Chemical Properties and Recovery of Vermicompost from Mixed Shredded Leaves and Poultry Manure Using *Eudrilus eugeniae* Under Different Loading Schemes

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Vermicomposting is a simple biotechnological procedure to produce excreta of earthworms called vermicompost. Vermicompost contains a high concentration of nutrients that are capable of improving soil health and quality. However, the complexity of interacting factors that affect vermicomposting is not yet fully understood. A study laid out in a completely randomized design was conducted to identify the effects of different loading schemes of mixed shredded leaves (SL) and poultry manure (PM) to vermicompost recovery and chemical properties using the *Eudrilus eugeniae*, a litter-dwelling species of earthworm which can consume and mix a large amount of soil and organic matter (OM) and convert it into fertile casts. Results showed the improved chemical properties of vermicomposts such as pH, organic matter (OM), available N, available P, and exchangeable K. A significant difference was also observed in pH, N, P, and K. The frequent loading that causes a sudden rise in pile temperature increased the mortality of earthworms affecting vermicompost recovery. Overall, the recovery was still high from all treatments based on the capability of the initial number of earthworms placed in each vermicomposting container to produce vermicompost.

Keywords: Vermicompost, earthworms, biomass, chemical properties, feedstock

INTRODUCTION

Millions of tons of organic wastes are disposed of in landfills and incinerated each year (Rostami, 2011). Large volumes of food wastes and the by-products of various food industries are not recycled or utilized for other purposes (Gupta et al., 2019). Poor manure management increases the burden of disease and causes negative environmental impacts (Lalander et al., 2015). Thus, the need to explore better and more efficient ways of managing and utilizing various organic wastes. Processing organic wastes could have dual beneficial effects by producing valuable products such as organic fertilizer and organic amendments while alleviating the detrimental effects of poor organic waste management. The decomposition of biomass is a natural process that helps transform organic raw materials into forms available for plant uptake. However, the amplified concentration of agricultural wastes due to improved production exceeds the natural decomposition capacity rates. Excessive agricultural wastes are a serious issue because of its various environmental impacts.

One of the challenges of decomposing some organic materials is that it takes longer to convert them into readily applicable fertilizer. Naturally, dry and brown wastes such as dry leaves, straws, and wood chips have high carbon (Inyim, 2019) and, hence, needs a longer period to decompose. On the other hand, poultry manure is wet and has a low C/N ratio, and although it contains a high amount of nutrients, it can cause environmental problems when not properly disposed of and managed. These challenges can be addressed by making its nutrients stable using earthworms through vermicomposting (Yuvaraj, 2018). The potential of poultry manure as a source of nutrients can be achieved when the compost is stable and mature. Attaining compost maturity is challenging due to differences in chemical composition and other characteristics in the finished compost. If unstable or immature compost is applied, anaerobic conditions will occur, and immature compost application releases phytotoxic compounds (Ch'ng, 2013).

Vermicomposting yields positive economic performance despite the weak economic environment (More, 2015). In 2015, vermicomposts had an 8.79% share of the world's organic fertilizer market. Compared to 2014, the vermicompost market managed to increase sales by 24.89% to 38.09 M USD worldwide in 2015. The major global players in vermicomposting are North America, Europe, China, Japan, the Middle East and Africa, India, and South America. In the Philippines, large-scale and commercial vermicomposting is done in the National Agribusiness Corporation (NABCOR farm in San Ildefonso, Bulacan, and in another operation in La Carlota, Negros Occidental (PCAARRD, 2014). The NABCOR farm used pig manure, while the latter used dried cattle and chopped rice straw as feedstocks. Similar to most of the methods in many countries that produce compost, the methods of local producers are patterned after the so-called "Beltsville aerated pile" method where sludge is mixed with bulking materials composted in a stationary aerated pile for weeks (PCAARRD, 2014). Also, research has been performed to develop proper management strategies for utilizing organic raw materials to understand the factors that influence decomposition.

Vermicomposting is one among many existing composting technologies that has been used to effectively convert raw materials into usable forms in agriculture. This is intended to remedy the rate of biomass deposition which is higher than the decomposition rate, thereby posing significant problems when not contained and managed. Vermicomposting is the process that utilizes earthworms for composting organic materials. Earthworms can ingest all kinds of organic materials and transform these into organic fertilizers. For instance, a litter-dwelling species of earthworm such as *Eudrilus eugeniae*, litter-dwelling, can consume and mix many soil and organic matter and convert it into fertile casts. They can consume the substrate as much as their body weight per day (Misa, 2003).

While there have been many studies exploring different methods and materials for vermicomposting (PCAARRD, 2014), there is a dearth of studies examining the effects of feedstock loading to earthworms and vermicompost recovery. This study aimed to investigate the effects of different loading schemes of the most common agrowastes in Silliman Farm such as rice straws, grass clippings, acacia leaves, and poulty manure (PM). The mixed shredded leaves (SL) and PM as feedstocks for earthworms under different loading schemes might be necessary to attain faster and high recovery of vermicompost from poultry manure using *Eudrilus eugeniae*. Specifically, the study sought to (1) examine the effects of different loading schemes of mixed shredded leaves (SL) and poultry manure (PM) on earthworm population and biomass; and (2) determine the effects of different loading schemes of mixed SL and PM on vermicomposting rate and recovery, and chemical properties.

MATERIALS AND METHODS

Poultry Manure Collection, Shredding, and Mixing of Dried Leaves

A mixture of acacia leaves, rice straws, and various grass clippings obtained from the Silliman University Campus and SU Farm were shredded into smaller pieces (2cm) to increase the surface areas exposed for faster earthworm ingestion and decomposition. Daily collection of PM from the farms' Poultry Project was done to prevent flies from laying eggs in the farm pile. The collected fresh manure and SL were placed inside the organic fertilizer production mixing area at Silliman University College of Agriculture (Figure 1).

The mixed SL and PM at a 3:1(w/w) ratio were used as raw feedstock. The mixture was stored inside the mixing area for two weeks to pre-decompose, allowing harmful gasses to volatilize. After two weeks, the mixture was bagged and piled inside the storage room, prepared for vermicompost loading.

Figure 1. (a) Weighing and mixing of the feedstock; (b) Storing of the feedstock mixture for two weeks before bagging

Plastic Drum and PVC Pipes Preparation

Nine 55-gallon, closed-top, blue poly drums were fully opened on top using an angle grinder. Three (3) perforated PVC pipes were placed inside each barrel to aerate the system. The holes of the pipes served as the outflow of hot air produced from the organic material mixture. They allowed the inflow of oxygen that activates the aerobic microorganisms involved in the decomposition of organic materials. In addition, small holes were formed at the bottom of each barrel to drain excess water from the system (Figure 2).

Figure 2. Perforated barrels were used to contain the substrate, with perforated PVC pipes utilized as aerators for the decomposing feedstock.

Shredded Leaves and Poultry Manure Mixture and Earthworm Loading

Treatment 1, the control, was loaded with the total 80 kg SL and PM mixture (3:1 w/w); T2 was loaded with 40 kg initially and reloaded with another 40 kg after two weeks, while T3 was loaded with 20 kg weekly. The feedstock's remaining mixture to be loaded weekly for T3 of 20 kg and 40 kg after 14 days for T2 were contained and tightly tied in a plastic-coated sack to prevent flies from laying eggs. All earthworms (1kg) were placed on each drum containing the mixed feedstock on day 1.

Parameters Gathered

Moisture Content

The moisture content of the setup was maintained to meet the requirement of earthworms inside each container. The moisture requirement of earthworms is between 70-90%, with an optimum at 80-85% (Domfnguez, 2004). The recovered vermicompost was air-dried before it was sieved and then weighed. Moisture content was determined by using 20g of vermicompost placed in oven-dried pre-weighed 50 mL-beakers and dried in the oven for 24 hours at 110˚C. The moisture content was calculated as follows:

$$MC = \frac{FW - ODW}{ODW} x\, 100$$

wherein MC is the moisture content, FW is the air-dry weight, and ODW is the oven-dry weight.

Temperature

Every day at 9:00 AM, during the process of vermicomposting, the temperature was determined in each vermicompost pile using a TEL-RU compost thermometer (Figure 3). In organic matter decomposition, the energy released, which the microorganisms do not use, is liberated as heat. High temperature is suitable for speeding up composting for killing the pathogens, but too much-prolonged heat retards decomposition.

Figure 3. A thermometer with a 30 cm stem was used to measure the temperature of the substrate weekly.

Feedstock Chemical Properties

The feedstock chemical properties such as pH, % organic matter (OM), % available N, % available P, % exchangeable K in the feedstock were analyzed. The pH was analyzed using water-calcium chloride ratio 1:1 (v/v) using a glass electrode of Oakton ® PH 550 Benchtop pH meter. The equation conventionally defined this measurement of the activity of ionized H+ in the solution, pH = log (1/H) = -log10 H.

Carbon is the chief element of organic matter that is readily measured quantitatively. Percent organic matter (% OM) is the estimate of organic carbon. The OM was analyzed using the Graham Colorimetric method ("Standard Methods," 1980). This analysis used potassium dichromate to oxidize readily oxidizable soil organic matter. The reduced chromium ions are measured spectrophotometrically at 625 nm using the Perkin Elmer Lambda 25 UV-visible spectrometer.

Percent available nitrogen (% N) was analyzed following the Cadmium Reduction method (Grasshoff, 1983). The analysis is using the soil that was extracted with 0.5% $CaSO_4$, and the nitrate was reduced in a Cadmium reduction column. The resultant nitrite reacts with sulfanilamide and N-(1-naphthyl) ethylenediamine dihydrochloride (NED) to yield a pink azo dye where color is proportional to nitrite concentration. Absorbance is read at 540 nm in the spectrophotometer.

Percent available phosphorus (%P) was analyzed using the Ascorbic Acid method (Environmental Protection Agency, 1978). The % P was measured through the adsorbed phosphorus that was removed from the soil by the Modified Truog extraction method (Parfitt, 1982), $(NH_4)_2SO_4$ in 0.02 N H_2SO_4. The antimony-phospho-molybdate complex is formed when ammonium molybdate and antimony potassium tartrate react in an acid medium with dilute phosphorus solutions. This complex is reduced to an extremely blue-colored complex by ascorbic acid. The color is proportional to the phosphorus concentration (Standard Methods of Analysis for Soil, Plant Tissue, Water and Fertilizer, Philippine Council for Agriculture and Resources Research, Los Baños, Laguna 1980).

Exchangeable potassium was analyzed using the Turbidimetric Cobaltinitrite method (Standard Methods of Analysis for Soil, Plant Tissue, Water and Fertilizer, Philippine Council for Agriculture and Resources

Research, 1980) through potassium that reacts with sodium cobaltinitrite to form an insoluble double salt of potassium-sodium cobaltinitrite. The turbidity was measured in the spectrophotometer at 625 nm.

Vermicompost Percent (%) Recovery

The weight of the feedstock was recorded at the start, while vermicompost and partially composted feedstock were documented at the end of the experiment. The difference of vermicompost recoveries from different loading schemes of the organic substrate was recorded after it was sieved (2mm). The equation below was used to determine the vermicompost productivity or vermicompost recovery (Ramnarain et al., 2019).

Earthworm Population

$$Vermicompost\ Recovery = \frac{Harvested\ vermicompost\ (kg)}{Total\ Mass\ (kg)}\ x\ 100\%$$

One kilogram of Eudrilus eugeniae of about 1,000 earthworms was placed in all treatments with three replicates. The earthworms were counted and weighed to compare the change in population and biomass before and after the experiment (Figure 4). The total earthworm population was determined using the hand-sorting method (Ramnarain, Ansari, & Ori, 2019); (Zicsi, 1962).

Figure 4. (a) Collected earthworms from the barrel; (b) Inspection of the biomass

of earthworms

Experimental Design

The experiment conducted was laid out in a Completely Randomized Design. There were three treatments with three replications. Treatment 1 (control) - 80 kg substrate fully loaded at the onset of the experiment. Treatment 2 – 40 kg substrate was loaded at the start and reloaded with another 40 kg after two weeks. Treatment 3- 20 kg of the substrate was loaded weekly.

Data and Statistical Analysis

The data gathered in this study that was laid out in a completely randomized design were analyzed using one-way ANOVA and least significant difference (LSD) through the Statistical Tool for Agricultural Research (STAR) 2.0.1 software developed by the International Rice Research Institute to determine the differences between treatment means at a 5% level of significance by LSD.

Ethical Considerations

Before conduct, this experiment was submitted for ethical clearance to the University Research Ethics Committee [UREC] of Silliman University.

RESULTS

Collection of Poultry Manure, Shredding, and Mixing of Dried Leaves

The collection of PM improved the sanitation of the farm. It prevented flies from laying eggs on the dung, thereby inhibiting their reproduction. When added into the SL, SL acts as an absorber of excess moisture and prevents anaerobic digestion that minimizes greenhouse gases release that have an unpleasant odor. The shredding of leaves increases its surface area enabling it to absorb and hold more water , making it more suitable for the chicken dung as moisture absorbent.

Moreover, shredding of the leaves promotes faster decomposition and easier incorporation into the mixture. The reduction of excess moisture of PM through SL mixing can eliminate unwanted odor from the final product with low heavy metal content and a comparable amount of nutrients (Ch'ng, 2013). Also, smaller particles of raw materials have increased surface area, making nutrients and energy more accessible to decomposing microorganisms. However, smaller particles inhibit air space within the composting feedstock, so a balance is needed (Landfilling, n.d.). Particle sizes ranging from 1/8 to 2 inches in diameter generally produce good results (Sherman, 2020). In the present study, the leaves' shredded size is within the recommended particle size range.

Plastic Barrel and PVC Pipes Preparation

The plastic barrels that were used maintained the ideal moisture requirement for the earthworms inside. The holes formed at the bottom of the barrel drained the excess water, leaving the substrate's moisture at water holding capacity, thereby allowing sufficient moisture for microorganisms, while the perforated PVC pipes provided oxygen to the substrate's void spaces, activating the aerobic microorganisms as well. Apart from aeration, the perforated pipes served as the heat outlet from the substrate, especially right after the first wetting. The heat generated when the air-dried mixture was saturated with water indicated that decomposition was happening.

Moisture and Aeration

The substrate's moisture content depends on the amount of water applied to the barrel and loss through evaporation and drainage. High moisture content (50-65%) was maintained in the substrate suitable for the earthworms. Watering is required to moisten, soften, and digest the feedstock partially to be consumed by the earthworm easily (Kaur, 2020). However, moisture availability may limit microorganisms' catabolic capacity in the substrate (Lavelle & Spain, 2003). The optimum water potential for organic material decomposition occurs between soil water potential of -0.03 and -0.10 MPa. Bacterial respiration declines rapidly as potentials decline below 0.30 MPa, while fungal activity may continue down to potentials of -4 to 5 MPa (Pual & Clark, 1989). Microorganisms need water to sustain their metabolic processes. A 40% to 60% moisture content range is recommended for most materials (Sherman, 2020). Below 40%, microbial activity slows down and ceases below 15%. However, when moisture exceeds 65%, porosity decreases because air spaces of materials are replaced by water, which leads to anaerobic decomposition conditions that release odors and slower decomposition (PCAARRD, 2014).

Temperature

Microorganisms release heat during decomposition, so the temperature is a good indicator of the composting process (Sherman, 2020). The decay of organic matter is faster in warm, humid conditions. However, decomposition of organic materials decrease as water availability and temperature decrease (Schomberg et al., 1994). In the present study, the temperature of the mixture pile ranged from 50-70 °C until the collection dried up, and the temperature declineds to 25-35 °C (Figure 5). The warming of the pile signified that decomposition occured. After two weeks, the pile was bagged when most excess moisture evaporated already from the mixture (Hansen et al., 2013). In the first two weeks before sacking, the pile temperature was 55-60 °C. This was the thermophilic phase of decomposition, where heat-loving microbes were abundant. Thermophilic microbes are responsible for the decomposition of protein and other carbohydrate compounds. Oxidation of lignin, a stable material, occurs in the prolonged thermophilic phase of decomposition (Ch'ng, 2013). To avoid prolonged heat that might kill the earthworms in the bins thermometer was used to check the pile constantly, and water was added when necessary to attain the temperature safe for earthworms.

Treatment 3 had the highest temperature of the three treatments of 46.3 °C, followed by T2 and T3, at 35 and 31 °C, respectively. A decline of temperature was observed in all treatments in the second and third week until it stabilized at 28-29 °C in the fourth week. This observation coincides with the findings of Ch'ng (2013) where the vermicompost temperature inside the barrel was almost the same as the ambient temperature at the end of the vermicomposting period.

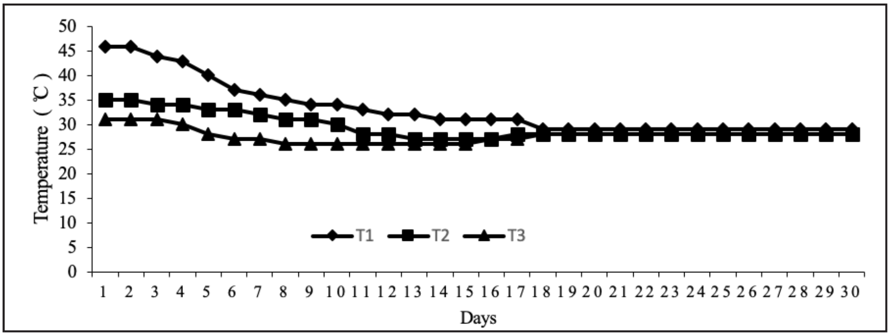

Figure 5. A daily recorded temperature of the feedstock pile from different treatments

Feedstock Physical Property

The physical property of the feedstock influences the rate at which it decomposes. Some of the physical features of resources are toughness, surface area, and particle size. For example, tough leaves are highly cuticularized compared to small and soft leaves that are readily compostable. Shredding the leaves reduces the particle size, increases its surface area, and exposes the hydrophobic waxy surface of leaves facilitating their ingestion by earthworms (PCAARRD, 2014). The matured vermicompost product was brownish-black, soft, had an earthy smell compared to the initial SL and PM feedstock. The recovered vermicompost was fine, and the original feedstock was already unidentifiable. The recovered vermicompost also had an earthy smell, which meant that the finished vermicompost was processed adequately by earthworms (Sunil, 2016).

Figure 6. Sifted vermicompost to separate fully and partially vermicomposted feedstock

Chemical Properties

pH. The feedstock used for vermicomposting had a pH of 7.09±0.06 (Table 2). Sose and Kulkarni (2017) stated that pH ranging from 6.4 to 7.6 was most effective of for vermicomposting. A decline of pH in the product of T1=6.47 ± 0.04, T2=6.56 ± 0.03, and T3=6.59 ± 0.27 was observed compared to the initial feedstock pH. The decrease in the compost pH was expected because when the composting process begins, the pH decreases due to the breakdown of carbonaceous components by microorganisms (PCAARRD, 2014). Furthermore, acid-forming microorganisms on the feedstock that contains C release organic acids that cause pH drop. The pH values of T1, T2, and T3 were not significantly different, but these were significantly different compared to the initial feedstock. Earthworms were very sensitive to the pH of the feedstock. The optimal worm growth was reported at a pH range of 5.0 to 9.0 (Dominguez & Edwards, 2011). However, pH below 6.0 slows down decomposition, while pH above 8.0 can cause the release of CH3 in the natural decomposition process (Sose & Kulkarni, 2017).

The pH determines the rate at which nutrients are absorbed in the soil. Micro-nutrients tend to be unavailable in soil with high pH, whereas macro-nutrients are not available at low pH (Manyuchi, 2017). The feedstock of near-neutral initial pH is optimal for the stabilization of waste with minimal processing time. The substrates with strong acidity initial pH are less suitable for vermicomposting (Singh et al., 2006).

Organic matter (OM). Generally, the initial feedstock's organic matter content, T1, T2, and T3 wasis very high at 24.16 ± 0.72, 22.26 ± 0.47, 22.91 ± 2.63, and 25.14 ± 2.81, respectively (Table 2). The OM from different treatments was not significantly different, but T3 was relatively higher than T1 and T2. The feedstock's initial organic matter dramatically impacts the finished product because its initial nutrient status changes after decomposition, depending on its chemical constitution. If the initial feedstock has lower nitrogen levels and higher carbon levels, then an expected outcome will have lower plant-available nitrogen levels (Beeks, 2014). The OM that can be derived from the decomposition of organic materials such as vermicompost is critical in the soil's physical, chemical, and biological health. The presence of organic matter as cementing agents is also important in helping clods and aggregates resist abrasion. This is one reason why sandy soils, which are low in such agents, are so easily eroded by wind.

Percent (%) Available N. The % available N of the initial feedstock is intermediate at (0.14 ± 0.01 %) compared to T1, T2, and T3, which is very high at 0.44 ± 0.01 %, 0.42 ± 0.03 %, and 0.82 ± 0.03 %, respectively (Table 2). However, T3 is the highest, which has almost twice the concentration of T1 and T2. This contradicts the findings of Ramnarain et al. (2019) who noted the highest N in the raw material. However, Suthar (2007) argued that the earthworms enhanced N levels in the vermicompost through their excretory products, mucus, body fluid, enzymes, and even the decaying earthworm biomass vermicompost subsystem. The reported values of N concentration in vermicompost in earlier studies was between 0.9 and 1.5 % (Kale, 1998). Nitrogen is the most critical element that plants can obtain from the soil, and nitrogen deficiency often limits plant growth (Gray, 2017).

Percent (%) Available P. The % available phosphorus is very high in the initial feedstock (1.84 ± 0.05) and in all treatments. However, there is a significant reduction observed in T1 and T2 (1.63 ± 0.11; 1.55 ± 0.07) and an increase in T3 (1.92 ± 0.10). The latter is consistent with the findings of Ramnarain et al. (2019) which showed an increase in P in the vermicompost. Similarly, Marlin and Rajeshkumar (2012) also recorded an increasing P in vermicompost from various organic wastes. During the vermicomposting process, the release of P from decaying organic wastes occured partly by earthworm gut phosphatases. This may be due to the P-solubilizing microorganisms in the worm casts that convert P to plant bio-available forms (Suthar, 2009).

Percent (%) Exchangeable K. A very significant difference of % exchangeable K was observed between the initial feedstock and the treatments. A very high concentration of % exchangeable K was observed in the feedstock, while there was a lower, yet, increasing concentration trend in T1, 2, and T3 (0.71 ± 0.00, 1.95 ± 0.39, and 3.79 ± 2.27), respectively. Although the exchangeable K decreased in the vermicompost compared to the raw material, it was generally high. The high concentration of K might be due to the enhanced microbial activity during the vermicomposting process, which enhances the rate of nutrient release (Suthar, 2009).

Total % NPK. The total NPK was highly significantly different. Based on the Philippine National Standards on Organic Soil Amendments, treatment 3 with 6.5% total NPK is considered organic fertilizer. Organic fertilizer is any product in a solid or liquid form derived from plants or animals that have undergone substantial decomposition that can supply available nutrients to plants with a total Nitrogen (N) - Phosphorus (P_2O_5) - Potassium (K_2O) content of five to ten percent (5-10%) (BAFS, 2016).

Feedstock and Vermicast Chemical Properties

Table 2.

Comparison of feedstock and vermicast chemical properties

Samples	Moisture*	pH	OM^{ns} (%)	available N* (%)	available P** (%)	exchangeable K** (%)	Total NPK** (%)
Initial Feedstock	7.63 ± 0.10 a	7.09 ± 0.06 a	24.16 ± 0.72a	0.14 ± 0.01 b	1.84 ± 0.05 a	5.00 ± 0.52 a	6.98a
T1	7.05 ± 0.18 b	6.47 ± 0.04 b	22.26 ± 0.47a	0.44 ± 0.01 b	1.63 ± 0.11 b	0.71 ± 0.00 b	2.78c
T2	6.90 ± 0.10 b	6.56 ± 0.03 b	22.91 ± 2.63a	0.42 ± 0.03 b	1.55 ± 0.07 b	1.95 ± 0.39 b	3.92b
T3	7.01 ± 0.16 b	6.59 ± 0.27 b	25.14 ± 2.81a	0.82 ± 0.03 a	1.92 ± 0.10 a	3.79 ± 2.27 a	6.53a

In a column for each treatment measured, means followed by the same letter are not significantly different at 5% Least Significant Difference.

Earthworm Biomass, Population, and Vermicompost Recovery

The organic feedstock loading and vermicomposting rates were compared in this study. Results show that the feedstock's different loading schemes significantly affected earthworm biomass and population (Figure 4). Moreover, there appeared to be slight differences among treatment means in terms of vermicompost produced, partially decomposed feedstock, and percent (%) feedstock. However, the differences were statistically insignificant (Table 3).

The sharp decrease of biomass and earthworms' population may be attibuted to the height of feedstock inside the barrel every loading that reached up to 30 cm. The addition of new feedstock in the vermicomposting containers causes a sudden rise in temperature detrimental to earthworms. Singh et al. (2004) stated that the depth of 5 cm, 7.5 cm, and 10 cm of the initial substrate remained aerobic while the thickness of 12.5 cm and 15 cm turned anaerobic during vermicomposting. This finding is related to T1, T2, and T3 loading schemes and the consequent earthworm population. Treatment 1, which was loaded once, had the highest population survival compared to T2 (loaded twice) and T3 (loaded weekly). Although T3 was loaded 20kg weekly, the height of the feedstock exceeded tolerable levels, where most deaths of earthworms were observed right after each loading. The weight of vermicompost recovered is correlated with the number of earthworm populations left in each treatment. Treatment 1 had the highest weight of vermicompost recovered and the highest earthworm population, followed by T2 and T3. Treatment 3 had the lowest feedstock loss among all feedstock mixtures. A difference in feedstock loss is observed but not significant (Table 3).

Treatment 1 had a relatively higher vermicompost recovery followed by T2 and T3, respectively. However, the partially decomposed feedstock followed an opposite trend of vermicompost recovery, where T3 is the highest, followed by T2 and T1, respectively. This observation suggests that the organic feedstock mixture can have a higher recovery when loaded simultaneously at the start of vermicomposting when handling feedstocks with lower C/N like PM. Also, the earthworm population decreased signficantly when the feedstock mixture was loaded weekly. This observation might be due to the fresh ammonia emitted by the feedstock every week as it is loaded, causing the sudden rise of temperature and decrease in pH. Similarly, Raza et al. (2021) noted that ammonia is emitted at a high frequency within the first week. Also, Donahue (2001) claimed the toxicity of ammonia increases as temperature increases.

Feedstock loss was observed among all treatments; however, no significant difference between treatments was noted. Adhikary (2012) noted that earthworms' consumption of organic feedstock reduced volume by 40-60%. Additionally, since the high-N materials (poultry manure) have higher initial water content than high-C bedding materials (shredded leaves), then weight losses during the vermicomposting process can be higher (Munroe, 2007)

Table 3.
Comparison of treatment means on earthworm biomass and population, vermicompost recovery, partially decomposed feedstock, and % weight loss of feedstock

Treatments	Earthworm Wt (g) **	Earthworm Population**	Vermicompost Wt (Kg)	Partially Decomposed feedstock (kg)	Percent (%) Feedstock Loss
T1	209.33 ± 33.85 a	213.33 ± 41.63 a	25.87 ± 8.21 a	37.83 ± 8.31a	20.37 ± 1.83a
T2	112.33 ± 13.65 b	106.00 ± 21.17 b	23.30 ± 4.64 a	40.63 ± 5.64a	20.09 ± 8.99a
T3	45 ± 22.00 c	34.67 ± 15.01 c	21.37 ± 1.65 a	43.52 ± 1.96a	18.9 ± 1.67a

In a column for each treatment measured, means followed by the same letter are not significantly different at 5% Least Significant Difference

DISCUSSION

Vermicompost Production Using *Eudrilus eugeniae*

African nightcrawler (*Eudrilus eugeniae*) is a remarkably versatile vermicomposting species of the tropics (Blakemore, 2015) . Under Philippine conditions, this earthworm species has been efficient for vermicomposting (PCAARRD, 2014). The life cycle of this species is 60 days. It has a maturation time of 45 days. It has a relatively high cocoon production rate (17 days) with a mean number of 2.7 hatchings per cocoon and a body mass attained of about 2100mg (Deepthi et al.,2019; Viljoen & Reinecke, 1988). The number or biomass of earthworms depends on food type, climatic conditions, etc. (Adhikary, 2012). Although more mortalities are observed in the present study, the vermicompost recovery is high in relation to the number and earthworm biomass placed in the vermicomposting containers. This is related to the observation of Munroe (2007) that earthworms consume in excess of their body weight under ideal conditions each day, although the general rule-of-thumb is half of their body weight per day.

Earthworms consume various organic wastes and reduce the volumes of wastes by 40-60% (Adhikary, 2012). Due to the varying characteristics of raw materials, mixing them would make appropriate food for earthworms. A suitable mixture of nutrition from different materials is essential for the rate of growth, reproduction, and nourishment of earthworms. Providing the desirable requirement for the earthworms can lead to high-quality vermicompost (Adhikary, 2012).

Vermicompost Chemical Property

Generally, the chemical properties of vermicompost such as pH, %OM, available N, available P, and exchangeable K improved. However, T3 produced vermicompost with total NPK within the range of 5-10%, making it as organic fertilizer based on BAFS (2016). Vermicompost contains enzymes like amylase, lipase, cellulase, and chitinase, which help break down the organic matter in soil and make nutrients available for plant uptake (Adhikary, 2012). Composting can work efficiently and effectively between the pH range levels of 5.5 to 9. However, it is most effective between 6.5 to 8.0 (Sherman, 2020). A pH level below 6.0 and above 8.0 slows decomposition. In the present study, the pH values of vermicompost are closer to neutral ranging from 6.4-6.6. According to Edwards and Bohlen (1996), this pH range promotes macronutrient availability like NPK. Furthermore, Schwalfenberg (2012) indicated that the optimum pH of soil for the best overall essential nutrient availability was between 6 and 7. Similarly, Ramnarain, Ansari, and Ori (2019) cited findings of many studies indicating that vermicompost was rich in macronutrients such N, P, and K.

Effect of Feedstock Loading Schemes on Temperature

In this study, frequent loading causes earthworm mortality due to increased temperature in a pile, affecting the recovery of vermicompost. This is consistent with the findings of Adhikary (2012) which noted that the sudden rise of temperature after loading caused earthworm mortality. Temperature can reach up to 45 °C after loading when there is sufficient moisture. Sose and Kulkarni (2017) showed that a good temperature range is between 25-35 °C for earthworm growth and survival. Numerous results show for many species of earthworms, temperature beyond 35 °C is lethal. The heat of a compost pile is a product of the metabolic heat by microbial activity and can also be affected by raw material physical properties. The heat production depends on the pile's size, moisture content, aeration, and C/N ratio (Trautmann, 1996). This has been a challenge in the present study as earthworms require sufficient moisture. Contrariwise, the heat flux can be regulated by aeration (Azim et al., 2018). However, sprinkling water every loading can help reduce heat by conduction, while the perforated PVC pipes reduce heat by convection. Trautmann (1996) stated that a compost pile must have sufficient size to avoid fast heat and moisture dissipation, yet small enough to allow good aeration.

CONCLUSION

The mixed SL and PM loading schemes significantly decreased the earthworm population but improved vermicompost recovery and chemical properties. The pH and OM of vermicomposts produced were within the optimum range for soil microorganisms. The vermicompost produced contained high levels of macronutrients such as N, P, and K , especially in T3 which also contained the highest total % NPK. In terms of compost recovery, T1 produced the highest, followed by T2 and T3, respectively. On the other hand, the pile thickness of the newly added substrate can quickly build up heat detrimental to earthworm populations. Therefore, the pile's size, moisture content, and aeration should be considered in each loading to manage heat buildup and minimize earthworm mortality.

RECOMMENDATION

This study did not consider the thickness of the pile of feedstock that might affect the earthworms. More aerators are recommended if the vermicompost pile heat buildup exceeds the tolerable levels for earthworms. More bulking materials should be added when the C/N ratio is lower such as poultry manure. It is further recommended to include the economic aspects of the study.

ACKNOWLEDGEMENT

This research was funded by the Silliman University Faculty Development Grant for Research.

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