O_5)

Phosphorus in the form of P_2O_5 is essential for root development, energy metabolism, and cell division [17]. The results showed that both solid and liquid organic fertilizers met the required standards. P_2O_5 levels ranged from 0.7–2.9% in solid compost and 4.7–5.4% in liquid fertilizer (Figure 5). The higher concentration in liquid fertilizer is likely due to increased availability at alkaline pH, following initial acid-phase fermentation influenced by microbial activity [18].

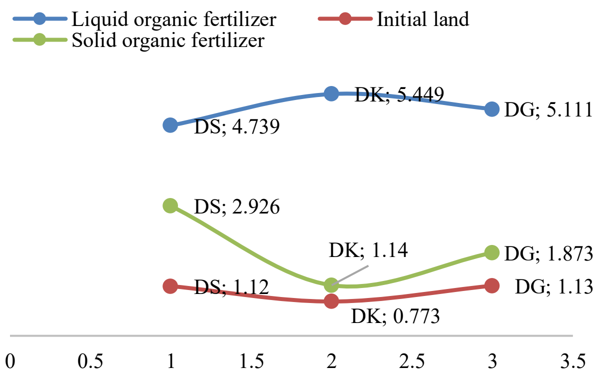

Figure 5. P_2O_5 test results

Total Iron (Fe)

The total Fe content in the liquid organic fertilizer ranged from 51.205–64.350 ppm, below the KEPMENTAN 2019 standard of 90–900 ppm. This indicates that the organic waste material was rich in organic matter but contained limited natural Fe [19]. Iron deficiency affects chlorophyll synthesis and leaf development, which can reduce photosynthetic efficiency and plant vitality [20].

Escherichia coli

The total *E. coli* count in the liquid organic fertilizer ranged from 95–99 CFU/mL, which complies with KEPMENTAN 2019 standards (<100 CFU/mL). The presence of *E. coli* is likely due to the use of cow manure as the primary substrate. However, microbial dynamics during fermentation (especially pH fluctuations) may have limited pathogen survival [21].

Plant Growth Observation

Mustard greens (*Brassica juncea*) were chosen as indicator plants due to their high nutrient demand and short cultivation cycle. The plants exhibited healthy growth, characterised by steady increases in leaf number and length. Leaf elongation of approximately 0.2 cm per day was recorded across all test sites. Leaf size has a direct impact on photosynthetic rate and overall plant biomass accumulation [22]. These findings confirm that the nutrients provided by both solid and liquid fertilizers from the vertical composter are sufficient to sustain healthy plant growth.

Figure 6. Plants in a vertical composter

Vertical composters can be placed on balconies or in small spaces. When the compost is directly used, a closed nutrient cycle occurs, strengthening small-scale food self-sufficiency, particularly for leafy vegetables and herbs, which provide nutritional value and high harvest frequency [23].

The results of this study are relevant to the following findings: a composter made using the aerobic method with a vertical design, a capacity of 60 liters, a composter height of 69.1 cm, a composter diameter of 38.1 cm, and a liquid organic fertilizer filter height of 19 cm. The results obtained from the study of liquid organic fertilizer produced from 5.4 kg of organic waste raw materials produced 2.5 liters during 30 days of decomposition. It has an initial C nutrient content of 2.39%, a final C of 0.267%, an initial N of 0.014%, a final N of 0.058%, has an initial C/N ratio of 170.71% and a final C/N of 4.6%. The temperature of the liquid organic fertilizer reached room temperature of 25.8ºC on the 30th day of fermentation, a final pH of 6.19 with a concentration value of 238 ppm [24].

Conclusion

The vertical composter offers an innovative, sustainable, and space-efficient solution to two critical urban challenges: the accumulation of organic waste and limited arable land. By integrating composting and urban farming functions, this technology aligns with the principles of the circular economy and the SDGs, fostering environmental stewardship and community food self-reliance. Further research should explore optimization of composting parameters, microbial enhancement, and scalability for community-level implementation.

Author's Contribution

H. Sholehah: compiling proposals, collecting and analyzing theories related to compost, vertical farming, food independence, and reviewing scientific references related to vermicomposter sustainability. Nurhidayah: designed and built a vertical composter. Tested the system's effectiveness in processing organic waste. Analyzed the resulting compost and soil quality. Recorded environmental parameters (humidity, temperature, pH, etc.). K. P. Rahmawati: Designs and builds vertical composters, prepares materials for presentations or seminars, and manages publications on social media or academic journals.

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