# Assessment of the suitability of pineapple waste as feedstock for vermicomposting

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**Abstract:** Declining soil fertility is a challenge to sustainable agricultural production in sub-Saharan Africa. However, large volumes of agricultural waste are generated from pineapples that could be converted into soil conditioners through vermicomposting utilizing earthworms. Several types of agricultural waste have been studied extensively as vermicompost feedstock, but little work exists on pineapple waste. The objective of this study was to investigate the suitability of pineapple waste as feedstock for vermicomposting. We assessed the physicochemical properties of fresh, pre-composted pineapple waste and the resultant vermicompost. We also studied the optimal feeding rate and stocking density of the system. The study revealed that pre-composting reduced the moisture content (29%), volatile organic carbon (VOC) (10%), and increased the pH (57%), which was helpful in waste stabilization as well as in the mass reduction of the waste. Vermicomposting after pre- composting increased the bulk density (92%), ash content (25.4%), pH (10%), EC (14%), total phosphorus (21%), and total potassium (28%). The technology also decreased the moisture content (1%), VOC (12%), total organic carbon (81%), total nitrogen (22%), and the carbon to nitrogen ratio (76.4%) of the pineapple waste hence yielding a more stabilized and mineralized vermicompost. The study further revealed an optimal feeding rate of 2 kg feeds/kg worms and a stocking density of 1 kg worms $m^{-2}$ for total nitrogen and phosphorus mineralization of the pineapple waste. The degradation of the pineapple waste by earthworms demonstrated the practicability of vermicomposting as a low-cost and straightforward technology of converting pineapple waste into a nutrient-rich soil amendment.

**Keywords:** pineapple waste, vermicompost, soil conditioner, stocking density, feeding rate

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## 1 Introduction

Due to the ever-growing world population, there is increased food production, contributing to the production of large volumes of waste (Alberti, 2010). In Sub-Saharan Africa (SSA), most of this waste which is rich in organic matter (Hoornweg and Bhada-Tata, 2012), is mainly generated from markets as a result of selling food in its raw form (Ekere et al., 2009). According to Vitali et al. (2013), crop wastes are often eliminated by dumping or open-air burning in many rural areas. These practices are associated with detrimental effects on the environment in the form of uncontrolled air emissions and lead to the loss of vital plant and energy resources (Komakech et al.,

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2014). At the same time, soil degradation is a widespread occurrence in these areas (Pender et al., 2006), majorly due to loss of crop nutrients from the field resulting from crop harvests (Mubiru et al., 2007). Replacement of the lost nutrients using mineral fertilizer is beyond the economic capacity for most small-holder SSA farmers (MAAIF, 2016). A more appropriate solution to this problem could be treating decomposable crop waste using proper methods and utilizing it as fertilizer or soil conditioner. One such treatment method is vermicomposting, an environmentally sustainable process and involves using worms to convert organic waste into a humus-like material termed vermicompost (Munroe, 2007). This earthworm-facilitated decomposition process provides newer opportunities for replenishing soil fertility (Jjagwe et al., 2020) while sustainably managing the environment (Komakech et al., 2016).

Vermicomposting is a viable, cost-effective, and rapid technique for efficiently managing biodegradable waste (Wani et al., 2013). The worms break up the biodegradable waste, thus quickening its decomposition and eventually stabilization (Garg et al., 2006). Vermicompost's popularity has significantly increased due to its higher economic return than conventional compost because its nutrients are in higher concentration than the fresh waste from which it was derived and are readily accessible for plant growth (Tripathi and Bhardwaj, 2004). Also, the worms used in vermicompost have high protein content and can therefore be used successfully as animal feed (Edwards and Arancon, 2004). Furthermore, the earthworms can be fed on a diversity of agricultural waste (Munroe, 2007), thus contributing to the value addition of agricultural wastes. Lalander et al. (2015) investigated the biomass conversion rate when earthworms were fed a mixture of cow dung in a low-cost non-optimized vermicompost reactor in Uganda. In the study, the authors observed a waste-to-biomass conversion rate of 3.6%. This waste-to-biomass confirmed that vermicomposting could be a sustainable waste management technology for urban small-holder farmers.

Several studies have assessed the viability of various feedstock to produce vermicompost. The different feedstocks assessed include distillery sludge (Suthar, 2009), tannery sludge (Vitali et al., 2013), bagasse (Sinha et al., 2010), food industry sludge (Yadav et al., 2010), water hyacinth (Garg et al., 2012) and oat straw (Singh et al., 2011). However, according to Sabiiti (2011), there are various agricultural wastes whose management is still a great challenge (Miito and Banadda, 2016; Zziwa et al., 2017). A case in point is pineapple waste that is under-utilized or openly dumped in many of the pineapple growing areas in SSA (Zziwa et al., 2017). The fibrous nature and acidity of pineapple waste (Chu et al., 2020) raises issues about whether the earthworms can degrade it to produce stable vermicompost. Zziwa et al. (2021) studied nutrient recovery from pineapple waste through controlled batch and continuous vermicomposting systems. Mainoo et al. (2009) studied Pilot-scale vermicomposting of pineapple wastes with earthworms native to Accra, Ghana. However, the focus of the studies was on the earthworm biomass growth, the mass balance of the systems, and the decomposition rates.

Therefore, this study's objective was to examine the suitability of pineapple waste as a vermicompost feedstock using *Eisenia fetida* earthworms and further determine the optimal feeding rates of the feedstock and the earthworm stocking densities.

## 2 Materials and methods

### 2.1 Study area

The pineapple waste samples used in the study were obtained from Kangulumira sub-county Kayunga district, one of Uganda's largest pineapple growing areas. The pineapple waste was transported in sealed containers to avoid any interference. The pre- composting and vermicomposting experiments were conducted inside a greenhouse constructed of polycarbonate mesh at Makerere University Agricultural Research Institute, Kabanyolo. The greenhouse was to safeguard the units from vermin and termites. During the experimentation period, ambient temperatures were between 80-85°F, and relative humidity ranged between 50%-70%. The experiments were sheltered from both rainfall and runoff.

### 2.2 Research design

The vermicomposting units used in the study were plastic worm-bins measuring 0.5 m × 0.4 m (diameter × depth) and a surface area of 0.2 $m^2$. Prior to vermicomposting, the pineapple waste was pre-composted under a constructed wooden shade for two weeks before being fed into the vermicompost units. The pre-composting period of two weeks was to ensure that the feedstock is well prepared for vermicomposting by degrading the fiber and reducing the acidity (Frederickson et al., 2007; Nair et al., 2006), but also to eliminate the heat generated during the initial decomposition of organic material. The composted feedstock was then manually shredded for size reduction and to increase its surface area. The shredded pre- composted pineapple waste feedstock was then mixed with dried cow manure (13 wt.%) in a ratio of 7:3 w/w and used as bedding and feed for the units. Eighteen vermifilter units (six treatments with three replications) were set up. The study investigated three feeding rates (1, 2, and 3 kg pre-composted feed/kg worms) and two stocking densities (0.5 and 1 kg worms $m^{-2}$) to ascertain the combination that yielded more vermicompost.

The earthworms used in this study were *Eisenia fetida*. This earthworm species is adapted to decaying organic material. The choice of earthworm species was based on previous vermicomposting studies that showed *Eisenia fetida* as a superior vermicomposting worm to other species (Babić et al., 2016; Kumar et al., 2016; Wang et al., 2017; Xu et al., 2013). On average, earthworms reached maturity after 30 days, and their body weight at maturity ranged between 0.4 and 0.8 g. The experiment ran for three months, a period deemed sufficient to stabilize the vermicompost (Mainoo et al., 2009). The vermicomposting units were fed with pre- composted pineapple waste every two weeks, as suggested by Soobhany et al. (2014) while maintaining the required feeding rates. Vermicompost units were kept moistened by water as and when required. At the end of the three months, vermicompost samples were picked and taken for analysis in the soil laboratory at the school of Agricultural Sciences, Makerere University.

### 2.3 Pineapple waste and vermicompost analysis

The new waste, cow manure, pre-composted waste, and vermicompost were all subjected to the analyses of physicochemical characteristics. We used standard procedures for all analyses. The physical properties considered are bulk density, ash content, volatile organic compounds (VOC), and moisture content (wet basis). In contrast, the chemical properties were pH, electro-conductivity (EC), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP), and total potassium (TK). All analyses were done in triplicates to cater to variability and error. The bulk density was determined using the bulk density core method (Al-Shammary et al., 2018), moisture content using gravimetric methods; the ash contents were measured by burning the samples dried to constant weight at 550°C in a muffle furnace. Volatile organic carbons were determined using the VOC Meter (PCE-VOC 1, Beijing, China). The total organic carbon (TOC) and carbon to nitrogen ratio (C/N ratio) of the samples were measured with a TOC/TN Analyzer (Agilent TOC/TN Analyzer). pH was determined using a pH meter (Hanna Pocket pH Tester, Washington USA), temperature and EC were monitored using a Hanna EC/Temperature Tester (DiST® 6, Washington USA). TN was determined using the total Kjeldahl nitrogen method (TMECC, 2002), TP was determined calorimetrically, and TK was extracted with ammonium acetate and measured with a flame photometer as proposed by Okalebo et al. (2002).

### 2.4 Data analysis

The calculation and analysis of all experimental data were performed using R-studio software. We performed outlier analysis on the data and performed outliers' analysis. The data were checked for normality, after which descriptive statistical analysis was done. Analysis of variance (ANOVA) was then done to ascertain whether differences between and within groups were significant ($\alpha$ =0.05). Post-Hoc analysis was then performed using Duncan multiple range tests (DMRT). The investigation was to assess the effect of the different treatments on the physicochemical properties of pineapple waste. All analyses followed the procedures specified in Venables and Smith (2019).

## 3 Results and discussions

### 3.1 Pre-composting

The changes in the physico-chemical parameters of feedstock during pre-composting were assessed by analyzing the parameters such as pH, TOC, TN, (C/N ratio, phosphorus (TP.), and potassium (TK.). Results show that pre-composting significantly reduced ($p < 0.05$) the bulk density (17.0%), moisture content (28.8%), the ash content (75.7%), and hence the VOC (10.3%) of the pineapple waste (Table 1). These reductions are attributed to carbon and moisture losses following the organic degradation of the waste (Garg et al., 2006) and some volatilization of the organic compounds in the waste. Regarding chemical properties, there was a significant increase ($p < 0.05$) in the pH (56.8%), EC (49.7%), and TP (115%), and the C/N ratio (18.5%) of the pineapple waste. The increases in these concentrations are attributed to various factors ranging from moisture loss, decomposition, and hydrolysis occurring during the composting phase.

**Table 1 Physico-chemical properties of the feedstocks and the resultant pre-compost (n=5)**

| | CM | PW | CM: P | PC |
|---|---|---|---|---|
| **Physical Properties** | | | | |
| Bulk density (g cc$^{-1}$) | $1.88^{c}$ | $2.65^{a}$ | $2.14^{b}$ | $2.21^{b}$ |
| Moisture Content (%) | $70.23^{a}$ | $70.94^{a}$ | $70.47^{a}$ | $50.52^{b}$ |
| Ash (%) | $29.21^{a}$ | $23.45^{b}$ | $21.37^{b}$ | $5.70^{c}$ |
| VOC (%) | $0.57^{d}$ | $26.03^{a}$ | $8.16^{c}$ | $23.36^{b}$ |
| **Chemical Properties** | | | | |
| pH | $8.0^{a}$ | $4.4^{b}$ | $6.8^{c}$ | $6.9^{c}$ |
| EC(dS m$^{-1}$) | $2.3^{b}$ | $1.9^{c}$ | $2.2^{b}$ | $2.8^{a}$ |
| TOC (g kg$^{-1}$) | $419.8^{a}$ | $405.0^{ab}$ | $414.9^{a}$ | $334.5^{b}$ |
| TN (g kg$^{-1}$) | $8.4^{a}$ | $7.8^{b}$ | $8.2^{a}$ | $7.9^{b}$ |
| TP (g kg$^{-1}$) | $5.6^{a}$ | $2.0^{c}$ | $4.4^{b}$ | $4.3^{b}$ |
| TK (g kg$^{-1}$) | $15.3^{a}$ | $14.3^{b}$ | $15.0^{a}$ | $14.8^{b}$ |
| C/N ratio | $50.00^{a}$ | $51.92^{a}$ | $50.59^{a}$ | $42.34^{b}$ |

Note: CM=cow manure, PW = Pineapple waste, PC= Pre-Compost

*Means with the same letter across rows imply no statistical significance ($p$>0.05) using Duncan multiple range test

Pre-composting however did not significantly ($p <$ 0.05) affect the TN, total organic carbon, and TK in the waste. Although effective vermicomposting requires a moisture content of between 55% to 65% and an approximately neutral pH (Lim et al., 2014), pineapple waste initially had higher moisture content (70.94% ± 5.6%) and was strongly acidic (4.4% ± 0.3%). Pre-composting thus helped reduce the moisture content and increase the pH, which was helpful in waste stabilization. These findings are similar to those reported by Frederickson et al. (2007) and Nair et al. (2006), who both reported the stabilization ability of pre-composting. Temperature profiles generated during the pre-composting process (Figure 1) to monitor the development of the composting phases also indicate that the system achieved mesophilic, thermophilic, and maturation phases as thus implying complete microbial breakdown of the organic matter (Francou et al., 2008). A similar trend was observed by Rashad et al. (2010) using rice-straw feedstock.

### 3.2 Vermicomposting

The changes in the physico-chemical parameters of pineapple waste during vermicomposting were assessed by analyzing changes in the pH, TOC, TN, C/N ratio, TP, and TK. Table 2 shows the effect of vermicomposting on the physicochemical properties of the pre-composted pineapple waste. Regarding physical properties, vermicomposting had no significant impact on the moisture content but increased the bulk density (92.3%) and ash content (25.4%) of the vermicompost. There was also a reduction in VOC (11.8%) because of volatilization and further degradation during the process. Regarding chemical properties, vermicompost increased the pH (10%), EC (14.3%), TP (20.9%), and TK (28.4%) but decreased organic carbon (81.4%), TN (21.3%), and hence the C/N ratio (76.4%). Lower C/N values imply more complete microbial degradation (Zhu, 2007), and thus a reduction in C/N ratio to (10.0 ± 2.2) signifies the generation of a fully degraded and stabilized vermicompost.

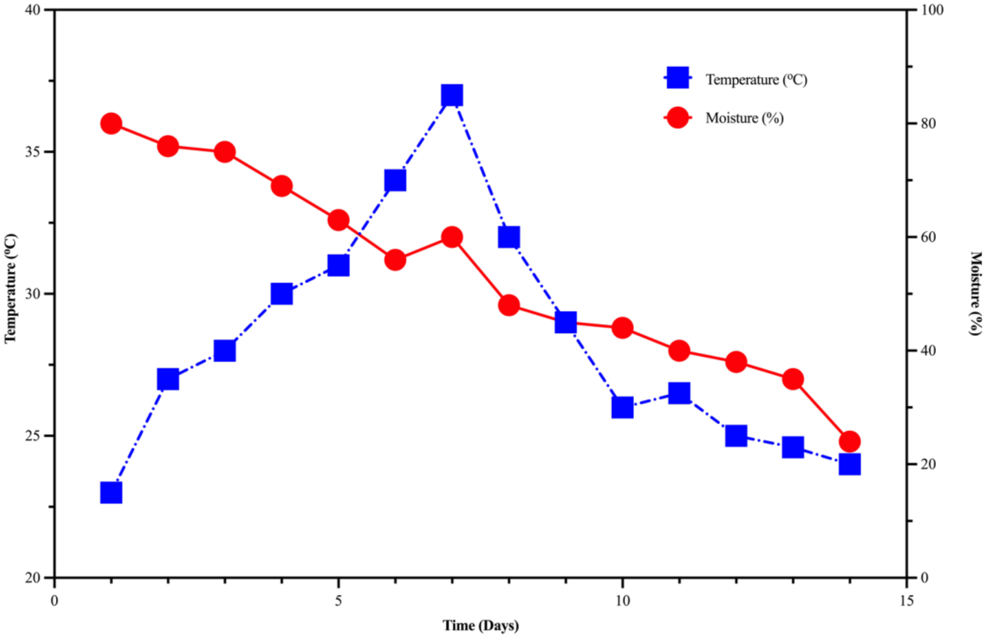

Figure 1 Temperature and moisture content variation during pre-composting

The increase in TP and TK is due to mass reduction since they are neither leached nor mineralized during vermicomposting (Komakech, 2014). The cutbacks in organic carbon and TN are attributed to leaching, degradation, and denitrification in the vermicomposting process (Dias et al., 2010; Domínguez et al., 2010). Most vermi-conversion studies have shown an increase of N, P, and K nutrients in the vermicompost (Jat and Ahlawat, 2004; Manyuchi et al., 2013; Stangel et al., 1993; Yadav et al., 2010). The increase in TP. is attributed to earthworm gut phosphatase and phosphorous solubilizing microorganisms in the worm casts, enhancing the release of more phosphorus. The increase in TK during vermifiltration is attributed to the mineralization of organically bound potassium. Since the vermicomposting technology increased TP and TK in the compost, higher concentrations imply more oxidation and degradation of the phosphorus and potassium-based forms. Despite pineapple waste being acidic and fibrous, the results indicate that it can be decomposed during vermicomposting.

Lalander et al. (2015) reported a significant increase ($p$<0.05) in the TN composition during the vermicomposting process. Ndegwa et al. (2000) reported no significant differences between TN concentrations in the initial feedstock and the resultant vermicompost. Yet, Parvaresh et al. (2004) observed no significant changes in nitrogen concentrations during the entire vermicomposting period. The observed differences in TN content during vermicomposting of various wastes could be due to the management of the units and the type of feedstock used. The management of the units and the physical-chemical composition of the feedstock play a key role in nitrogen variation as they affect processes like the mineralization of nitrogenous organic compounds and the amount of nitrogen derived from these compounds (Benito et al., 2009). From this study, the nutrient content of the pineapple waste vermicompost as a fertilizer was lower than that from animal manures found in previous studies, but this could have been partially due to pineapple waste being fairly a nutrient-poor organic feedstock used and some nutrient losses through leaching observed during pre-composting and mineralization during vermicomposting. The loss in nutrients agrees with Fornes et al. (2012), who reported significant leaching and mineralization in vermicomposting tomato crop waste. In Lalander et al. (2015), the vermicompost unit was housed in a cool shade and was regularly kept moist. But in this study, the unit was in a greenhouse which by its nature is relatively warmer. The higher temperatures could, therefore, have contributed to the loss of nitrogen through volatilization.

**Table 2 Physico-chemical properties of the pre-compost and the resultant vermicompost (n=5)**

| | Pre-compost | Vermicompost |
|---|---|---|
| **Physical Properties** | | |
| Bulk density (g cc$^{-1}$) | 2.20$^b$ | 4.23$^a$ |
| Moisture Content (%) | 50.52$^a$ | 50.00$^a$ |
| Ash (%) | 5.70$^b$ | 7.15$^a$ |
| VOC (%) | 23.36$^a$ | 20.60$^b$ |
| **Chemical Properties** | | |
| pH | 6.9$^b$ | 7.6$^a$ |
| EC (dS m$^{-1}$) | 2.8$^b$ | 3.2$^a$ |
| TOC (g kg$^{-1}$) | 334.5$^a$ | 62.2$^b$ |
| TN (g kg$^{-1}$) | 7.9$^a$ | 6.2$^b$ |
| TP (g kg$^{-1}$) | 4.3$^b$ | 5.2$^a$ |
| TK (g kg$^{-1}$) | 14.8$^b$ | 19.0$^a$ |
| C/N ratio | 42.34$^a$ | 10.0$^b$ |

Note: *Means with the same letters within rows imply no statistical significance ($p$>0.05) using Duncan multiple range test

### 3.3 Feeding rate and stocking density

The effect of stocking density on major nutrients (a) TN, (b) TK, and (c) TP concentrations of resultant pineapple vermicompost for various feeding rates are shown (Figure 2). A stocking density of 0.5 kg worms m$^{-2}$ yielded pineapple vermicompost with significantly higher TN. concentrations (7.9 ± 3.1 g kg$^{-1}$) compared to 1 kg worms m$^{-2}$ (5.6 ± 3.3 g kg$^{-1}$). A similar trend was observed in the TP concentration (6.3 ± 2.3 g kg$^{-1}$) and (4.8 ± 0.7 g kg$^{-1}$). However, the trend was different for TK concentrations, which were significantly higher in higher stocking densities (13.6 ± 3.2) and (17.2 ± 3.2 g kg$^{-1}$). Some TN, TP, and TK concentrations at various feeding rates were not significantly different for the different stocking densities, but the general trend exhibits significant differences. The lower TN in the concentrations in the vermicompost implies more ammonification-denitrification occurred and thus more mineralization (Domínguez et al., 2010). Lower TP and TK in the vermicompost imply more mineralization of the organic nutrient forms. Since feedstock with similar characteristics was used, the stocking densities with significantly lower concentrations of major nutrients represent more earthworm and microbial activity. The TN and TP concentrations were significantly lower ($p$ < 0.05) in the stocking density of 1 kg worms m$^{-2}$. However, lower TK concentrations were observed in the lower stocking density (0.5 kg worms m$^{-2}$). The lower TN and TP concentrations at higher stocking densities are attributed to higher earthworm activities in these systems. Thus, more microbial degradation of the organic material and, therefore, higher stocking densities positively affect the feedstock's degradation process. The lower TK concentration at lower stocking densities is attributed to the potassium accumulation in the vermibed.

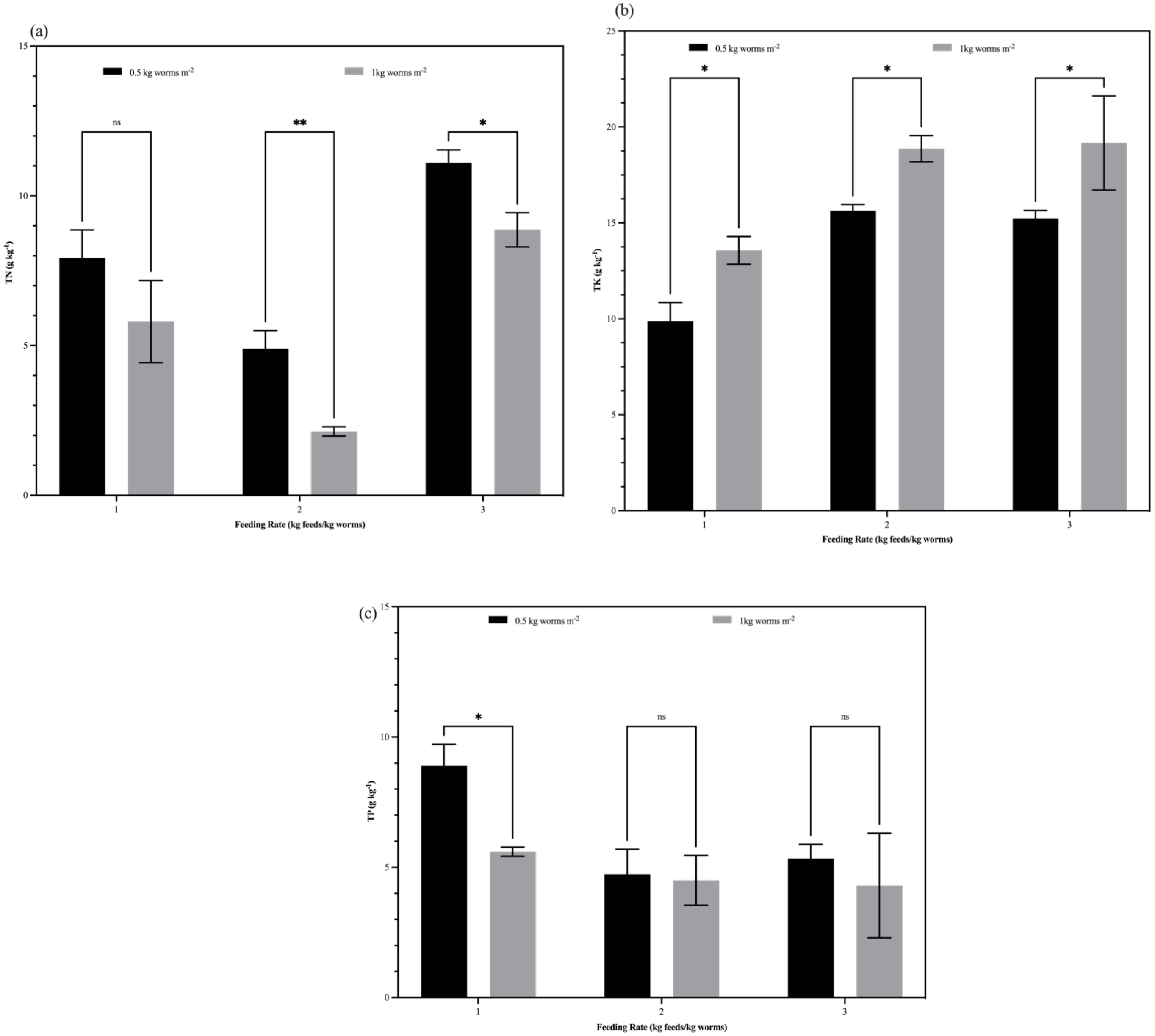

Figure 2 The significance of stocking density on (a) TN, (b) TK, and (c) TP concentrations of resultant pineapple vermicompost for various feeding rates.

Note: *, **, *** implies statistical significance (α = 0.05, 0.01, 0.001) respectively

The effect of stocking density on major nutrients (a) TN, (b) TK, and (c) TP concentrations of resultant pineapple vermicompost for various feeding rates are shown (Figure 3). Lower feeding rates yielded vermicompost with TN concentrations of 6.8 ± 1.5 g kg$^{-1}$, which was significantly higher than 3.5 ± 2.0 g kg$^{-1}$ but lower than 9.9 ± 1.6 g kg$^{-1}$ at the highest feeding rate of 3 kg feeds/kg worms. A similar trend was observed in TP concentrations with 7.3 ± 2.3, 4.6 ± 0.2, and 4.8 ± 0.7 g kg$^{-1}$ for 1, 2, and 3 kg feed/kg worms. TK concentrations for the three feeding rates were 11.7 ± 2.6, 17.3 ± 2.3, and 17.2 ± 2.8 g kg$^{-1}$. 2 kg feeds/kg worms performed best to reduce TN and TP concentrations, but 1 kg feeds/kg worms performed best regarding TK. Higher feeding rates led to higher TN concentrations, and this is attributed to increased organic loading of the vermifilters hence negatively affecting the microbial activity in the units. Lower feeding rates also performed poorly due to a lack of sufficient food for the microorganisms. We thus observed that lower feeding rates yielded higher nutrient stabilization rates in the vermicompost.

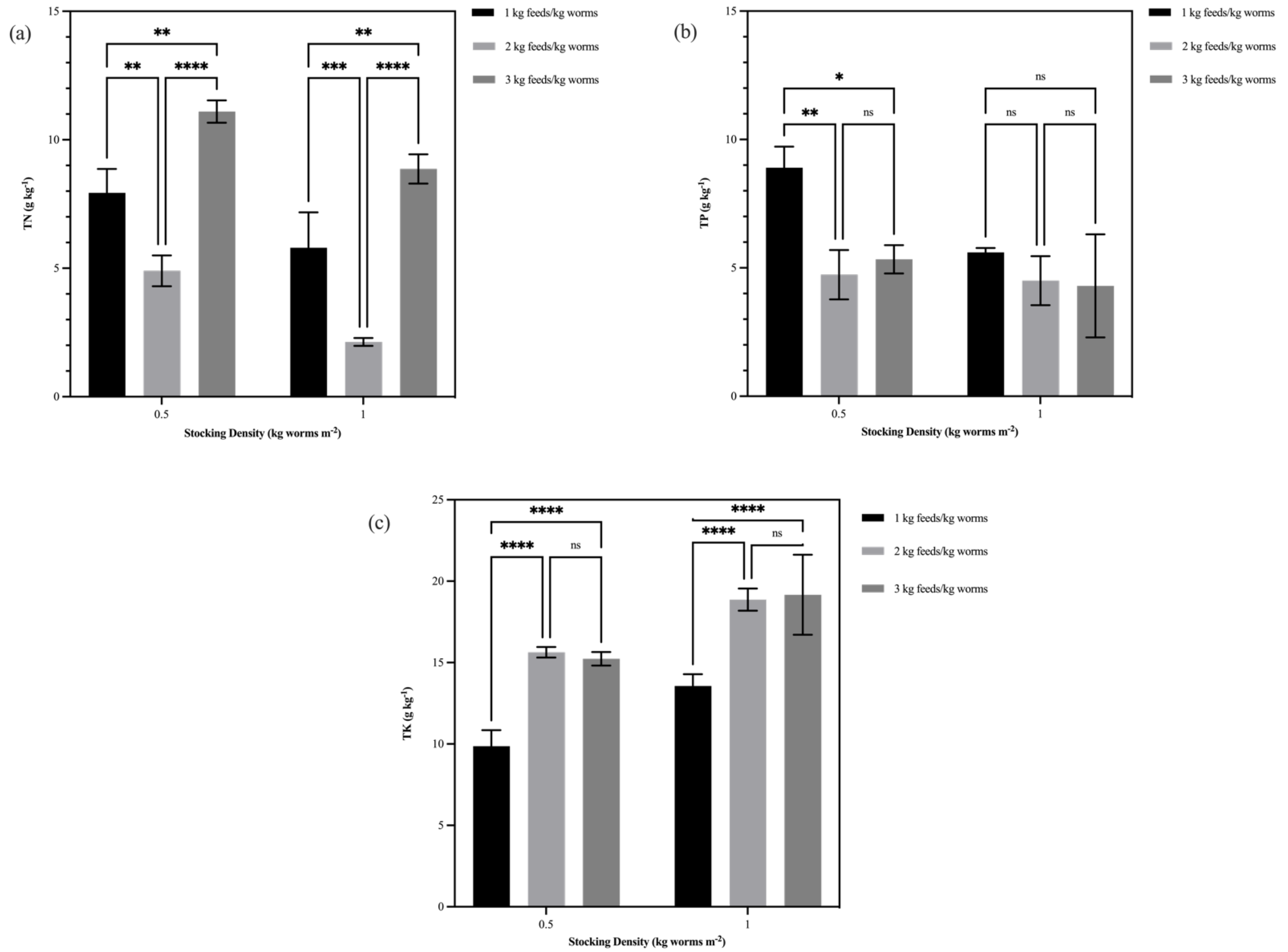

Figure 3 The significance of feeding rates on (a) TN, (b) TP, and (c) TK concentrations of resultant pineapple vermicompost for various stocking densities.

Note: *, **, *** implies statistical significance (α = 0.05, 0.01, 0.001) respectively

From the study, we observed that higher stocking densities of earthworms yielded more mineralization in vermicomposting than lower stocking densities. Higher feeding rates and very low feeding rates negatively affect the vermicomposting process as they directly influence the earthworm and microbial activities in the vermibed. Focusing on complete ammonification-nitrification of nitrogen-forms, total mineralization of phosphorus forms in pineapple waste, a feeding rate of 2 kg feeds/kg worms, and a stocking density of 1 kg worms m$^{-2}$ were found ideal for better degradation of the organic material and complete mineralization of the nutrients. The optimal stocking densities and feeding rates were 0.5 worms m$^{-2}$ and 1 kg feeds/kg worms regarding TK concentration. The suggested feeding rates in the current study are higher than those reported by Ndegwa et al. (2000), and earthworm stocking values are lower. Ndegwa et al. (2000) reported an optimal feeding rate of 0.75 kg-feed/kg-worm/day and a stocking density of 1.60 kg-worms m$^{-2}$ for the best cow manure vermicompost. The difference in values could be due to the difference in the feedstock used and the vermicomposting management practices.

To determine the effect of stocking density and feeding rate on the maturity of the vermicompost, we monitored the C/N ratio during the vermicomposting period (Figure 4). According to Zhao et al. (2012), and Zhu (2007), lower C/N ratios imply complete degradation of the organics in the vermicomposting system. From the results, higher stocking densities had a significantly more rapid reduction C/N ratio than lower stocking densities. It was also observed that by the end of the experiments, the units fed 2 kg feeds/kg worms had significantly lower C/N ratios implying a more decomposed/stable vermicompost. These results further explain how higher stocking densities and average feeding rates affect the microbial activity in the vermicomposting units, affecting the quality of vermicompost produced.

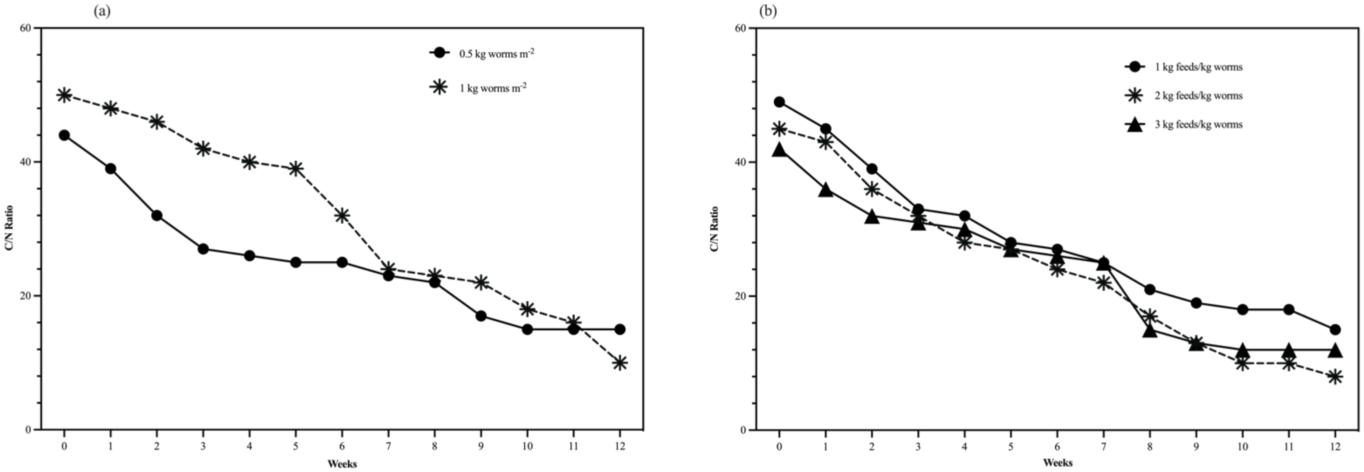

Figure 4 Effect of (a) Stocking density and (b) feeding rate on C/N ratio

## 4 Conclusion

The objective of the study was to ascertain the possibility of managing pineapple waste by vermicomposting. The vermicompost technology was proven to be an efficient means of pineapple waste handling. The key findings of this study were as follows: A Pre-composting period of 14 days was sufficient in waste stabilization and mass reduction of the waste. After pre-composting the pineapple waste, Vermicomposting was further able to stabilize and mineralize the major nutrients in the pineapple waste into nutrient-rich pineapple waste vermicompost. Even though TN content was reduced during the process, it was converted to a more mineralized form which is ideal for plant growth. TK and TP contents increased during the process. We also observed that the feedstock feeding rate and earthworm stocking density greatly influence the final concentrations and form of the vermicompost nutrients, as thus should be considered while adopting the technology. Focusing on nitrogen and phosphorus content, medium-range feeding rates, and higher stocking density values gave rise to better, more mineralized vermicompost. This possibility of deriving nutrient-rich vermicompost from the pineapple waste indicates that farmers can ably utilize their pineapple waste to generate a high-value soil amendment. There is a further need to blend the pineapple waste with other more nutrient-rich feedstocks to improve its nutrient concentration further.

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