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Effect of Initial Carbon to Nitrogen Ratio on the Degradation of Oil Palm Empty Fruit Bunch with Periodic Addition of Anaerobic Palm Oil Mill Effluent Sludge

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ABSTRACT

The objective of this study was to evaluate the effect of different initial carbon to nitrogen (C/N) ratios on the organic matter degradation during active co-composting of oil palm empty fruit bunch (OPEFB) and palm oil mill effluent (POME) anaerobic sludge. The initial C/N ratio was varied from 25:1, 35:1 and 45:1. Co-composting was conducted by periodic addition of sludge to maintain the moisture content and enrich the compost product. The organic matter (OM), carbon to nitrogen profile and compost maturity index were analysed. The results showed that the initial C/N ratio of 35:1 was the best initial C/N ratio. In addition, the C/N ratio of 35:1 gave the best OM degradation. The appropriate amount of initial C/N ratio coupled with the correct composting process parameters such as daily mixing, suitable pH

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and moisture content improved the organic matter degradation. It reduced the composting time from 40-60 days to 30 days.

Keywords: Anaerobic sludge, composting system, composting, oil palm empty fruit bunch, periodic addition

INTRODUCTION

Composting is a proven method to mitigate greenhouse gases emission by stabilising agricultural solid waste, landscape waste and food waste, which will otherwise be converted into methane and CO_2 (Kumar et al., 2010). Composting is a process of degradation of organic waste into a stable organic matter with the dynamic interactions among the physical, chemical and biological factors (Białobrzewski et al., 2015; Onursal & Ekinci, 2016). Thermophilic conditions generated during the process is a reflection of the biological heat of microbial growth and activity. Most agricultural solid wastes such as the OPEFB are not suitable for composting on their own due to the high lignocellulosic content and low nitrogen content. However, the degradability of the highly lignocellulosic feedstocks can be enhanced by co-composting with nitrogen-rich waste (Singh et al., 2010).

C/N is considered one of the essential parameters that can influence the process conditions in terms of nutrients for microbes, composting time and the final characteristics of the compost as a product (Cundiff & Mankin, 2003). OPEFB has been co-composted with several types of waste materials with comparatively high nitrogen content and low carbon, such as poultry litter, goat dung, cow dung and palm oil mill effluent (POME) (Alkarimiah & Rahman, 2014; Zainudin et al., 2013). The range of the initial C/N ratio from 64:1 until 22:1 have been studied, and the time for composting to achieve maturation was between 40-60 days. Composting period has been reduced by controlling other parameters, especially moisture content. This moisture addition can be achieved by adding anaerobic sludge POME regularly (Baharuddin et al., 2009). The work of Baharuddin et al. (2009) was significant as information on composting period can be deduced from moisture content and C/N. According to the findings of Zainudin et al. (2013), the addition of sludge POME contains indigenous microbes and nutrients. Since about June 2016, there are an estimated 75 composting plants, 2 of which use 90-100% POME and the rest only partially in Malaysia (Loh et al., 2017). Thus, lower C/N would eventually takes less time. This means less space is needed, less fuel is consumed, and labour costs are reduced. It would be more beneficial if the optimum C/N ratio for effective co-composting OPEFB can be determined.

This research aimed to investigate the initial effect of the C/N ratio using two different forms of waste with the periodic addition of POME sludge. Co-composting was performed in this work using OPEFB and POME anaerobic sludge as primary and co-substrate, respectively. Specific initial C/N ratios were selected, and sludge was applied periodically until almost the end of the composting period. The profiles such as C/N ratio, the total mass of composting material, moisture content, oxygen concentration and temperature were analysed throughout the co-composting period.

MATERIALS AND METHODS

Raw Materials

Pressed and shredded OPEFB with a size range from 15 cm to 20 cm was obtained from Jugra Palm Oil Mill Sdn. Bhd. (Selangor, Malaysia), while POME anaerobic sludge was obtained from FELDA Besout (Perak, Malaysia).

Composting Set-Up

Figure 1 presents the compost reactor system used in this study. The system is comprised of an insulated 120 litres reactor capacity with a diameter and height of about 46 cm and 75 cm, respectively. The system is equipped with a 1.5 horsepower electrical motor, airflow meter, compressor pump for aeration and sludge pumps for sludge intake and leachate recycling. Airflow for aeration was controlled at 0.27 m^3/h, which flowed through an air humidifier before aeration in the reactor. The temperature sensor and carbon dioxide sensor were purchased from STAN BURRAGE (UK) (Model CP11) and CO_2meter.com (USA) (Model K33/CM-0040), respectively.

Co-composing Procedure

The experiment was carried out using three different ratios of OPEFB to POME anaerobic sludge. The ratios were set to 1:4, 1:1 and 4:1, having an initial C/N ratio of about 25:1, 35:1, and 45:1, respectively. Experiments were performed in triplicate for each ratio. The mixture was loaded manually into the composter. POME anaerobic sludge was gradually pumped until it reached the required amount. The sludge was added about 10% of the total initial weight every 3 days for 8 days until a week before the 30th day of composting. The total amount of OPEFB and POME anaerobic sludge used was 50 kg as initial weight. Aeration was supplied every 3 days for 3 hours per day. The leachate was pumped to circulate the material (mainly water). It will help achieve homogeneity and maintain the moisture content of the composting material. The moisture content was maintained between 70-80%. Agitation was done for one hour per day. Aeration was subjected throughout the composting process to ensure the carbon dioxide was not more than 5% (Nakasaki et al., 1990). The pH was determined using a pH meter (Hanna Instruments, USA). One gram of composting sample was taken and mixed with 10 ml distilled water using a 25 ml falcon tube.

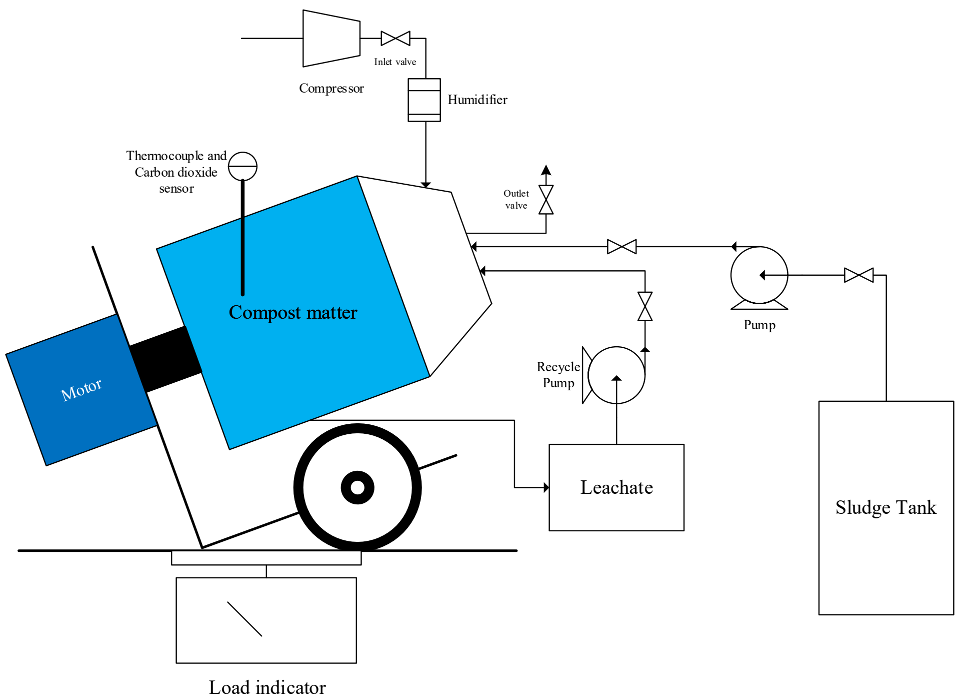


Figure 1. Schematic diagram of composting system

Analysis

Sludge acts as a medium to maintain the moisture content instead of using water. Each sample was dried at 105°C for 24 hours for moisture content analysis. The muffle furnace (KSL-1700X, MTI Corporation, USA) was used to measure the OM of compost material based on ignition loss at 550°C for 4 hours. The percentage of OM and total organic carbon (TOC) was determined using Equations 1 and 2:

$$\mathrm{OM_{loss}}(\%) = 100 \cdot \frac{\mathrm{DM_0} \cdot \mathrm{OM_0} - \mathrm{DM}_T \cdot \mathrm{OM}_T}{\mathrm{DM_0} \cdot \mathrm{OM_0}} \tag{1}$$

$$\mathrm{TOC} = \frac{m_{\mathrm{OM}} \times 100}{1.8} \tag{2}$$

For total nitrogen analysis of the sample, Total Kjeldahl Nitrogen (TKN) was carried out according to Kjeltec 2300 Analyser (FOSS Analytical AB, Sweden) manufacturer's manual. Cellulose and lignin content were determined using Fibertec 2010 and the Acid

Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) methods, respectively (FOSS Analytical AB, Sweden). Moreover, since ADF contains both cellulose and lignin, whereas ADL contains only lignin, cellulose content was calculated by subtracting the value of ADF from the value of ADL. Mass of degradable organic matter (OM) with three different components, such as easily degradable OM content, slower (''moderate'') degradable OM, which is a cellulosic constituent and hardly degradable, which is lignin content within the co-composting material as defined by Talib et al. (2014).

Compost maturity was determined using the Solvita® compost maturity kit (Wood End® Research Laboratory Inc., Mt Vernon, Maine) at 25°C. The kit was used to measure carbon dioxide and ammonia emission using gel paddles. The compost maturity measurements were conducted in Solvita® jars, where the samples must be filled until the fill line. In addition, they must be in moist condition by following the manufacturer's instruction (Guide to Solvita® testing for compost maturity index). Solvita® carbon dioxide and ammonia test paddles were carefully inserted into the jar without touching the gels part. The lid of the jar was closed tightly. The test paddles were allowed to remain at 25°C in the closed jar for 4 hours to allow any emissions to occur. The data was collected for detecting colour changes on the gel using a Solvita® digital colour reader. The reader detected colour changes for the Solvita® maturity index and emissions value for carbon dioxide and ammonia. The maturity index was measured over a scale of 1 to 8 for the carbon dioxide test result and 1 to 5 for the ammonia test result. The combined rating of the two scales result was assessed to determine the Solvita® maturity index (1-fresh, raw compost; 8-very stable compost).

Statistical Analysis

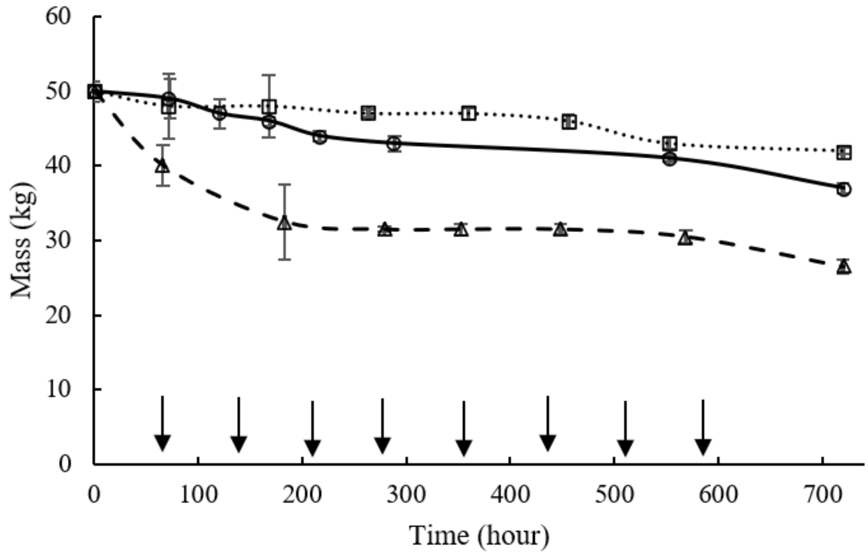
Statistical Analysis System Version 9.2 was used to analyse data collected for means and standard deviations using Analysis of Variance (ANOVA) at p0.05 for the treatment effect and post-hoc analysis by Duncan new multiple range test (DNMRT) for mean comparison.

RESULTS AND DISCUSSION

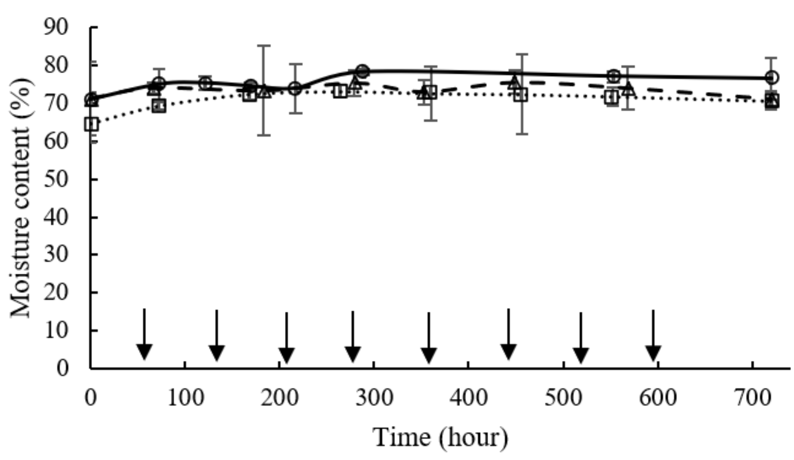
Compost Physico-chemical Evolution

The results for total mass curves at different initial C/N ratios during composting are presented in Figure 2a. The downward-facing arrows in the graph indicate the periodical additions of sludge during the process. The mass for the feedstock material with a 35:1 C/N ratio decreased at a much higher rate, followed by feedstock with the highest nitrogen content (25:1 C/N ratio) and lowest nitrogen content (45:1 C/N ratio). It can be seen that the decrease in mass was not necessary due to leachate runoff and evaporation, which causes the loss of moisture content as opposed to Figure 2b, where the level of moisture was almost maintained throughout the process. This is thought to be due to consumption of easily and moderately degradable and remaining of hardly degradable fraction in organic matter as confirm this results obtained agreed with previous work carried out by Talib et al. (2014). As shown in Figures 4a and b, the C/N ratio of 35:1 has higher moderate OM than the C/N ratio of 25:1. However, recalcitrant carbon such as hard degradable OM mass in both C/N ratios was about the same. Hence, this explains why the ratio C/N of 35:1 decreased further due to biodegradable C/N ratio needing to be considered and not as total, assuming both nutrient sources are fully degradable as mentioned by Puyuelo et al*.* (2011).

a



b



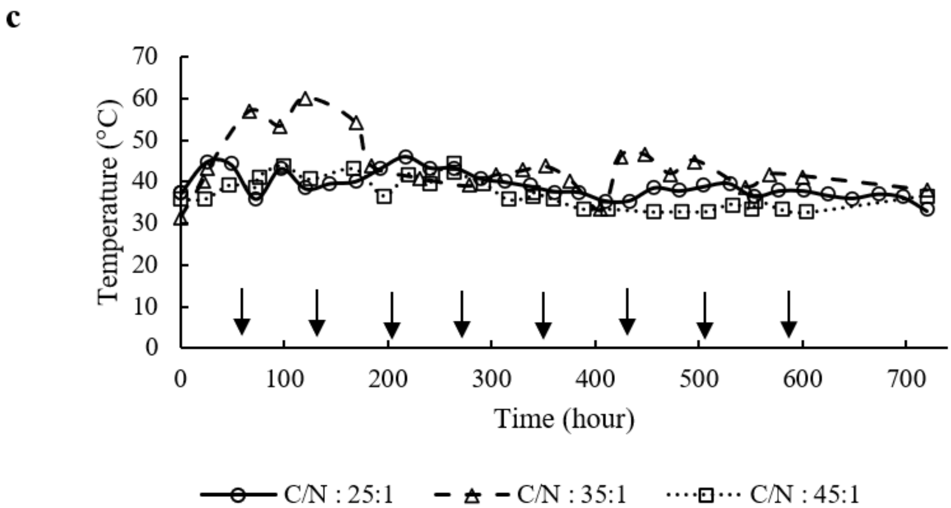


Figure 2. Profiles of mass, temperature and moisture content during the co-composting process. Arrows indicate periodical sludge addition

A moisture content plot of the periodical addition sludge into the compost reactor is shown in Figure 2b. After 150 hours or twice the addition of sludge, the moisture level was maintained in the range of 70 to 80%. The C/N ratio of 45:1 moisture content is the lowest compared to the other due to more OPEFB composition than sludge; the initial low moisture content was 65%. The other following C/N ratio has an initial adequate moisture content level of about 71%. The result suggests that the moisture content were relatively stable, probably due to the design of the compost reactor have fully insulated. Piping of inlet supplied gases was small within around 15 mm, and air supplied was only every 3 days interval which prevents moisture loss from evaporation. The inclined reactor position and the addition of sludge also contribute to water retention in the compost reactor. Another potential moisture loss is condensate, which was mainly produced during the thermophilic stage. It may drain as the leachate was less regulated due to experiment activity—only 3 days for 8 times, contributing to less water loss.

The variation of temperature profiles with three different initial C/N ratios of composting is shown in Figure 2c. C/N ratio of 35:1 achieved a high temperature of about 60°C before 100 hours of composting. The range of temperature within the thermophilic phase was above 40°C until 550 hours. Maximum temperatures of the C/N ratio for both 25:1 and 45:1 were found between 46°C and 44°C, which is lower than the 35:1 C/N ratio. As shown, the temperature keeps fluctuating between mesophilic and thermophilic phases until 720 hours. In general, the temperature profiles did not show a typical temperature pattern of co-composting. It represents the fluctuating temperature resulting from the periodic addition of sludge every 3 days, and mechanical turning effects may contribute to heat loss. It is in agreement with the results reported by other researchers (Zervakis et al., 2013). The heating of compost is also related to the energy content of the substrate and degradability (Ryckeboer et al., 2003).

Hence, the composting rate also depends on the C/N ratio, where carbon is the source of energy and the main component of cell structure, and nitrogen is the second most significant element for cell growth and synthesis. The lower temperature may be due to less abundant nitrogen, which is associated with low microbial growth or quantity and less degradable of carbon such as the high composition of recalcitrant lignocellulose, which could contribute to a time delay to maturity (Zhou, 2017). All experiments were periodically added with sludge which assists in nutrient needs. However, the initial C/N ratio may also influence the time of process degradation. The obtained results support the use of control initial C/N ratio as a part of composting acceleration which agreed with those carried out by Zainudin et al. (2014) and Razali et al. (2012).

Figure 3a shows the carbon dioxide level during co-composting. The carbon dioxide level for 25:1 and 45:1 C/N ratios was higher than 5%, especially during the initial composting period (i.e. within 200 hours). After 300 hours, the carbon dioxide level drops below 4% until the end of composting. In the beginning period, the level of carbon dioxide increased, primarily in the thermophilic stage where the biodegradation process occurs. It indicates that the supply of oxygen from aeration and agitation for the composting system is appropriate. Lower aeration rates may negatively affect the OM degradation process. The resulting delayed thermophilic phase due to the rate of biological oxygen demand is higher than the rate of oxygen supply (Talib et al., 2014). Later period, carbon dioxide decreases due to less active aerobic oxygen-consuming microorganisms than the start of the process and an adequate supply of air which is expected to be below 5% of the carbon dioxide level as suggested by Nakasaki et al. (1990). Zainudin et al. (2017) also demonstrate that oxygen levels decrease during the thermophilic stage, and bacterial communities shift during different temperature phases. Because of the consistent interval supplies of aeration throughout the experiment, adding the sludge may not affect the oxygen levels.

The pH measurement was plotted in Figure 3b to represent the composting acidity or alkalinity. The range of pH throughout the composting period is about 8.11 to 8.99. All C/N ratio has slightly higher than neutral pH. The increase in pH measurement is associated with ammonia content due to biochemical reactions of nitrogen-containing materials producing ammonium hydroxide from ammonia-releasing proteolysis due to protein degradation, as explained by Razali et al. (2012). Increased pH also results in a lower C/N ratio than its higher ratio due to rapid metabolic degradation of organic matter and increased ammonium content due to nitrogen degradation (Gao et al., 2010; Tumuhairwe et al., 2009). The amount of nitrogen in composting continues to increase may be due to a concentration

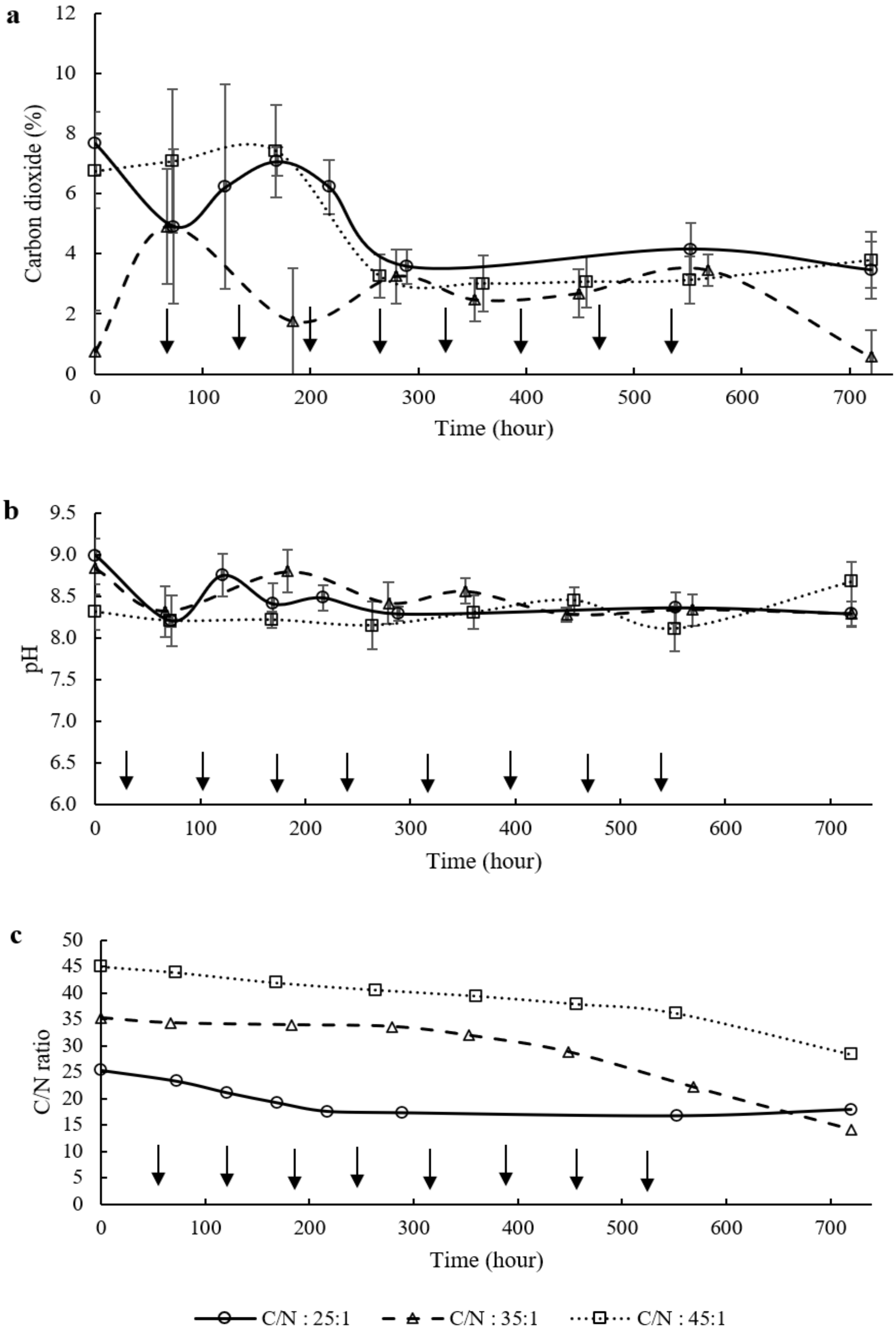


Figure 3. Changes in carbon dioxide, pH and C/N ratio during co-composting process. Error bar denotes standard deviation

effect where carbon has a higher loss rate compared to nitrogen and causes an increase in the pH reading and the resulting decrease in the C / N ratio (Lin, 2008).

Figure 3c shows a C/N ratios profile during the co-composting. The initial C/N ratio of 35:1 has decreased lower value compared to other ratios. The initial C/N ratio of 45:1 has the slightest decrease compared to the others. The reduction of the C/N ratio indicates the decomposition of organic matter by microbial activity (Bernal et al., 2009). It indicates the initial C/N ratio plays a vital role in substrate ratio because carbon source and nitrogen source will provide a sufficient amount for mainly metabolism and growth of microorganisms, respectively. The results show that the periodic addition of sludge during the process did significantly impact the profiles. Due to anaerobic sludge, POME consists of main water consisting of 4% to 5 % solid content with of C/N ratio between 4:1 to 17:1. The finished product, compost, will reach a C/N ratio of below 20 is considered acceptable maturity and below 15 is preferable (Hock et al., 2009; Satisha & Devarajan, 2007). This indicator has been confirmed by Kumar et al. (2010), where C/N of 19 can still degrade more than 30% of organic matter if compost moisture is maintained at a minimum of 60%. Decreased C/N ratio of 35:1 is slightly higher than 25:1, which is 14:1 than 18:1. The value of degradation is significant with different letters between initial and final from the statistic analysis. The sludge composition is too high to limit aeration. The evidence of a carbon dioxide content for C/N of 25:1 and 45:1 higher than 35:1 can be explained in Figure 3a. Other possibilities are the composition of hardly degradable in the C/N ratio of 25:1 relatively higher than 35:1 as an exhibit in Figure 4. The maximum temperature for the initial C/N ratio of 25:1 and 45:1 is low. It may represent low biological activity towards organic matter depletion. As shown in Table 1, indications of an improved initial 35:1 degradation C/N ratio were obtained from the compost maturity index by using the Solvita maturity package. The values display the index of 6, which is the composting stage in the curing stage and is supported by the maximum loss of OM (74.15 %). These results also show that it is unnecessary to provide excessive sludge or OPEFB during initial composting as a partial quantity of both wastes can improve composting. Composting time was also reduced to 30 days.

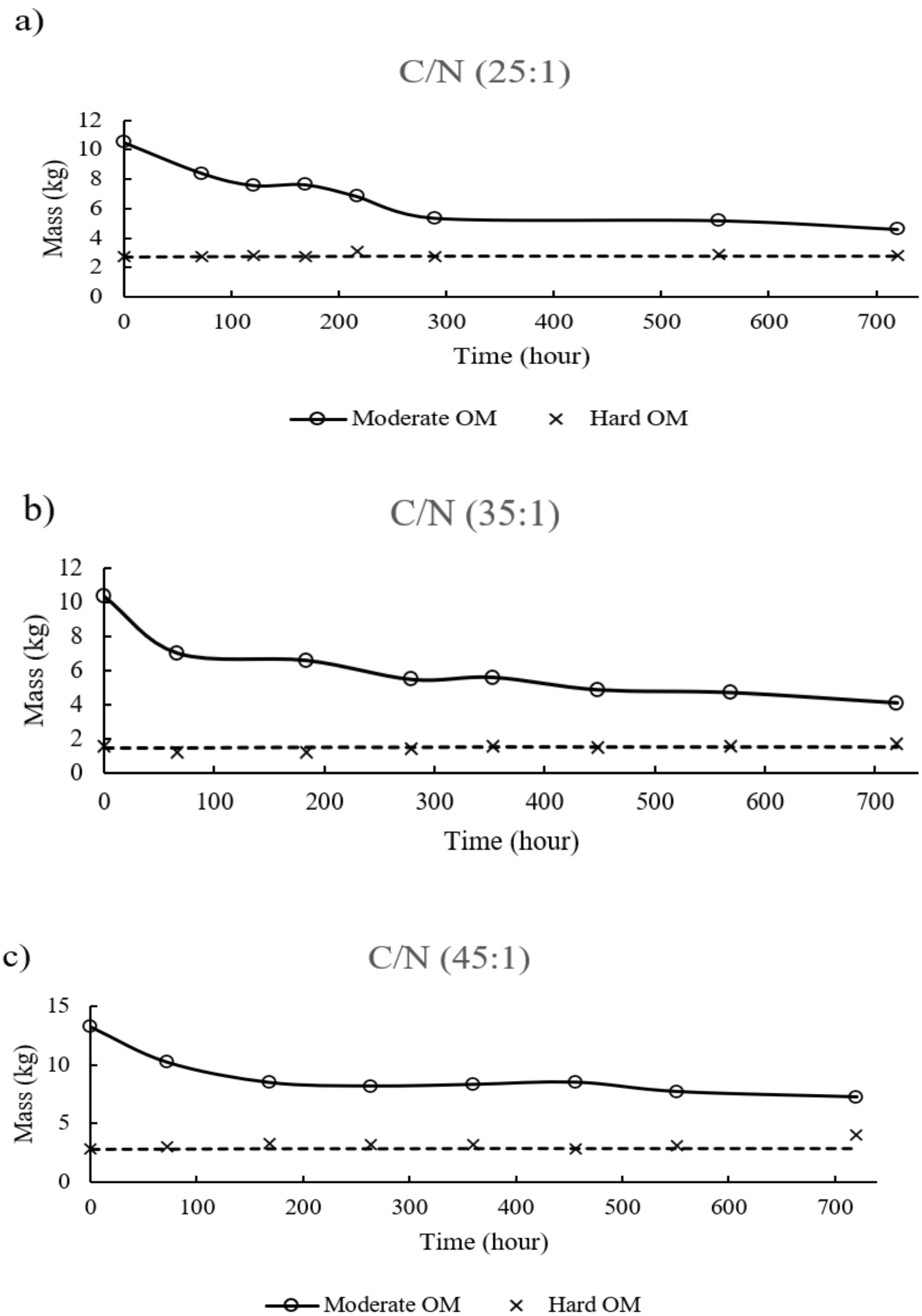


Figure 4. Organic Matter composition degradation

Table1

Data for TOC, TKN, C/N ratio, OM loss, and Compost maturity index

Experiment	TOC (g/kg)		TKN (g/kg)		C/N ratio		OM loss (%)	Compost maturity index (interpretation)
	Initial	Final	Initial	Final	Initial	Final		
C/N(25:1)	516.70	475.90	20.33 ± 0.11[b]	26.49 ± 0.49[b]	25.41 ± 2.78[a]	17.95 ± 4.84[a]	63.25 ± 3.00[b]	Very Active
C/N(35:1)	514.40	424.29	14.59 ± 0.24[a]	30.00 ± 0.65[a]	35.26 ± 1.22[a]	14.13 ± 2.78[d*]	74.15 ± 3.13[a*]	Curing
C/N(45:1)	516.70	483.50	11.50 ± 0.08[a]	17.00 ± 0.22[b]	44.98 ± 11.17[a]	28.41 ± 6.56[a]	49.63 ± 3.22[c]	Very active

Expression of results as means ± standard deviation

[*]Letters denotes significant differences across columns ($p<0.05$).

CONCLUSION

In this work, the initial C/N ratio was set up into three different levels. The experiment was designed using periodic addition of sludge to assess the effect of degradation organic matter composition and composting process parameters. This investigation showed that the initial C/N ratio of 35:1 obtained the best results in terms of degradation (reduce to 14:1) and achieved compost maturity into the curing stage. However, the appropriate amount of initial C/N ratio with control of the composting process parameter can contribute significantly to the C/N ratio profile. Furthermore, it is supported by the degradation of OM effectively compared to the high initial ratio. Thus, the 35:1 initial C/N ratio and below have a more significant impact on the degradation C/N ratio than higher ones. Since this work is only limited to its type and size of operation, therefore, for further works, variables and parameters of different types of composting operation are suggested to validate its operability on an industrial scale.

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