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Influence of Nitrogen Containing Wastes Addition on Natural Aerobic Composting of Rice Straw

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Abstract: Problem statement: Rice straw is an agricultural residue. Typically, the rice straw can be burn in the rice field after the harvesting process. The burning can cause air pollution. Another alternative rice straw management method is animal feed. The amount of rice straw is enormus in Thailand. Another sustainable way to manage rice straw is required. Rice straw is used as main waste to compost with nitrogen containing wastes such as golden apple snail, cattle dung and urea in natural aerobic composting reactors. The golden apple snail is a pesticide and cattle dung is an animal waste. Both materials are all waste of low values. The main purpose of this study was to determine the influence of nitrogen containing wastes addition to rice straw on the performance of natural aerobic composting process in terms of the following parameters: pH, temperature, organic matter, C/N ratio, electrical conductivity and GI. The impact of this study is to reuse agriculture residue by composting. **Approach:** The experiments was consisted of three reactors. The reactor 1 contains the rice straws and golden apple snails while the reactor 2 contains the rice straws, golden apple snails and urea. The reactor 3 contains the rice straws, cattle dung and urea. The experiments were carried out in designed natural aerobic reactors (60 L) under controlled laboratory conditions over 60 days. The analysis was done every 5 days however the temperature was measured daily. **Results:** The experimental results showed that the initial C/N ratio was 30.7, 30.3 and 31.8 in the reactor 1, 2 and 3, respectively. After the 60-day period, the final C/N ratio was reduced to 17.9, 16.9 and 18.4 in the reactor 1, 2 and 3, respectively. The main nutrients (N: P: K) from all reactors achieved the standard level for Thai compost standard. The rice straw as agricultural residue was suitable for co-composting with golden apple snails and cattle dung as the nitrogen containing wastes. **Conclusion:** The final compost is the good quality compost according to the Thai compost standard. The moisture content is slightly higher than the Thai compost standard. The final compost can be dry in the air to reduce moisture before use. The final compost can be use as a fertilizer.

Key words: Rice straw, golden apple snail, cattle dung, compost, C/N ratio

INTRODUCTION

The compost is an important alternative method in sustainable waste management for Thailand. The compost is conducted from plant residues or organic waste, watering for suitable moisture content. Organic waste through a degradation process was transformed by microorganism activity. Until the organic waste is stable, that is odorless and turns a black or dark brown color. The finished compost will be able to use to improve and treat the soil. The fermentation can be divided into two types of fertilizers; (i) aerobic composting and (ii) anaerobic composting. The aerobic composting is the decomposition of organic matters in the presence of oxygen. The end-products biological metabolism are carbon dioxide, ammonia, water and heat (Huag, 1980). The oxygen serves two functions in the metabolic reactions: as the terminal electron-acceptor in aerobic respiration and as a substrate required for the operation of the class of enzymes called oxygenase (Jimenez and Garcia, 1991). The aerobic composting is decomposed by aerobic microorganism under the optimum conditions of moisture content, temperature, oxygen content and C/N ratio (Huag,

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1980). The optimum C/N ratio provides the faster degradation rate. It involved the energy in the heat generated form by the oxidation of organic carbon to carbon dioxide, as well as the organic matter decomposed to small size. The compost pile can keep heat caused the decomposition reaction in the compost pile. Aerobic composting does not produce an obnoxious odor. The temperature during composting is high enough to inhibit pathogens that can cause harm to human. The main purposes of composting are the waste stabilization, pathogen inactivation and nutrient and land reclamation.

Rice straw is an organic agricultural residue from rice harvest. Rice is the main economic crop of Thailand for a long time. Thai people consume rice as the main food. Rice is also the prime export agricultural products of Thailand. Thailand consumes about 50% of agricultural holding in rice cultivation. This can be seen that the rice cultivation area has about 65 million hectares of rice yield about 30 million tons in 2010. In general, the proportion of rice grain and straw yield of about 1:1. Then, it is estimated that there was up to 30 million tons of rice straw in 2010. The straw has a very important role in increasing the fertility of soil and also improves the soil nutrients as well. Rice straw is a significant source of carbon, but a small amount of nitrogen needs to be added for faster degradation of organic matter in natural aerobic composting process.

For the golden apple snail or the southern America snail, is an imported animal. It originated in South America, imported to Asia in 1980. The golden apple snail has spread rapidly and it is resistant to drought. Each year the golden apple snail is breeding and spawning as many as 3 to 4 times. The eggs are laid about 1,000-1,200 pieces per time. In the present, the golden apple snail has become a major rice pest. In 1999, the outbreak of golden apple snails is more than 60 cities across the country. While, the golden apple snail is considered a high nutritious i.e. protein, major nutrient, minor nutrient and nutrient supplements. Therefore, the reuse of agricultural residue for composting is the sustainable waste management way and to benefit further.

Composting rice straw with golden apple snails and cattle dung could offer many environmental and economic benefits for the regions where rice straw, golden apple snail and cattle dung are available in great amounts. The main applications in Thailand are as bedding livestock and as animal feed. Since rice straw, cattle dung and golden apple snail are available in agricultural land, there are no transportation costs. As the first step to demonstrate the performance, the aim of this study, was to determine the influence of rice straw in addition to nitrogen containing wastes on performance of natural aerobic composting process.

MATERIALS AND METHODS

Composting materials: The properties and characteristics of raw wastes are shown in Table 1. The raw wastes in this experiment are the rice straw, golden apple snail and cattle dung. The rice straw is the leftover of rice harvesting. The golden apple snail is the tropical and sub-tropical freshwater snails. At present, it is a major pest problem in the rice production. The golden apple snail came from South America via Taiwan. Nutritive value of golden apple snail fresh consists of protein, fat, carbohydrates, phosphorus, sodium, potassium, zinc, copper, manganese and iodine. Its property is suitable for composting. The cattle dung is the animal waste from cattle and the undigested residue of plant matter. Cattle dung contains useful nutrients and rich in organic matter which can be recycled into agricultural land where it can dry out and remain on the pasture, grazing land which is unpalatable to livestock. It is often used as manure and soil fertilizer for agriculture for many centuries (Lunnan, 1997). Moreover, the cattle dung composting can reduce greenhouse gas emissions.

Composting reactor and method: A laboratory-scale natural aerobic composting system as shown in Fig. 1 was used for this study. The natural aeration composting reactor (60 L in volume) was used in this experiment. The aeration is important for the success of composting, thus, the reactors in this study can be turned. The reactor consists of a cylindrical vessel tank made from Poly Ethylene (PE) and a mixer handle for turning the compost reactor. The cylindrical vessel tank is drilled 77 holes of 1 cm diameter, the total holes is 61 cm^2 for natural aerated (Fig. 2). The inside of the reactor is lined with mesh to prevent the compost materials leak. The bottom of reactor has an open-valve for dropping the leachate and condensate. The composting period is 60 days in batch process. A total of three composting reactors were used in the experimental setup and the difference in mixture materials was the difference in input materials. The reactor 1 contains the rice straw and golden apple snails. The rector 2 contains the rice straw, golden apple snails and urea. The reactor 3 contains the cattle dung, rice straw and urea (Table 2).

Analytical procedures: The natural aeration was provided by turning the reactors every 4 days using a handle mixer. The compost samples were taken every 5 days for analysis. The pH, moisture content, nitrogen, organic carbon, organic matter, C/N ratio are analyzed. The phosphorus as P_2O_5 and potassium as K_2O were analyzed on date 0, 30, 45 and 60 of the experimental period.

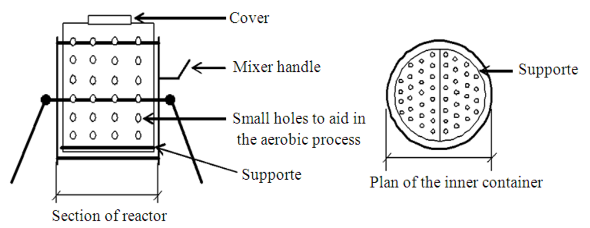

Fig. 1: Schimatic of the natural aerobic composting reactor

Fig. 2: Natural aerobic composting reactor

Table 1: Properties and characteristics of raw wastes

Parameters	Rice straw	Golden apple snail	Cattle dung
Moisture content (%)	23.80	66.50	28.20
pH	6.70	4.70	7.90
Organic matter (%)	60.40	37.10	25.20
Total nitrogen (%)	0.65	3.29	1.64
C/N ratio	53.90	6.50	16.70
Total phosphorus (%)	0.23	0.41	1.38
Total potassium (%)	1.72	0.69	1.55
Total calcium (%)	0.85	22.06	1.77
Total magnesium (%)	0.52	0.20	0.45
Total sulfur (%)	0.20	0.14	0.15

Table 2: Prepared mixed wastes for composting

Reactor	Mixed waste components
1	3.0: 1.4 ratio of rice straw: golden apple snail
2	3.0: 1.0: 0.007 ratio of rice straw: golden apple snail
3	3.0: 2.0: 0.007 ratio of rice straw: cattle dung: urea

Electrical conductivity and pH were measured using an EC meter and pH meter. The moisture content, nitrogen (digested) and phosphorus (digested) were analyzed according to the standard methods (APHA, 1988). Three replicate samples were analyzed. Organic matter and organic carbon were analyzed by Walkley-Black method. Nutrients such as calcium, magnesium and potassium were analyzed by inductively coupled plasma (ICP-OES) spectrometry. The carbon, hydrogen, oxygen, nitrogen and sulfur were analyzed on a Perkin-Elmer Series II CHONS Analyzer (Perkin-Elmer, Urberlingen, Germany).

The samples were collected and analyzed phosphorus, potassium, electrical conductivity, calcium, magnesium and sulfur and germination index on days 0, 30, 45 and 60. The final compost was taken for pH, moisture content, nitrogen, phosphorus, organic carbon, organic matter, carbon, potassium, electrical conductivity, germination index, temperature, calcium and magnesium and sulfur analysis. The Germination Index (GI) is calculated as described in the Association of Official Seed Analysts using the following formula:

$$GI = \frac{\text{No.of germinated seed}}{\text{Days of first count}} + \_\ \_ + \frac{\text{No. of germinated seed}}{\text{Days of final count}}$$

GI is a complete degradation. It shows the seed germination and the plant growth experiments to measure the percentage of seed germination and vigor of plants germinated from compared seeds.

RESULTS

Mixed waste characterizations: The chemical and physical properties of each reactor before composting are analyzed. The reactor 1 is the mixture of rice straw and golden apple snail. The reactor 2 is the mixture of rice straw, golden apple snail and urea. The reactor 3 is the mixture of rice straw, cattle dung and urea. The property showed in Table 3. The moisture content of compost materials of all reactors is suitable for a compost process. The C/N ratio of all reactors is optimum for the aerobic composting. The initial C/N ratio for composting is range between 25 and 40 (Huag, 1980; Kumar *et al*., 2008; Jimenez and Garcia, 1991). The other properties are appropriate for composting. The optimum moisture content for composting should be 50-60% (Gajalakshmi and Abbasi, 2008). When the moisture content exceeds 60%, the air movement is inhibited and the composting process achieves anaerobic condition (Yu *et al.*, 2007).

Factors affect the composting process: The composting process effectiveness is dependent upon the groups of microorganisms that inhabit and stabilize the organic matter. The main factors controlling the composting process control include: (i) environmental parameters such as temperature, moisture and pH; and (ii) substrate parameters such as C/N ratio, particle size and nutrient content.

Temperature: The results show that the temperature of all reactors was high from the start. The temperature has a significant impact on the composting efficiency (Kaosol and Wandee, 2010).

Table 3: Properties and characteristics of mixed wastes

Parameters	Reactor 1	Reactor 2	Reactor 3
Moisture content (%)	54.80	55.20	54.10
pH	5.10	5.30	6.50
Organic matter (%)	55.10	59.90	38.90
Total nitrogen (%)	1.04	1.15	0.71
C/N ratio	30.70	30.30	31.80
Phosphorus-P_2O_5 (%)	0.26	0.25	0.35
Potassium-K_2O (%)	1.23	1.14	0.92
Electrical conductivity (dS/m)	2.52	2.39	1.91
Calcium-Ca (%)	5.52	4.47	1.32
Magnesium-Mg (%)	0.14	0.15	0.17
Sulfur-S (%)	0.15	0.11	0.22

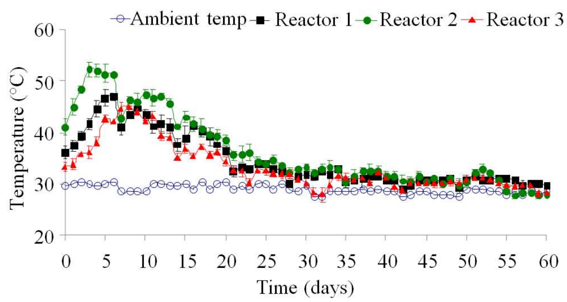

Fig. 3: Changes in temperature during natural aerobic composting

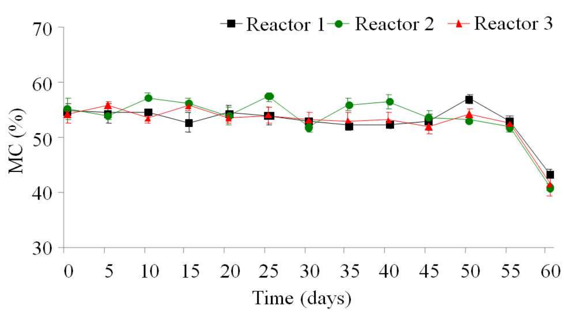

Fig. 4: Changes in Moisture Content (MC) during natural aerobic composting

The heat is generated from microorganisms on decomposing process (Kumar *et al.*, 2008). The highest temperature is 47.0, 52.2 and 44.9°C of compost reactor 1, 2 and 3, respectively (Fig. 3) showed the temperature reached up to the thermophilic phase due to the increasing degradation by the microorganisms. At the thermophilic phase, the temperature rises to the highest level. The thermophilic phase helps to inactivate pathogen in the compost reactor as well. The pathogen destruction is more effective. Usually, the compost in the thermophilic phase is stable and pathogen free (Kumar *et al*., 2008). After that the temperature in the compost reactor reduces gradually until close to the ambient temperature (Solano *et al.*, 2001) and later remains stable which is shown a sign of composting stabilization (McMahon *et al*., 2009). It also found that the temperature inside the compost reactor increases when the atmospheric temperature rises. Therefore, the environment temperature is an important factor that affects composting.

Moisture Content (MC): The optimum moisture content is between 50 and 60% for composting (Yamada and Kawase, 2006). When the MC is too low, the decomposition of organic matter will be very slow and the composting period takes longer than normal. However, the high MC also affects the aerobic condition that is the anaerobic bacteria start decomposed on compost reactor. As a result, the oxygen is not enough for composed requirement of microorganisms. Thus, the final compost product becomes lower quality. The initial MC of reactor 1, 2 and 3 is 54.8, 55.2 and 54.1%, respectively. The MC of mixture materials in all compost reactors are close to the suitable value (Fig. 4).

pH: The pH is one factor of the composting operation. The suitable pH is range between 6.0 and 7.5 (Yamada and Kawase, 2006). It was found that in the first stage of the composting operation, the pH is decreased as a result of the microorganism's activity that grows rapidly at this stage. After the first stage, the pH increased. The pH tends to be stabilized at 7-8 at the end of the composting process (Fig. 5).

Organic Carbon (OC): The organic carbon is the primary energy source for microorganism's growth. The initial OC of reactor 1, 2 and 3 is 31.9, 34.7 and 22.6%, respectively. After 60-day decomposition, the OC in the compost reactor decreased as a consequence of microorganism's activity of the decomposition (Fig. 6). During the composting, the OC in the organic matter changed into carbon dioxide. The OC is mainly influenced by the temperature (Said-Pullicino *et al.*, 2007).

Total Nitrogen (TN): The result showed that the total nitrogen content was increased in all reactors. The initial TN content of reactor 1, 2 and 3 is 1.04, 1.15 and 0.71%, respectively. The TN content at the end of the compost period is 1.37, 1.48 and 1.10% observed from reactor 1, 2 and 3, respectively (Fig. 7). The TN increased during the compost process caused by the activity of microorganisms that is using nitrate to grow and produce cell in an organism or nitrogen-fixing nitrogen from the environment during the degradation of cellulose in the material culture (Yamada and Kawase, 2006).

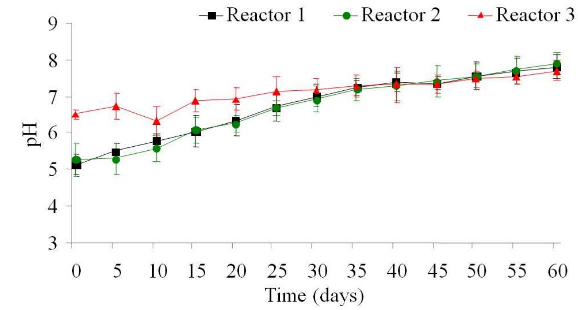

Fig. 5: Changes in pH during natural aerobic composting

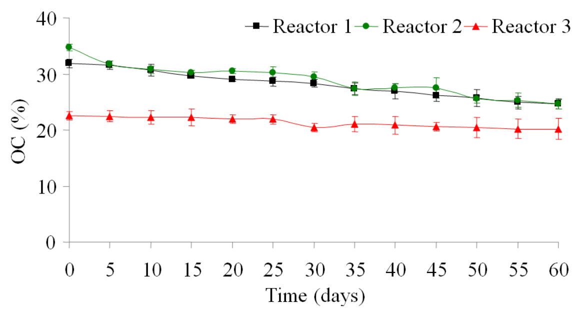

Fig. 6: Changes in Organic Carbon (OC) during natural aerobic composting

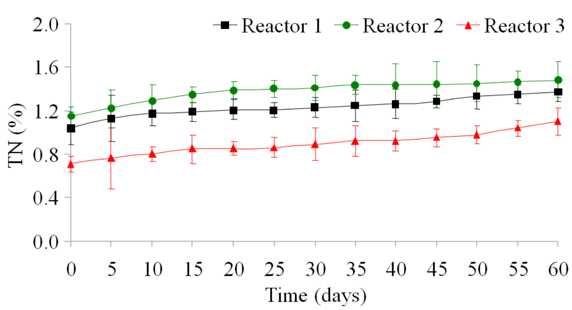

Fig. 7: Changes in Total Nitrogen (TN) during natural aerobic composting

Organic Matter (OM): Organic matter is an important component of all soil types and it has an important role in the soil structure, available nutrient and water absorption ability. The initial OM of reactor 1, 2 and 3 is 55.1%, 59.9% and 38.9%, respectively. Decomposition of OM is brought about the microorganisms that use the carbon as a source of energy and nitrogen for cell structure building. During the composting, the OM decreased due to the activity of microorganisms for growth and new cell. At the end of the compost period, the OM decreased in all reactors.

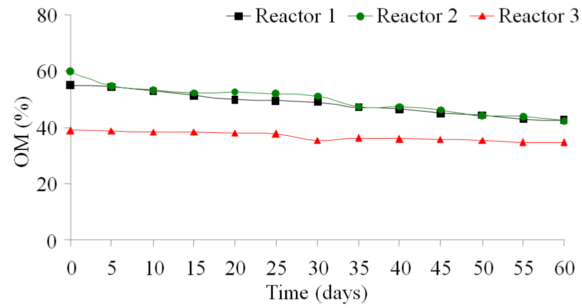

Fig. 8: Changes in Organic Matter (OM) during natural aerobic composting

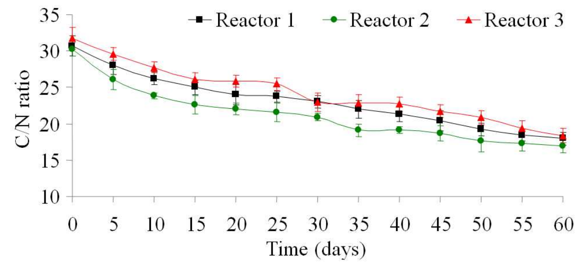

Fig. 9: Changes in C/N ratio during natural aerobic composting

The final organic matter is 42.4, 42.4 and 34.8% in reactor 1, 2 and 3, respectively (Fig. 8).

C/N ratio: In this experiment, the initial of carbon to nitrogen ratio (C/N ratio) is suitable for composting. The C/N ratio in all reactors is approximately 30. The initial C/N ratio is 30.7, 30.3 and 31.8 for reactor 1, 2 and 3, respectively. The optimum of C/N ratio is in the range of 20 and 35 for composting (Yamada and Kawase, 2006) which is recommended for successful aerobic composting (Saludes *et al*., 2007). The C/N ratio decreased during the compost process. The final C/N ratio is 17.9, 16.9 and 18.4 for the reactor 1, 2 and 3, respectively (Fig. 9).

Phosphorus (P_2O_5): Phosphorus as P_2O_5 form is one of the plant nutrient. It helps to synthesis protein and organic matter in plants. The results showed that the phosphorus content of all reactors had increased at the end of the compost period. At the end of the compost period, the P_2O_5 value is 0.45, 0.48 and 0.53% in reactor 1, 2 and 3, respectively (Fig. 10). The increased phosphorus may be resulted from the microorganism's activity which used phosphorus in the growth and cell creation.

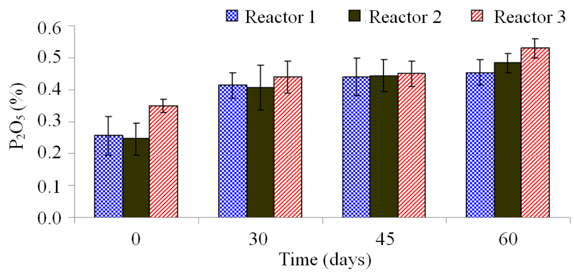

Fig. 10: Changes in Phosphorus (P_2O_5) during natural aerobic composting

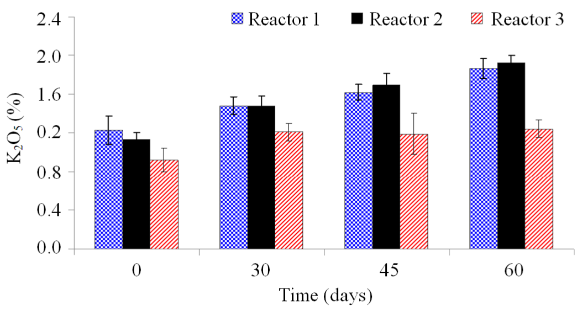

Fig. 11: Changes in potassium (K_2O) during natural aerobic composting

Potassium (K_2O): Potassium as K_2O form is the major nutrient of plants. The results showed that potassium of all reactors hasd increased. At the end of the compost period, K_2O value is 1.86, 1.93 and 1.24% for reactor 1, 2 and 3, respectively (Fig. 11). The results meet the compost standard of the department of agriculture, Thailand. That is, potassium should be greater than 0.5%.

DISCUSSION

Evaluation of compost maturation: The degree of maturity compost is an important factor affecting the successful application of compost for agricultural purpose (Said-Pullicino *et al.*, 2007). The approaches to determine the degree of maturity compost include (i) temperature diminution at the end, (ii) decrease in organic content, (iii) absence of obnoxious odor and (iv) white or gray color presence due to the growth of actinomycetes (Huag, 1980). The final composts in all the reactors turn brown to brownish black color and soil-like texture after the maturation period. The C/N ratio of all the reactors is lower than 20 which are found to be similar to the recommended values (Table 4). The C/N ratio of the final compost above 30 may be toxic and can cause damage to plants (Tiquia *et al.*, 1996). Huag (1980) reported that C/N ratio of compost less than 20 is an ideal for nursery plant production. Therefore, the final compost can make a good fertilizer.

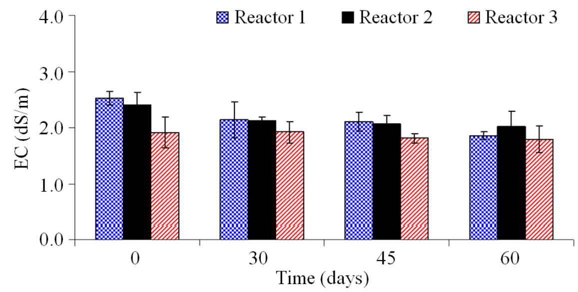

Fig. 12: Changes in Electrical Conductivity (EC) during natural aerobic composting

Table 4: Properties and characteristics of mixed wastes

Parameters	Thai Standard*	Reactor 1	Reactor 2	Reactor 3
Moisture content (%)	<30	43.29±0.91	40.83±0.70	41.38±1.69
pH	5.5-8.5	7.80±0.05	7.88±0.09	7.69±0.11
OM (%)	>20	42.4	42.4	34.8
TN (%)	>1	1.37±0.02	1.48±0.01	1.10±0.03
C/N ratio	<20:1	17.93±0.41	16.90±0.31	18.37±0.04
Phosphorus-P_2O_5 (%)	>0.5	0.45±0.02	0.48±0.04	0.53±0.04
Potassium-K_2O (%)	>0.5	1.86±0.04	1.93±0.03	1.24±0.03
EC (dS/m)	>10	1.85±0.15	2.01±0.09	1.79±0.07
GI (%)	>80	86.88±3.02	97.60±2.17	76.73±4.50
Temperature (^{o}C)	-	29.67±0.34	27.89±0.38	28.44±0.20
OC (%)	-	24.62±0.27	24.59±0.94	20.21±0.28
Ca (%)	-	5.50±0.20	4.73±0.12	1.66±0.27
Mg (%)	-	0.14±0.03	0.16±0.02	0.24±0.03
S (%)	-	0.19±0.03	0.14±0.02	0.24±0.04

*: Compost standard from Departmentof Agriculture, 2008

During the composting, both volume and mass of mixture materials within the reactors were significantly decreasing. It was observed that the organic matter degradation was more intense in reactor 2 than others during the first 6 days. This can be explained by higher porosity of the material in reactor 2 as a consequence of the higher proportion of rice straw. Adding more nitrogen containing wastes gave higher nitrogen content resulting in a lower C/N ratio. The temperature becomes greater than 65°C, then the bacteria, actinomycetes and fungi are inactive (Korner *et al.*, 2003). Temperature in all reactors was maintained above 45°C about 9 Days, which should be sufficient to maximize sanitation and to destroy pathogens. The temperature of all reactors decreased immediately after reaching their maximum values.

Electrical Conductivity (EC): Electricity is used to measure salt content in soil. Typically, pure water does not conduct electricity. EC is the material ability to transmit (conduct) an electrical current and EC is commonly expressed in units of DeciSiemens per meter (dS/m). EC estimates the amount of total dissolved salts, or the total amount of dissolved ions in the soil.

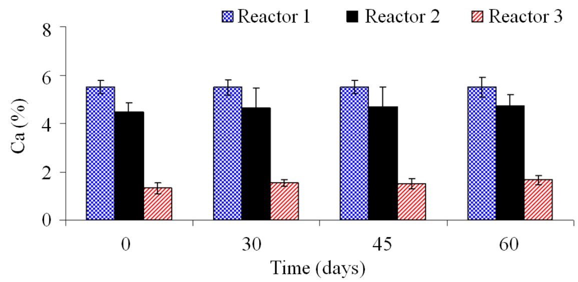

Fig. 13: Changes in calcium during natural aerobic composting

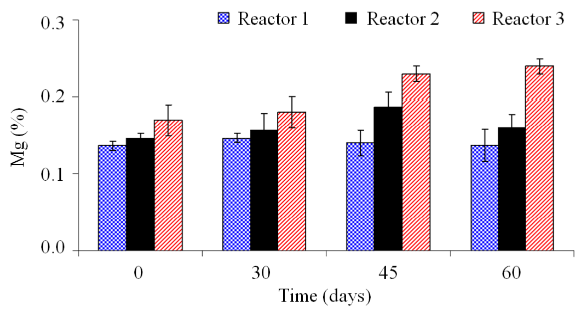

Fig. 14: Changes in magnesium during natural aerobic composting

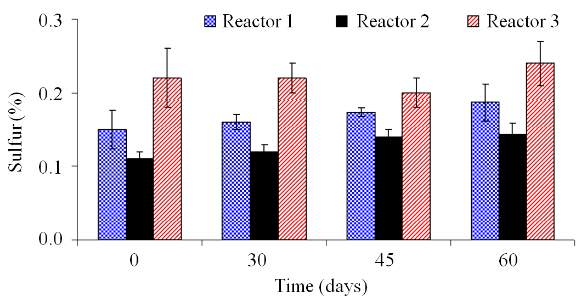

Fig. 15: Changes in sulfur during natural aerobic compostin

By agricultural standards, soils with an EC greater than 4 dS/m are considered saline. Actually, the conductivities less than 4 dS/m can have slight effect on salt-sensitive plants. However, salt tolerant plants can receive up to 8 dS/m conductivities (Fig. 12).

Trace nutrients: The trace nutrients in this study are calcium (Ca), magnesium (Mg) and sulfur (S). The trace nutrients increases during the composting period which is enough to denominate as a fertilizer (Fig. 13-15) The increasing value of trace nutrients during the composting may be caused by (i) loss of organic fraction as carbon monoxide (Hamoda *et al.*, 1998) and (ii) respiration of microorganisms.

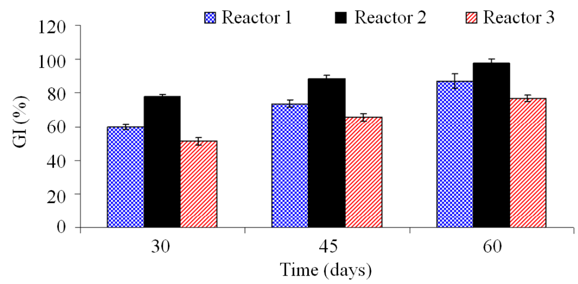

Fig. 16: Changes in Germination Index (GI) during natural aerobic composting

Germination Index (GI): The GI for compost product should be more than 80% of compost standard from Department of Agriculture (2008). Phototoxicity decreased during composting because the toxic substances are metabolized by microorganisms. The final composting process disappeared completely at the end of composting process (Tiquia *et al.*, 1996). The absence of phototoxicity occurs at GI greater than 60% (Tiquia *et al*., 1996). Figure 16 shows the GI increased when the compost time increased. The GI of the final compost in reactor 1, 2 and 3 is 86.88, 97.60 and 76.73%, respectively (Table 4). The final compost in the reactor 1 and 2 is suitable for plant growth. The N: P: K ratio is 1.37: 0.46: 1.86, 1.48: 0.48: 1.93 and 1.10: 0.53: 1.24 for reactor 1, 2 and 3, respectively.

Table 4 showed the characteristics of final compost in reactor 1, 2 and 3 and the Thai compost standard from the Department of Agriculture. The moisture content of the final compost is higher than that of the Thai compost standard. Therefore, the final compost should be dry in the wind or the sun before use. The phosphorus of reactor 1 and 2 is 0.45 and 0.48, respectively which is slightly lower than the Thai compost standard. The GI of reactor 3 is 76.73% which is lower than the Thai compost standard. The optimum GI for the Thai compost standard should be higher than 80%. It can be concluded that the final compost of reactor 2 is the best quality and meet the Thai compost standard. The reactor 3 consists of golden apple snail, rice straw and urea. The mixture ratio of golden apple snail: rice straw: urea is 1.0: 3.0: 0.007 by weight.

CONCLUSION

The final compost of rice straw and cattle dung or golden apple snail was characterized by determinations of parameters such as pH, moisture content, C/N ratio, organic matter, temperature, nutrients, EC and GI.

The high-nitrogen containing waste exerted a great influence on natural aerobic composting performance since the appropriate conditions of the physical environment for air distribution must be maintained during the composting process. The cattle dung and golden apple snail are superior to straw for natural aerobic composting. Golden apple snail, tend to be located in rice producing areas where rice straw is available in abundance.

The results showed that the rice straw as agricultural residue is suitable for composting with high nitrogen containing wastes. The urea helps to improve the composting process. The moisture content is slightly high and the final compost can be dried to reduce moisture before use as fertilizer. The major nutrients (N, P and K) are high enough to allow it to be denominated as a fertilizer in the legal sense. The composting appears very attractive, but much research is needed to establish its economic feasibility. The final compost of all reactors has a high fertilizer value, a high level of stability and an absence of phytotoxicity. The results indicated that the reuse of agricultural residue as composting material can be environmental-friendly sustainable method to solve the rice straw burning problem, which is in turns, can help reducing the air pollution from burning.

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