Application of agro-waste compositional data to predict composting efficiency
(Aplikasi data komposisi sisa pertanian untuk meramalkan kecekapan pengkomposan)

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Keywords: C/N ratio, compost quality, compost efficacy

Abstract
Composting is one of the effective approaches for reducing the amount of disposed organic waste and produces value added products to optimise its use for agriculture. In order to improve compost quality and efficacy, the use of agricultural wastes compositional data can be an effective tool to improve efficiency, especially in estimating the initial C/N ratio of the composts and predicting the final compost quality. In this study, characterisation on 25 types of local agricultural wastes was conducted to determine the basic chemical characteristics of the waste materials. Data from the samples were ultimately used as reference to determine and formulate basic material combinations for compost. The compositional data of these common agro-wastes are usable for formulating nutritionally ideal mixtures of composts. A field study on composting of a mixture of baled rice straw and goat manure (weight ratio of 1:1 for straw:manure) was conducted to determine changes in C/N ratio from initial composting to the final products. During the 8 weeks composting process, the total C/N losses were found to be between 43.7 and 67.6%. The compost reached a C/N ratio of 10:1 after 2 weeks. The optimum temperature ranged from 55 to 60 °C within the first 2 weeks of composting and leveled off below 40 °C after 38 days. The study confirmed that the process of achieving matured compost can be optimised if ideal combinations of initial C/N ratio were used.

Introduction
Composting is the biological decomposition of biodegradable organic wastes under controlled, predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture (Luis et al. 1996). It is a decomposition process in which the substrate is progressively broken down by a succession of living organisms. The breakdown products of one microbial population serve as the substrate for the succeeding population. Although the process has been known, the practice could be said to be intermittently used depending on trend, social and economic situations of different historical periods. In Malaysia, the price increases in imported fertilizers have created renewed interest in fertilizer production using local raw materials. Total value of

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imported fertilizer was RM 9.17 billion in 2008 (Sabri 2009).

In tandem with increased awareness and consumer preference for organic food, practices of organic agriculture are also becoming popular. Aerobic composting again found its rightful place, together with composting of local agro-waste materials. Composting provides the farmers with the best opportunity to recycle manures and plant residues which otherwise may cause environmental problems (Baldwin and Greenfield 2006).

The composting process is affected by many factors such as nutrition (Huang et al. 2011), environment and aeration rate (Hanajima et al. 2010). Nutritional factors include macro and micro-nutrient contents as well as carbon (C) to nitrogen (N) ratio, while environmental factors include pH, temperature and moisture content.

In composting, carbon to nitrogen ratio (C/N) is an important factor. The theoretical ratio is 25:1, based on relative demands for carbon and nitrogen in microbial cellular processes (Tripetchkul et al. 2012). Much more carbon is needed because it is utilised in cell wall formation as well as protoplasm and storage products synthesis. Additionally, nitrogen also serves essentially as a constituent of protoplasm (Fagundes 2012). Moreover, an appreciable amount of C is oxidised to carbon dioxide (CO₂) during metabolic activities.

Generally, recommendation for C/N ratio in composting of waste materials is in the range of 25:1 to 30:1 (Erickson et al. 2009). The rate of decomposition generally declines when this range is exceeded (Ogunwande et al. 2008). Meanwhile, ratios lower than that would promote the loss of N due to conversion of surplus N into ammonia (Jiang et al. 2011). A general decline in C during composting indicates mineralisation of organic matter.

During field composting, the practitioners usually could monitor and control environmental factors and aeration rate. However, the nutritional factors cannot be controlled because normally practitioners will use whatever available waste materials in a particular locality. Economic reality does not allow the practitioners to transport raw materials from outside the localities. Thus it is not uncommon to find non-ideal C/N ratios and nutrient composition in composting operations, resulting in decreased efficiencies as well as increased maturity periods.

Yet, the fact that time is the important factor still applies to composting business, and therefore, the practitioners should weigh the opportunity cost of providing ideal nutritional composition against loss of time. The objective of this work was to provide compositional data of common agro-wastes to practitioners who could use them as a guide to formulate nutritionally ideal mixtures for composting of agro-wastes.

**Materials and methods**

Twenty five agro-waste samples were collected including cattle manure, chicken manure, goat manure, sheep manure, horse manure, oil palm empty fruit bunches, palm oil mill effluent, rice straw, rice husk, sawdust, pineapple skin, pineapple plant residue, durian skin, sugarcane bagasse, grass clippings and vegetable waste. The materials were obtained at the respective sites where the waste was being disposed. A few materials, such as pineapple skin and durian skin were obtained by direct purchasing from local fruit stalls. Vegetable wastes were obtained from the Pasar Borong wet market in Selangor.

The physico-chemical compositions of the agro-waste materials were analysed including the dry matter and ash (AOAC 1995), carbon and nitrogen contents (determined using C, N and S elemental analyser, Vario El III) and organic carbon (analysed using the method of Walkey and Black 1934). The C/N was calculated according to the method of Zhu (2006). The values for carbon in the C/N calculations were represented by total organic carbon. Phosphorus (P), potassium (K), calcium (Ca)
and magnesium (Mg) were determined by acid digestion (Campbell and Plank 1992) followed by the use of Inductively Coupled Plasmas-Atomic Emission Spectrometer (ICP-AES, Perkin Elmer).

Based on the compositional data obtained, theoretical agro-waste combinations are formulated to contain ideal C/N ratios. To demonstrate the use of the compositional data, a small scale field study (size of 1 m x 1 m x 1 m for each compost heap) was conducted to determine the physical and chemical changes of the compost. The study was conducted using three combinations of compost mixture utilising rice straws and goat manure. The rice straws obtained from the rice granary area in Sungai Besar, Selangor were packed and formed into bales. For compost production, the bales were disassembled and directly applied with goat manure. For each of the composts mixture, the rate for combination was based on 1:1 ratio (weight basis). The weight ratio of straw to the goat manure was 100 kg straw: 100 kg manure for mixture 1 and 2 and 110 kg straw and 110 kg manure for mixture 3. The compost heap was prepared by conventional layering process between the rice straws and goat manure. The compost heap was turned every three days.

The theoretical values of C/N ratio for combination between 2 and more agro-waste materials were calculated using the following formula (Richard and Trautmann 1996) using values obtained from the agro-waste compositional data:

\[ R = \frac{Q_1 [C_1 x (100 - M_1)] + Q_2 [C_2 x (100 - M_2)] + Q_n [C_n x (100 - M_n)]}{Q_1 [N_1 x (100 - M_1)] + Q_2 [N_2 x (100 - M_2)] + Q_n [N_n x (100 - M_n)]} \] (1)

Where, \( R = \) C/N ratio of the compost mixture, \( Q_n = \) waste materials (wt %), \( C_n = \) organic carbon %, \( N_n = \) nitrogen % and \( M_n = \) moisture %.

To study the changes in C/N ratio, the agro-waste mixtures were allowed to undergo the composting process for 2 months. Additional data on composts temperature and moisture were also taken. The samples were collected at weekly intervals for a period of 8 weeks. Temperature of the compost was recorded on daily basis. All data were collected in triplicate.

**Results and discussion**

**Agro-waste compositional data**

The general compositional data of the 25 selected agro-wastes are listed in *Table 1*. It can be seen that the range for carbon compositions for most of the local agricultural wastes varied between 20 and 50% (on dry matter). The highest composition of organic carbon was identified in sample from rice bran (41.4%), while other sources such as broiler chicken dung (38.1%), sugarcane bagasse (32.8%) and cocoa husk (34.5%) were also among the wastes with high C sources.

For a good initial combination of C/N ratio, sources such as coconut fronds, pineapple residues and sheep dung were among the waste with optimum C/N ratio (closer to the range of 25:1 to 30:1). Coconut fronds which contain 1.3% N and 32.3% C gave a C/N ratio of 25.8. Pineapple residue (skin) contains 1.2% N and 31.0% C gave a C/N ratio of about 27.6. Other C/N ratios obtained, however, are slightly below or beyond the optimal range. These included corn cob (30.6), sheep dung (20.5) and rice bran (18.2).

In local agricultural scenario, much of the wastes are presently generated from the rice and oil palm industries. Initial C/N ratios for rice straw and oil palm empty fruit bunches (EFB) can be as high as 78.2 and 68.5 respectively (due to high percentage of carbon and low percentage of nitrogen) (*Table 1*). In order to lower the percentage to the appropriate level, combinations with manures with high percentage of N can be done to lower the initial ratio. This will further be discussed in the subsequent sections.
Table 1. Chemical and physical composition of 25 selected agro-wastes

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Moisture %</th>
<th>Ash %</th>
<th>% On dry matter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Rice bran</td>
<td>10.6 ± 0.6</td>
<td>12.7 ± 0.6</td>
<td>2.4 ± 0.5</td>
</tr>
<tr>
<td>Rice husk</td>
<td>7.5 ± 1.0</td>
<td>19.2 ± 1.8</td>
<td>0.3 ± 0.1</td>
</tr>
<tr>
<td>Rice straw</td>
<td>9.4 ± 0.5</td>
<td>17.6 ± 1.6</td>
<td>0.4 ± 0.1</td>
</tr>
<tr>
<td>Durian skin</td>
<td>78.0 ± 2.4</td>
<td>10.4 ± 1.5</td>
<td>2.0 ± 0.1</td>
</tr>
<tr>
<td>Broiler chicken dung</td>
<td>31.3 ± 11.4</td>
<td>34.3 ± 11.5</td>
<td>3.0 ± 0.6</td>
</tr>
<tr>
<td>Layer chicken dung</td>
<td>60.0 ± 3.0</td>
<td>64.9 ± 4.3</td>
<td>2.3 ± 0.4</td>
</tr>
<tr>
<td>Goat manure</td>
<td>49.4 ± 5.1</td>
<td>56.2 ± 5.7</td>
<td>2.5 ± 0.2</td>
</tr>
<tr>
<td>Duck manure</td>
<td>72.6 ± 7.6</td>
<td>77.7 ± 5.8</td>
<td>1.7 ± 0.1</td>
</tr>
<tr>
<td>Palm oil sludge</td>
<td>10.8 ± 0.8</td>
<td>11.0 ± 1.8</td>
<td>1.7 ± 0.2</td>
</tr>
<tr>
<td>Pineapple residue (plant)</td>
<td>85.4 ± 2.7</td>
<td>97.9 ± 0.7</td>
<td>2.1 ± 0.1</td>
</tr>
<tr>
<td>Pineapple residue (skin)</td>
<td>86.3 ± 1.0</td>
<td>48.6 ± 0.4</td>
<td>1.2 ± 0.3</td>
</tr>
<tr>
<td>Cut grass</td>
<td>80.5 ± 0.6</td>
<td>13.7 ± 2.3</td>
<td>2.2 ± 0.1</td>
</tr>
<tr>
<td>Copra cake</td>
<td>8.1 ± 2.0</td>
<td>14.4 ± 7.0</td>
<td>3.0 ± 0.2</td>
</tr>
<tr>
<td>EFB</td>
<td>54.6 ± 4.8</td>
<td>28.5 ± 2.9</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Guine grass</td>
<td>81.4 ± 3.2</td>
<td>86.8 ± 1.3</td>
<td>2.0 ± 0.1</td>
</tr>
<tr>
<td>Cocoa husk</td>
<td>8.8 ± 0.7</td>
<td>10.3 ± 1.0</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>Oil palm front</td>
<td>6.9 ± 2.9</td>
<td>50.3 ± 3.1</td>
<td>2.4 ± 0.4</td>
</tr>
<tr>
<td>Coconut front</td>
<td>52.4 ± 0.8</td>
<td>53.7 ± 4.4</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Vegetable wastes</td>
<td>94.6 ± 1.3</td>
<td>10.8 ± 1.1</td>
<td>3.1 ± 0.2</td>
</tr>
<tr>
<td>Sugar cane bagasse</td>
<td>6.2 ± 1.4</td>
<td>59.0 ± 0.5</td>
<td>0.5 ± 0.1</td>
</tr>
<tr>
<td>Corn cob</td>
<td>53.6 ± 4.9</td>
<td>34.9 ± 0.9</td>
<td>1.0 ± 0.1</td>
</tr>
<tr>
<td>Horse dung</td>
<td>53.2 ± 5.7</td>
<td>56.8 ± 5.6</td>
<td>1.6 ± 0.3</td>
</tr>
<tr>
<td>Sheep dung</td>
<td>39.0 ± 3.7</td>
<td>42.6 ± 5.4</td>
<td>1.6 ± 0.2</td>
</tr>
<tr>
<td>Dairy cattle dung</td>
<td>58.9 ± 11.4</td>
<td>66.9 ± 10.7</td>
<td>1.3 ± 0.1</td>
</tr>
<tr>
<td>Beef cattle dung</td>
<td>42.7 ± 2.6</td>
<td>49.5 ± 4.4</td>
<td>2.2 ± 0.6</td>
</tr>
</tbody>
</table>
Together with C, the N, P, Ca and K form the macronutrients (Table 1). Other elements that are required in trace amounts are known as essential trace elements and these included Mg, Mn, Co, Fe and S. These are seldom lacking in agro-waste materials.

**Characteristics of raw materials for composting**

Each agro-waste material has its own characteristics that must also be taken into consideration for usage in compost mixture. For example, grass clippings tend to form mats during composting if mixing is inadequate. The matting problem reduces porosity and can cause anaerobic conditions to appear. With adequate mixing, it is actually a good material since it decomposes readily and has appreciable nitrogen content.

In the case of manure from the chicken industry, manures from broiler chickens would have a higher C/N ratio than that from laying hens (Table 1). This is because broilers are reared on a litter of bedding materials consisting of sawdust or wood shavings (López-Mosquera et al. 2008), while layers are kept in raised-floor battery cages where manures dropped directly onto the floor. There are no bedding materials for layers (Dunkley 2010). Thus, broiler litters are mixtures of high-carbon sawdust and manure with some feathers, while manures from layers are almost totally manures with feathers as possible contaminant.

It must be admitted that the nature of C and N in the agro-waste may affect the ease of microbial attack. In such cases, a process of chipping and shredding of the materials into finer size will provide larger surface areas for microbial activation (Whiting 2011). Rice straw, oil palm empty fruit bunches (EFB) and pineapple residues are among the bulky wastes that should be shredded prior to composting.

EFB is a residue with low water-holding capacity (Suhaimi and Ong 2001). On the one hand they need to be reduced in size by shredding to form larger surface areas, on the other hand, it dries out easily upon size reduction. Thus, moisture adjustment becomes critical in the case of EFB. The dry matter of the material may depend on the state of the materials collected. The dry matter may be higher if the collected sample was low in moisture. Similarly, the percentage may be lower if the moisture is higher (samples may become wet if exposed to the open environment and outside weather conditions such as rain). However, for effective production of compost, aeration and moisture need to be constantly supplied and controlled. Ideal moisture content between 65% and 75% (Guo et al. 2012) needs to be supplied to the materials regardless of the initial moisture of the raw materials. This is to ensure effective condition for microbial decomposition and degradation of the compost material.

**Determination of initial C/N ratios of compost mixtures**

The recommended C/N ratio at the start of the composting process is 25:1 to 30:1 (Pace et al. 1995). Based on the compositional data obtained (Table 1), theoretical agro-waste combinations are formulated to contain ideal C/N ratios. However, the examples provided are only for combination of two different sources of waste materials since it represents the basic waste combinations from local compost making. The proposed combinations are shown in Table 2 which incorporated the use of rice straw in combination with goat’s manure, cattle manure or chicken dung. All the data for calculations are based on the initial C/N ratios of 25:1 and 30:1. Calculations of the initial C/N ratios of 2 or more agro-waste mixtures are based according to the formula of Richard and Trautmann (1996). Physical and chemical compositions used for calculations are from Table 1.

Recommendations for the weight of rice straw are based on the local waste scenario. Normal weight for a bale of rice straw is around 100 kg to 120 kg. Therefore, it is recommended that a bale of rice straw is used (100 kg) to be mixed with 110.5 kg
Prediction of composting efficiency

Table 2. Selected agro-waste combinations with initial C/N ratios

<table>
<thead>
<tr>
<th>Combinations</th>
<th>C/N value</th>
<th>Raw materials A (kg fresh weight)</th>
<th>Raw materials B (kg fresh weight)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice straw and goat manure</td>
<td>25:1</td>
<td>100 kg of rice straw</td>
<td>110.5 kg of goat manure</td>
</tr>
<tr>
<td></td>
<td>30:1</td>
<td>100 kg of rice straw</td>
<td>75.4 kg of goat manure</td>
</tr>
<tr>
<td>Rice straw and beef cattle manure</td>
<td>25:1</td>
<td>100 kg of rice straw</td>
<td>140.8 kg of cattle manure</td>
</tr>
<tr>
<td></td>
<td>30:1</td>
<td>100 kg of rice straw</td>
<td>90 kg of cattle manure</td>
</tr>
<tr>
<td>Rice straw and layer chicken dung</td>
<td>25:1</td>
<td>100 kg of rice straw</td>
<td>139.8 kg of layer chicken dung</td>
</tr>
<tr>
<td></td>
<td>30:1</td>
<td>100 kg of rice straw</td>
<td>97.4 kg of layer chicken dung</td>
</tr>
</tbody>
</table>

goat manure to obtain a C/N ratio of 25:1 or 75.4 kg goat manure to obtain a C/N ratio of 30:1. Similar calculations are made with combinations of rice straw with cattle manure or chicken dung (Table 2). For moisture content used in the calculation, Buzarovska et al. (2008) suggested 10 – 12% for a dry base rice straw and 60% on a wet basis. Therefore, moisture content of 9.4% obtained is a value that is considered suitable for general use (Table 1).

Performance of compost mixture

C/N ratio The purpose of studying the performance of the compost mixture is to identify the rate of losses from the initial C/N ratio of the composts. Rice straw and goat manure were selected because these agro-waste materials are easily available. Furthermore, the goat manure is obtained from the goat industry, a prominent smallholder subsector in Malaysia. Therefore, composting could be an additional economic activity for the smallholders. The practice of composting has been described as one of the best approaches for effective manure management (Mohammad Hariz and Mohd. Fairuz 2011). Similarly, the rice straws obtained from the granary area in Sungai Besar also forms part of the smallholder’s activities.

The study was conducted with 3 compost mixtures using rice straws and goat manures. The rate of combination of the raw materials was based on a 1:1 ratio (weight basis). Theoretical calculations based on the C/N ratio from the applied weight of both raw materials (rice straw and goat manure) of 100 kg: 100 kg has an initial C/N ratio of 26.2:1. The reason for not mixing with the exact C/N combinations of 25:1 (100 kg straw: 110.5 kg manure) (Table 2) is to use mixture combinations normally carried out by the farmers. This was usually done in the ratio of 1:1 on the weight basis or 3:1 on the volume basis. Nevertheless, the combination is suitable for both purposes, which is to formulate the appropriate C/N ratios (25:1 to 30:1) and also to suggest a weight ratio that can be easily applied by the farmers.

Although the theoretical calculation was 26.2:1, the actual C/N ratio of the samples taken right after the compost heaps were prepared (15.3:1, 19.7:1 and 24.8:1) (Figure 1). The differences between the theoretical values of C/N to the actual values maybe due to the process of compost heap making. The process involved conventional layering of the agro-waste materials which initially formed intermittently into three layers of combinations between rice straw and goat manure. It was only during the third day that the turning process began. Since mixing of the materials were not uniform during the first three days, this could be one of the reasons why there were differences between the initial theoretical C/N values and actual values.

Results showed that percentage of carbon losses were higher within the first two weeks of composting process (Figure 2). This is in relation to the performance of the compost temperature.
which was between 55 and 60 °C within the first 16 days of the process (Figure 4). Similarly, the greatest decrease in C/N ratio was observed during the first two weeks of sampling (Figure 1). A study by Zhu (2007) which combines composting of swine manure with rice straw observed the C/N ratio decreased within 21 days of composting. It was suggested that the decrease might be caused by the easy-to-degrade total organic materials in the mixture (Li and Zhang 2000; Solano et al. 2001; Zhu 2006). Throughout the 8 weeks composting process, C/N ratio reduced from 15.3 to 24.8 (direct C/N from sampling) at zero day and 7.1 to 8.6 on the eighth week (Figure 1). Total calculated C/N losses were between 43.7 and 67.6%.

Looking at the trends in carbon compositions in the samples, the lowest content in C percentages were seen on the fifth and sixth weeks, before it increased to a stable content at week 7 and 8 (Figure 2). Compost maturation occurs when the C/N
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The C/N ratio approaches the value of 12:1 (Bernal et al. 1998). In this study, although there were some differences in C/N value between the fourth week of sampling to the eighth week, it can be seen that the C/N ratio of the composts tend to stabilise at the beginning from week 2 and reaching a C/N ratio of not more than 10:1 at week 8 (Figure 1).

**Nitrogen contents**  During the composting process, changing trends in the amount of N indicate a good process of aerobic composting. From Figure 3, it can be seen that total N increased from an average 1.2% at the beginning to 2.2% at the end of the process. The increase in total N occurred as a result of the mass losses during composting (Bernal et al. 2009). As more of the carbon (C) becomes degraded, total N increased in concentration.

**Temperature and moisture**  Throughout the process, turning of the compost was done many times (at days 3, 5, 10, 13, 20, 24, 29, 41, 56 and 62). Sudden drop in temperature can be seen after the turning process (Figure 4). The purpose of turning is to provide adequate aeration to the compost heap and to avoid excessively high temperature beyond the optimum. The compost reached temperature stability (below 40 °C) after 38 days.

In terms of moisture, the compost heaps were watered every alternate day during the first week of the process. The purpose is to increase the moisture content during the first week of the composting process (Figure 5). This will optimise the performance of the thermophilic microbes to perform the degradation process. Study by Miyatake and Iwabuchi (2005) observed that the highest level of thermophilic bacterial activity was at 54 °C. The moisture was maintained at 70 to 75% up until the third week before gradually decreasing from 55 to 60% towards the end of the composting process.

**Conclusion**  The use of agricultural wastes compositional data has been very effective in estimating the initial compositions of the compost mixture. Additionally, it can be used to optimise the overall amount of carbon losses and final C/N ratio of composts in relation to the initial mixtures. Calculations based on the initial characteristics of the raw materials can assist in compost efficiency.
Figure 4. Changes in compost temperature within a period of 62 days

Figure 5. Changes in moisture content in mixtures of goat’s manure and rice straw composts

and improve the quality of the final products while simultaneously increasing the rate of composting. In this study, compost mixtures with initial C/N ratio of 25:1 and 30:1 were suggested. During field composting of rice straw and goat’s manure, the C/N ratio was stable (10:1) after 2 weeks. However, temperature stability was reached (below 40 °C) after 38 days. It is suggested that the ideal compost (both from C/N and temperature factors) can be achieved within 30 to 40 days depending on the materials and environmental conditions under which the composting process is performed.

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**Abstrak**

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