A Study on Dry Leaf Composting in Reused Small-Size Bottle

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***Abstract*—Daily falling tree leaves generate a large number of dry leaves that requires a proper management. Among traditional waste disposal methods, composting is considered more sustainable and eco-friendly for handling the leaf waste. The final product of the process is an organic fertilizer (compost) which is very useful to apply for soil amendment. However, the composting of dry leaves has difficulties because a degradation of the material is a time-consuming process. This paper proposed a way to increase the rate of dry leaf degradation in a composting process. A survey of literature to investigate major factors affecting composting process and experiments on dry leaf composting in a small-size reactor made of discarded water bottles were conducted. Operational conditions in the experiments were based on the most recommended values including the C/N ratio of 25, the moisture of 60%, and the particle size of 3.35-20 mm. From experimental results, the co-composting of dry leaves and vegetable waste under the above conditions resulted in 31.2% reduction of organic matter within three weeks. The final product of the co-composting contained a C/N ratio of 14.3 indicating the maturity of the obtained compost. It was found that the initial ratio of C/N in composting material played a key role among other factors. This was evidently indicated by comparing degradation rates in terms of organic matter reduction between the composting of dry leaves with the C/N ratio adjustment and that without the C/N adjustment. The reduction of organic matter in the first case was nearly twofold that of the second one within the same period.**

***Index Terms*—compost, dry leaves, C/N ratio, reused bottle, organic waste, waste management**

I. Introduction

Dry leaves have fallen from trees every day causing a large amount of leaf waste. Traditional methods for leaf waste disposal are burning and landfilling. Both methods have several drawbacks. By burning, several toxic compounds occur, causing air pollution problems [1]. By landfilling, a large amount of leaf waste increases transportation cost and requires more landfill space. Naturally, dry leaves can be degraded by microorganisms into an organic fertilizer, called compost, which can be used safely for soil amendment [2]. The process of transforming organic wastes into compost is referred to as composting. This process has several benefits such as the reduction of disposal costs, the alleviation of pollutant emission and the recycling of organic wastes [3]-[5]. Thus, in terms of environmental sustainability, the composting is considered attractive for handling the dry leaf waste.

Although the degradation of leaf litter can occur naturally, its degradation rate is very slow. In this study, the proper operating conditions to get a higher rate of the degradation were investigated by surveying literature and conducting experiments. A focus of this study was to seek for a simple and cheap way to compost dry leaves. Thus, a reactor made of discarded water bottles was designed and used in the experiments. Reusing the bottles can reduce the amount of plastic waste and decrease the investment costs. This could promote the composting at home. Details of important factors affecting composting process and the experiments of dry leaf composting are described as follows.

II. Factors Affecting Composting Process

According to a literature survey, the decomposition rate is controlled by factors which affect microbial activities. These factors include C/N ratio, moisture, particle size, temperature, and oxygen. Lack of necessary substrates, low moisture content, non-optimum temperatures, and poor oxygen diffusion can limit the rate of waste decomposition. In contrast, an operation under appropriate conditions can provide rapid and effective composting process. The optimum values of these factors which were recommended in literature are sometimes different. However, most of them are quite similar. This paper summarized the conditions mostly recommended for composting as follows [6]-[14].

A. C/N Ratio

C/N ratio is a ratio of the mass of carbon to the mass of nitrogen in a substance. Microbes use carbon for their energy and nitrogen for protein synthesis. The carbon and nitrogen values vary in each material. Naturally, dry and brown wastes such as dry leaves, straw, and wood chips have high carbon while wet and green materials such as vegetable and food scraps contain high nitrogen. The microbes need 20 to 25 times more carbon than nitrogen to remain active. Thus, the C/N of composting materials at the beginning is recommended to be in a range of 25-30. In the composting of waste having too low C/N ratio, the carbon will be used up while most of the nitrogen is not stabilized. In this case, a smelly odor of ammonia

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might occur due to excess nitrogen emitting as ammonia gas. This can cause odor problem from the composting pile. In contrast to the low-C/N case, a high C/N ratio in a substance indicates the limit of nitrogen. As a result, the degradation of the organic waste may be incomplete or proceeds at a slow rate. In the latter case, a nitrogen-rich substance has to be added to decrease the C/N value.

To prepare a compost mixture having the proper C/N, two or more types of organic wastes should be blended together. The C/N ratios of some organic wastes that contain low C/N value are listed in Table I. A proper combination of each waste to attain a required C/N can be approximated by the weighted mean based on these ratios.

TABLE I. EXAMPLES OF LOW C/N RATIO ORGANIC WASTES

Organic wastes	C/N ratio
Chicken manure	7
Fresh grass clippings	17-20
Food scraps	20
Vegetable scraps	25
Coffee grounds	20-25

B. *Moisture*

Moisture content is the measure of the quantity of water in the material, expressed as a percentage of total weight. Water is essential for microorganisms. It is used to transport nutrients and to allow the microbes to move in the material. Moisture contents between 50% and 60% are most desirable. The moisture below 40% limits the availability of nutrients and inhibits microbial activity. If the moisture drops to below 15%, their activities will cease entirely. On the other hand at the moisture above 60%, excess water will displace air in the pore and block air flow. This condition leads to anaerobic decomposition that creates a foul odor in the compost pile. A composting mixture with too high moisture content can also result in loss of nutrients to the leachate. The moisture content generally decreases as the organic matter is decomposed. Thus, the initial moisture above 50% is strongly recommended. In order to supplement moisture to the entire material, the water should be added during turning or mixing the material.

C. *Particle Size*

Particle size is a physical property as important as the moisture. The microbial activities in a compost pile occur on the surface of particles. Smaller particles have greater surface area per unit volume than larger ones. Thus, decreasing particle size can increase the degradation per unit volume of the waste which increases the overall rate of the decomposition. However, small particles result in decreased pore size in the composting material and cause greater compaction of the pile which hinders aeration. An ideal particle size is impractical to specify because it depends on the type of waste and aeration system. For a rapid composting, a mix of coarse and fine particles in the range of 3-50 mm in size is recommended.

D. *Temperature*

As the microorganisms decompose organic matter, they give off heat which increases the temperature of the pile. There are three phases of the temperature change during composting. The initial phase is carried out by mesophilic microbes, which actively decompose readily degradable substances. In this phase, the temperatures rise, ranging between 20°C and 40°C. As the temperature rises to above 40°C, the mesophilic microorganisms are replaced by thermophilic type and then the composting process proceeds in thermophilic phase in which the degradation rate rapidly increases. The temperatures in the second phase are in a range of 40-65°C. In the final phase of composting, most of the organic matter is degraded and the energy source for the microbes becomes exhausted. As a result, the temperature decreases and the mesophilic microbes once again take over. The final phase is known as curing or maturation phase. It should be noted that at a temperature of 55°C and above, many microbes that are pathogens are destroyed. However, the temperature must not exceed 65°C because most of the microbes will die and the decomposition will be slower or stops.

E. *Oxygen*

Composting is basically an aerobic process in which oxygen is necessary. Rapid decomposition only occurs in the presence of sufficient oxygen. In the absence of the oxygen, anaerobic conditions occur, leading to a foul smell and a slow decomposition rate. To avoid such conditions, the oxygen concentration in the compost pile should be more than 10%. Adding oxygen into the composting material might be forced aeration or natural aeration. Mixing or turning the compost material or inserting one or more perforated tubes into the center of the pile can enhance aeration. It should be noted that excessive air flow can reduce the decomposition rate by cooling the composting material and remove a lot of moisture, resulting in negative effects to the composting process.

III. DRY LEAF COMPOSTING EXPERIMENTS

A. *Composting Materials*

Dry leaf waste used in composting experiments was fallen leaves of mango tree (scientific name: *Mangifera indica*). This tree is widely planted in Thailand and many tropical countries. It is a large fruit tree which can grow easily and is popularly planted in gardens of many houses and in many orchards for their edible fruit. A mango tree is plenty of leaves and consequently causes a large amount of yard waste from its fallen dry leaves.

From results of laboratory analysis (see Table II), dry leaves of the mango tree contain carbon and nitrogen with average values of 47.41 and 0.94, respectively, providing an estimated C/N ratio of 50.44 (dry weight basis). To decrease the ratio to 25-30 (optimum values), the dry leaves must be blended with nitrogen-rich materials. In this study, leaf scraps of Chinese kale, also called Kailaan (scientific name: *Brassica oleracea*) were used. Chinese kale is a leafy vegetable with dark green in color. It is a popular vegetable for cooking food in Thailand. Its leaf scraps are commonly found in markets and kitchens. Leaves of Chinese kale have the C/N around 21 by dry weight.

Before being mixed together, the dry leaves and fresh vegetable leaves were chopped to reduce their size and screened by using standard sieves to obtain the size of 3.35-4.75 mm and 10-20 mm, respectively. The purpose of reducing the particle size of these wastes is to increase surface area per unit volume of the materials which can increase the overall rate of decomposition. These ranges were chosen based on the recommended particle size of materials for composting.

Based on the characteristics of the raw wastes (Table II), the chopped dry leaves with particle sizes of 3.35-4.75 mm and the chopped vegetable leaves with particle sizes of 10-20 mm were mixed together in a proportion of 1:3 (dry weight basis). The approximate C/N ratio based on the weighted mean was 28.8. The moisture of the mixture was adjusted to around 60% by spraying water to the mixture. A mature compost from tree leaf composting was also added to the mixture (5% by weight) to supply microorganisms to the mixture. The well-mixed mixture was analyzed for its moisture content and C/N ratio again.

TABLE II. CHARACTERISTICS OF RAW WASTES

Raw wastes	C (%)	N (%)	C/N	Moisture (%)
Dry leaves	47.41	0.94	50.44	9.08
Vegetable leaves	41.57	1.82	21.65	72.16
Mature compost	10.52	1.85	8.39	20.65

B. Experimental Set-up

The composting reactor as shown in Fig. 1 was made of two 500-L discarded plastic bottles (6-cm diameter and 15-cm height). The first bottle was cut the top off just above the shoulder and the second one was cut off just below the shoulder. A larger piece of the first bottle was used as a container of the prepared composting mixture and a smaller piece of the second bottle was used as a lid. To avoid the compaction of the mixture in the reactor which might hinder aeration into the mixture, on all sides, at the lid, and at the bottom of the reactor were drilled to make many small holes. The holes on sides and at the lid of the reactor were used for aeration and ventilation while the holes at the bottom were used to drain leachate out of the reactor. These holes were also used for pricking a thin stick to the mixture to prevent compaction. A vertical perforated tube was inserted into the middle of the mixture to supply air into the inner part. A perforated plastic plate was placed at the 2.5 cm from the bottom of the reactor to support the mixture and to drain leachate during composting.

The reactor was filled with the prepared mixture, closed with the lid and kept indoors. The temperature of the compost layer was measured daily. Batch composting was carried out until the temperature dropped to ambient temperature, then the experiment was terminated. This experiment was conducted in triplicate and the analytical results of each parameter were averaged. Three sets of the control experiment (dry leaf composting without the C/N adjustment) were concurrently carried out. The controlled mixture was prepared by mixing the chopped dry leaves (3.35-4.75 mm in size) with 5 % of mature compost (dry weight basis).

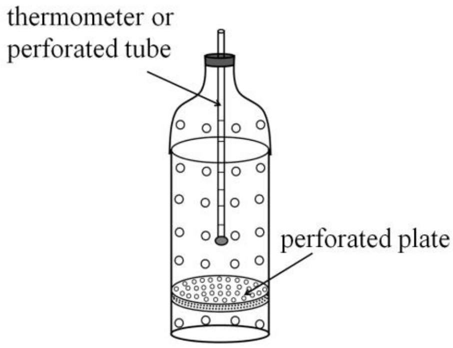

Figure 1. Composting reactor

C. Physical and Chemical Analysis

Solid samples were randomly taken at the beginning and the end of the composting period and were analyzed for the following parameters. The moisture content was determined by drying fresh samples in an oven at 103 ℃ for 24 hours. The organic matter was determined by heating oven-dried samples in a muffle furnace at 550 ℃ for 4 hours. The total organic carbon was calculated by dividing the organic matter by 1.83. The total nitrogen was determined by Kjeldahl method [15]. To monitor the microbial activities in the reactor, the temperature was measured daily at the middle of the compost layer using a glass thermometer.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

In this study, the decomposition of the composting mixture was evaluated from a temperature change of the mixture and the quality of the end product was evaluated from the remaining organic matter and the C/N ratio. The increase in compost pile temperature is a sign that the organic decomposition works well. Fig. 2 showed the temperatures of the composting mixture and the ambient air throughout the composting period. It was found that the temperature of the mixture rose to the highest level at 45.1°C on day 3, indicating the decomposition of the materials with a rapid rate. At this temperature, the composting process proceeded in the thermophilic phase. The temperature of the mixture remained around 45°C for two days. Then it dropped to 41°C on day 5 and varied between 38.3°C and 40.3°C until day 15. After that time the temperature dropped again until it was near the temperature of ambient air which varied between 31.4°C and 34.8°C. The experiment was conducted until the temperature dropped to near the ambient temperature for seven days; then the experiment was terminated. The product was taken to analyze for its characteristics.

After finishing the experiment, the final product was randomly sampled for the analysis of moisture, organic matter, carbon, and nitrogen. Table III showed the final product characteristics compared to the initial values of the composting mixture and the compost specifications of Thai Agricultural Standard (TAS) [16]. This indicated a good quality of the final product which can meet the specification of the TAS.

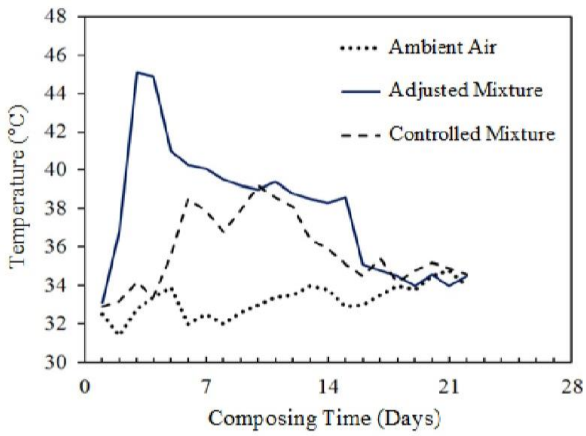

Figure 2. Temperature variation during composting

TABLE III. CHARACTERISTICS OF THE ADJUSTED MIXTURE

Materials	OM (%)	N (%)	C/N	MC (%)
Raw mixture	80.5	1.7	25.6	61.2
Final product	55.4	2.1	14.3	26.1
Compost specifications	≥ 35	≥ 1.0	≤ 20	≤ 35

Compost maturity and stability are generally used to describe the degree of decomposition and transformation of organic matter in the compost [17]. Commonly, C/N ratios between 10 and 15 in the compost indicate a good degree of maturity [18]. In this study, the composting of the adjusted mixture produced a stable end product with the C/N ratio of 14.3, indicating its maturity. A reduction of organic matter of 31.2% within three weeks also indicated a rapid rate of the degradation.

In addition to the C/N ratio, this final product also had moisture meeting the requirement (moisture ≤ 35%). The moisture content of compost affects its bulk density (weight per unit volume) and, therefore, affects handling and transportation. Dry compost (35% moisture or below) might be dusty but very wet compost (55-60%) can become heavy and clumpy, making its application more difficult.

Fig. 2 also showed the temperature change of the composting of the controlled mixture (dry leaves mixed with mature compost). The highest temperature of the control was 39.2°C occurring on day 10 of the composting. This indicated the decomposition of the control at a slow rate. The reduction of organic matter in the controlled material after composting for three weeks was lower than that in the adjusted mixture as shown in Table IV.

TABLE IV. CHARACTERISTICS OF THE CONTROLLED MIXTURE

Materials	OM (%)	N (%)	C/N	MC (%)
Raw mixture	87.8	1.1	45.7	60.7
Final product	73.7	1.3	31.4	40.2

From the experimental results, it showed that the initial ratio of C/N in the composting material played the most important role among other factors. This was evidently indicated by comparing degradation rates in terms of organic matter reduction between the composting of the adjusted mixture and the controlled mixture. The reduction of organic matter in the first case was nearly twofold that of the second one within the same period

V. CONCLUSION

Dry leaves contain the C/N ratio too high and the moisture content too low which are unsuitable for the decomposition process. This study demonstrates that the adjustment of the initial C/N ratio of the waste together with the adjustment of its particle size and the moisture can enhance the degradation rate of the leaf wastes. Among the three factors, the C/N ratio plays the most important role in the organic substance degradation. The effectiveness of composting is indicated by the higher rate of the temperature increase and the higher amount of organic matter reduction of the adjusted mixture compared to those of the controlled material. The final product obtained from composting the adjusted mixture has the organic matter, the nitrogen, the moisture content, and the C/N ratio meeting the specifications of Thai agricultural standard. It can be said that the adjustment of the material properties to attain the proper conditions for composting can reduce the time required for composting. The small-size reactor made of discarded water bottles can be effectively used for this composting. In this study, in addition to the recycling of leaf waste, the discarded bottle is also reused.

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