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# Co-composting of coir pith and cow manure: initial C/N ratio vs physico-chemical changes

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## Abstract

**Background:** As objective of this study was focused on efficacy of composting of a recalcitrant organic waste material, co-composting of coir pith with cow manure and rice bran was endeavored to evaluate influence of initial C/N ratios, i.e., 30, 25, and 20, on physico-chemical changes, e.g., temperature, pH, organic matter (OM) degradation, and total nitrogen (TN) losses.

**Results:** Results showed that OM and TN losses were significantly affected by C/N ratio ( $p < 0.05$ ), whereas C/N ratio played insignificant role on temperature and pH evolution within the pile ( $p > 0.05$ ) during composting process. OM and TN losses were highest within the first 2 weeks of thermophilic phase. Through the composting process, pile with 25 C/N ratio showed the highest biodegradation rate constant of organic matter ( $k = 0.309 \text{ day}^{-1}$ ) and the highest TN losses (41.9%), while pile with C/N ratio of 30 showed the lowest N loss (-7.3%). However, for all three compost piles, maturity, as indicated by the pile temperature converging to the ambient temperature, was attained within 1 month post-composting.

**Conclusion:** Results suggested that simple pile turning yielded effective co-composting of coir pith under comparatively low C/N ratio. Considering the composting performance and the amount of coir pith to be utilized, the initial C/N ratio of 30 was considered suitable for coir pith composting.

**Keywords:** Coirpith, Composting, C/N ratio, Organic matter degradation, Total nitrogen loss

## Introduction

Thailand is the sixth largest coconut producer of the world with annual coconut production of 1.5 million tons (Office of Agricultural Economics of Thailand 2011). One of the post-harvest processing of coconut in Thailand confines to oil extraction where large amount of coconut wastes, particularly coconut husk and coconut juice totaling 50,000 tons and 182,000 m<sup>3</sup>, was generated annually Fuangworawong et al. (2008). Coir pith, a by-product of the coir fiber manufacturing industry, is generated during coir fiber extraction from coconut husk. Only 20% of such wastes produced in Prachuap Khiri Khan Province, a large coconut producer in Thailand, were efficiently utilized, while the rest was left and/or discarded inattentively leading to environmental problems Fuangworawong et al. (2008).

Coconut coir pith has found applications in brick and particle board production Dan (1993); Viswanathan (1998), animal husbandry as bedding materials Maheswarappa et al. (2000), and production of charcoal capable of adsorbing several toxic metal ions such as Cd, As, Cu, and Pb. Additionally, coir pith has been widely utilized in agriculture due to its physical properties such as high porosity and water holding capacity rendering it suitable for employing as planting materials Ravindranath (1991). The coir pith contains high carbon to nitrogen (C/N) ratio, 75 to 186, together with 35% to 54% lignin content Abad et al. (2002); therefore, coir pith is highly resistant to biological degradation. Composting in general converts organic materials into a readily usable form as indicated by the decline of the C/N ratio. Although composting is of high potential as an effective method for treating coir pith to land application Srinivasan et al. (2005), efficacy of coir pith composting suffers still from several drawbacks. For example, Fuangworawong (2008) found that several months were necessary in order to obtain matured coir pith compost even though aeration was provided. Even

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though few attempts have been made to accelerate composting of coir pith such as inoculating with different microbes, inocula, improving the process design to ensure the success of oxygen distribution within the compost pile Ghosh et al. (2007), results attained were marginally satisfactory.

C/N ratio is one of the most important factors affecting composting process and compost quality Golueke (1991). Generally, composting could be carried out under a wide range of initial C/N ratios, namely, 11 to 105, depending on the starting materials Eiland et al. (2001); Ghosh et al. (2007). However, it was recommended that composting of recalcitrant raw materials should be conducted under low ranges of C/N ratios. Recent studies have shown that composting can be carried out effectively at a lower C/N ratio of 15 Zhu (2007). Eiland et al. 2001 have successfully co-composted *Miscanthus* straw with pig slurry at low initial C/N ratio of 11 to 35. The authors found that low initial C/N ratios led to high degradation rate (40% to 80%) of both cellulose and hemicellulose indicating high microbial activities, whereas high initial C/N ratios yielded inferior efficacy, approximately 10% to 20% degradation. Kumar et al. (2010) attempted composting of food waste together with green waste at the initial C/N ratio ranging from 14 to 20 and found that effective composting was attained with the C/N ratio of 19.6. Ekinici et al. (2000) reported that during composting of short paper fiber and broiler litter, an increase in initial C/N ratio led to a decline in NH<sub>3</sub>-N loss given further that, at pH lower than 7, NH<sub>3</sub>-N loss decreased more rapidly. Additionally, Huang et al. (2004), by co-composting of pig manure and sawdust at the initial C/N ratios of 30 and 15, reported that the pile with initial C/N ratio of 30 reached maturity within 49 days. Therefore, the aim of this study was to investigate the influence of low C/N ratio on naturally aerated composting of high lignocellulosic materials, particularly coir pith, under several C/N ratios in terms of physico-chemical changes, organic matter (OM) degradation, and total

nitrogen loss providing that qualities of the compost were evaluated.

## Methods

### Composting materials

Materials employed for composting in this study are coir pith, cow manure, rice bran, molasses, and coconut juice. Physical and chemical characteristics of each raw material are provided in Table 1.

### Compost preparation

The three composting materials, namely, coir pith, rice bran, and molasses, were prepared at the ratio of 3:1:0.08 by wet weight. Subsequently, cow manure at the ratios of 1, 2, and 3 (by wet weight) was added and then designated respectively as treatments 1, 2, and 3 whose corresponding initial C/N ratios of 30, 25, and 20, respectively. Moisture content was adjusted to 50% to 60% initially using coconut juice. Each treatment was then transferred to store in a separate vessel (0.09 m<sup>3</sup>), covered with sack, and incubated at room temperature for an entire period of composting. Intermittently, moisture content was adjusted using coconut juice in order to maintain at approximately 50% to 60%. Aeration of the compost pile was accomplished through periodic pile turning at every 7-day interval during bio-active phase, in other words, the time period of which temperature of the compost pile was higher than that of ambient Kuo et al. (2004). Sample was collected at 0, 3, 7, 14, 21, 28, 35, 60, and 120 days.

### Analytical methods

Temperature evolution during composting was closely monitored for the entire composting process. Moisture content was measured by subjecting to drying in an oven at 105°C for 24 h or until constant weight. Changes of pH were followed according to the method recommended by AOAC (1995). Total OM was determined by incineration at 550°C for 24 h AOAC (1995) and total carbon was, subsequently, determined as suggested by Navarro et al. (1993). Total nitrogen (TN) was measured by macro-Kjeldahl method AOAC (1995). Contents of both OM and TN losses were calculated according to the procedure

**Table 1 Physical and chemical characteristics of raw materials**

Property	Coir pith	Rice bran	Cow manure	Molasses	Coconut juice
Moisture content (%)	6.35 ± 1.12	8.18 ± 0.08	3.70 ± 0.10	22.64 ± 1.52	95.80 ± 0.01
pH	5.68 ± 0.01	6.08 ± 0.01	8.25 ± 0.01	5.10 ± 0.02	6.25 ± 0.03
Ash (%)	47.11 ± 9.07	9.17 ± 0.11	67.91 ± 1.97	7.43 ± 5.21	12.41 ± 0.52
Organic matter (%)	52.89 ± 9.07	90.83 ± 0.11	32.09 ± 1.97	92.57 ± 5.21	87.59 ± 0.52
Total carbon (%)	29.38 ± 5.04	50.46 ± 0.06	17.83 ± 1.09	51.43 ± 2.90	48.66 ± 0.29
Total nitrogen (%)	0.44 ± 0.03	1.04 ± 0.03	0.89 ± 0.04	0.81 ± 0.06	1.59 ± 0.25
C/N ratio	66.13 ± 11.3	48.33 ± 0.06	20.02 ± 1.23	63.84 ± 3.59	30.58 ± 0.08

proposed by Paredes et al. (2000). Phosphorus and potassium were quantified using ascorbic acid colorimetric method and atomic absorption spectrophotometer as recommended by AOAC (1995). Physical and chemical analyses were conducted in triplicate. Data were subjected to ANOVA, and treatment means were compared using least significant difference (LSD) at  $p < 0.05$ , using Minitab 14 (Minitab Inc., PA, USA).

## Results and discussion

### Physical characteristics

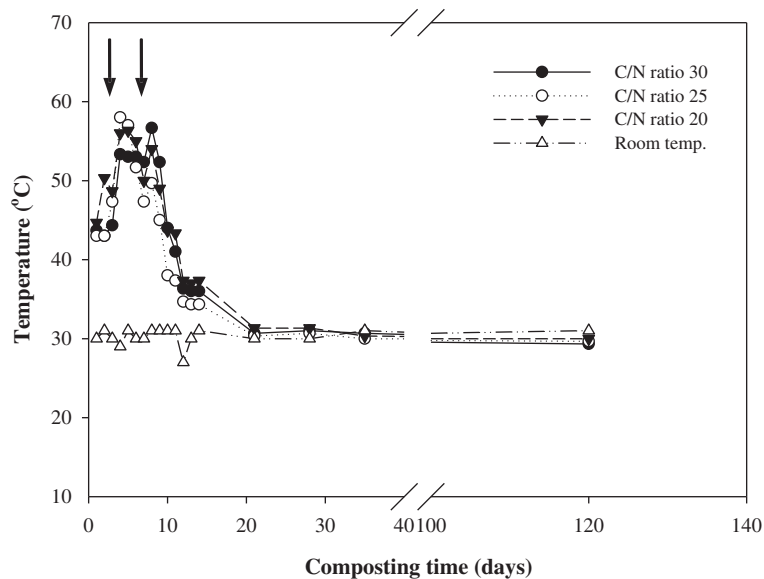
Visual observation in terms of texture, color, odor, and microbial evolution during the whole period of composting revealed that physical characteristics of all compost piles were similar during the first week of composting. Insignificant physical changes were noticeable except that an appearance of white fungi was observed from day 1 of composting. During the second and third week of composting, composting materials were of smaller sizes with brownish color given that white fungi could still be visually observed. From the fourth week of composting onwards, qualities of coir pith compost prepared conformed well to those of the organic compost standard specified by the Department of Agriculture of Thailand (2005) in that compost became loose, easy to pulverize, and of blackish brown color with humus-like fragrance.

### Composting process performance

Temperature evolution directly reflects microbial activities during composting Golueke (1991) which may be considered as a good indicator of the bio-oxidative phase. In this study, the bio-oxidative phase could also be classified into two phases: the thermophilic (70°C to

40°C) and mesophilic (40°C to 25°C) phases Kuo et al. (2004) which are typically reported in the literature as lasting at 11 and 23 days, 9 and 25 days, and 11 and 23 days, respectively, for treatments 1, 2, and 3. It is evident from Figure 1 that the temperature profiles for the three treatments were of similar pattern. Further, a rapid increase in temperature was noticeable since day 1 post-composting, reaching 56°C to 58°C, the thermophilic temperatures at eight, fourth, and fifth days of composting, respectively, and maintained for 9 to 11 days. Results found are in line with that recommended by the USEPA in that temperature of the compost pile should be higher than 40°C and maintained for at least 5 days in order to ensure elimination of pathogenic microorganisms USEPA (1993). After the thermophilic stage, temperatures of all treatments rapidly declined until day 14 post-composting and then gradually decreased to that of the ambient temperature. Subsequently, from day 21 onwards, temperature remained at ambient until the end of composting process indicating maturation phase providing that composting materials whose color were more intense became loose in character (Diaz and Savage 2007).

An increase in temperature observed in all treatments on day 8 may possibly be due to a result of delayed microbial growth stemming from pile turning and moisture content adjustment on day 7. Generally, pile turning could reactivate the composting process due to an increase in oxygen availability to microorganisms present during composting Cayuela et al. (2006). From day 8 onwards, temperature of treatment 2 declined more rapidly than those of treatments 1 and 3. Results further suggested that, for 25:1 C/N formulation, high



**Figure 1** Temperature profile of coir pith composting under various initial C/N ratios. Arrow indicates moisture adjustment.

microbial activities occurred leading subsequently to rapid degradation of organic matters of the compost. The results are in line with that of Zhu 2007 who investigated the effect of low initial C/N ratio on composting of wheat straw with pig manure and reported that formulation containing 25:1 C/N ratio exhibited a more rapid decrease in temperature than pile formulated with the 20:1 C/N ratio.

As is obvious from Figure 2, the initial C/N ratios affected pH changes during the thermophilic phase insignificantly during the first 2 weeks of composting process ( $p > 0.05$ ). For all three compost preparation, pH increased gradually from 4.8 to 5.4 on day 1 to 7.3 to 8.1 on day 7 post-composting. After 2 weeks of composting, the pH values of all composts prepared gradually declined from 8.0 to 8.3 to 6.9 to 7.3. Additionally, the pH values of all treatment piles remained rather constant ( $p > 0.05$ ) since day 35 post-composting. At the end of the process (day 120), the pH values of all treatments were not significantly different ( $p > 0.05$ ) which abided by the Thai standard of organic compost Department of Agriculture of Thailand (2005).

An increase in pH of all compost piles at the commencement of composting, especially during the thermophilic phase, was due likely to the metabolic degradation of organic acids Satisha and Devarajan (2007) and the ammonification process taking place during organic matter degradation Mahimairaja et al. (1994). After the 14th day, the pH values of all piles were significantly declined which is likely to be a consequence of phenolic compound production and organic acid production during biodegradation of

lignocellulose in the compost piles Satisha and Devarajan (2007).

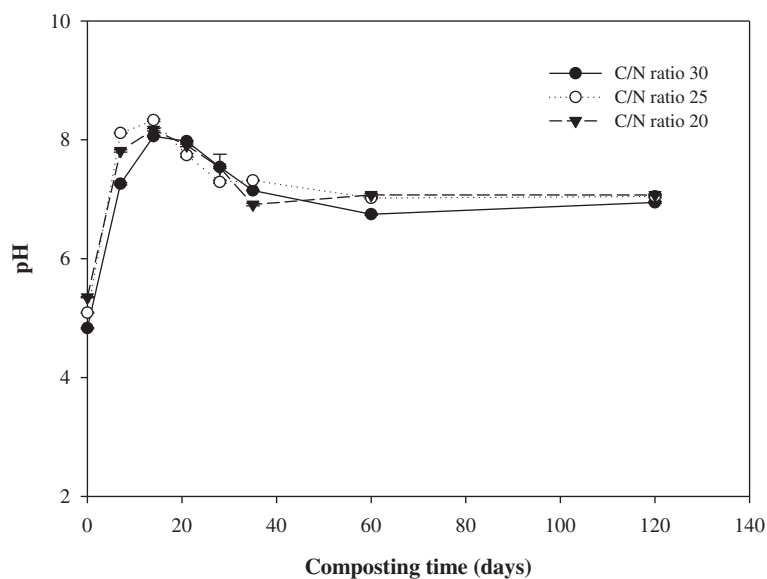
#### C/N ratio

The C/N ratio is usually employed to indicate the maturity degree of compost Bernal et al. (1998). A decrease in C/N ratio implies an increase in the degree of humification of organic matter. As can be observed from Figure 3, the C/N ratio of the three piles decreased substantially until 21 days of post-composting and became comparatively stable. The compost piles containing 30:1 and 25:1 C/N ratio yielded a more rapid decrease in C/N ratio than that observed with the 20 C/N ratio formulation. Such evolution coincided well with the significant reduction in organic matter (Figures 4 and 5) indicating a rapid biodegradation rate.

#### Organic matter degradation

The evolution of organic matter during composting of coir pith with different cow manure concentrations is shown in Figure 4. For treatments 1, 2, and 3, organic matter declined from 75.8%, 84.5%, and 80.1% at day 1 to 68.1%, 64.8%, and 63.7%, respectively, at the end of the process (day 120). The decrease in organic matter indicated the biodegradation within the compost piles.

In general, OM is oxidized to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  including microbial biomass during the aerobic composting process. Therefore, the rate of organic matter loss reflects the overall composting rate Diaz and Savage (2007). As is shown in Figure 5, OM degradation of the three compost piles during the initial phase of composting was more rapid than that of the latter composting



**Figure 2** pH evolution during co-composting of coir pith with various concentrations of cow manure.

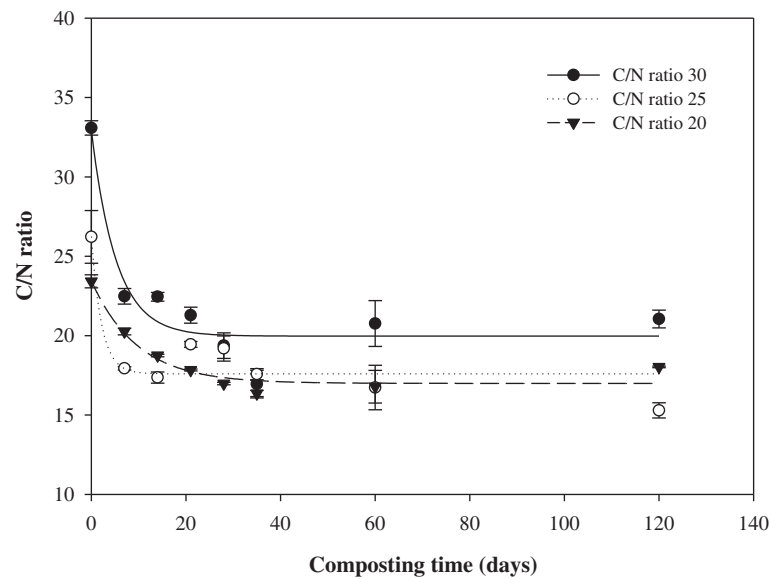


Figure 3 The time profile of C/N ratio of coir pith composting under several initial C/N ratios.

stage, from day 14 onwards. The OM degradation for an entire composting process, expressed in terms of OM loss, fitted well to the first-order kinetic ( $p < 0.05$ ) of the form Paredes et al. (2000):

$$OM \text{ loss} = A(1 - e^{-kt}),$$

where  $A$ ,  $k$ , and  $t$  are maximum OM degradation (%), degradation rate constant ( $\text{day}^{-1}$ ), and composting time (days), respectively.

The high reaction rate constant ( $k$ ), ranging from  $0.08 \text{ day}^{-1}$  (C/N ratio of 20) to  $0.31 \text{ day}^{-1}$  (C/N ratio of

25) indicated the rapid biodegradation of the composting materials, coir pith and cow manure. Formulation containing C/N ratio of 25 (pile 2) appeared to degrade the most rapid, as demonstrated by the highest values of both  $k$  ( $0.31 \text{ day}^{-1}$ ) and the product  $A \times k$  ( $18.4\% \text{ day}^{-1}$ ) indicating an extent of material degraded per time (Table 2). For treatment 2, 57.5% of the initial OM was mineralized during the first 14 days of composting given further that by the end of composting 66.1% OM loss was attained (Figure 5). When initial C/N ratio was either higher or lower than 25, namely, 20 and 30 in this study, the total OM losses during composting process

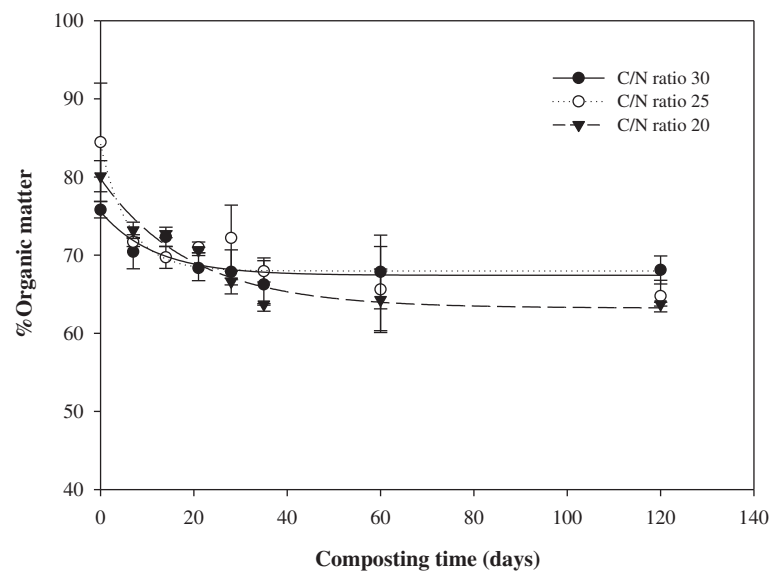
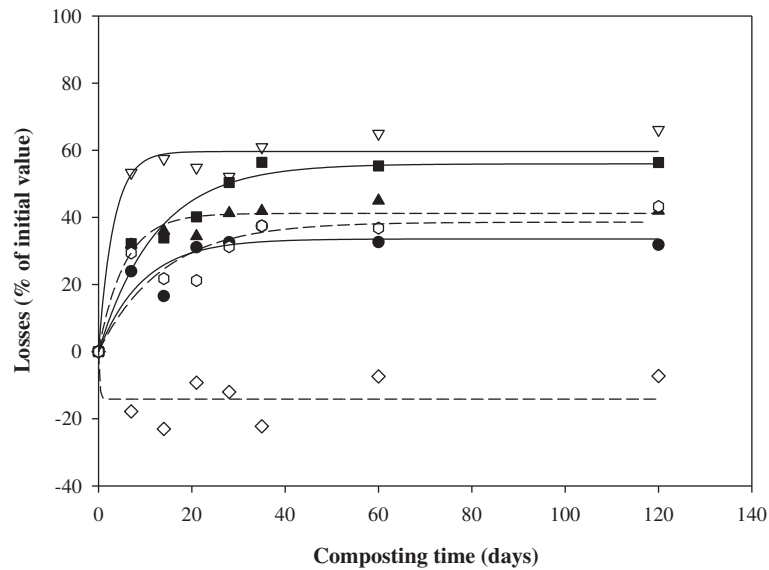


Figure 4 Changes of organic matter of coir pith co-composted with various amounts of cow manure.



**Figure 5** Losses of OM and nitrogen during composting of coir pith under different initial C/N ratios. Solid line indicates OM loss, and its corresponding C/N ratios are indicated as follows: 30 (black circle), 25 (inverted triangle), and 20 (black square). Broken line indicates TN loss, and its corresponding C/N ratios are as follows: 30 (diamond), and 25 (black triangle), and 20 (hexagon).

were much lower; in other words, approximately 31.8% to 56.4% of the initial OM was mineralized by the end of the composting process.

**Total nitrogen and nitrogen losses**

Table 3 shows total nitrogen (TN) changes observed for treatments 1, 2, and 3 during composting. The TN of all treatments tended to increase from 1.27%, 1.79%, and 1.90% on the first day of composting to 1.80%, 2.35%, and 2.00%, respectively, at the end of process (120 days). The increase of total nitrogen during composting process might be caused by the weight loss of the compost piles during composting process Dias et al. (2010).

In general, the TN loss was controlled by the initial C/N ratio Goyal et al. (2005; Dias et al. (2010) as well as the OM degradation Barrington et al. (2002). For all three compost treatments, TN losses conformed satisfactorily to the first-order degradation kinetic Paredes et al. (2000) with coefficients of determination ( $R^2$ ) of greater than 90% (Table 2) except for nitrogen loss of the treatment containing initial C/N ratio of 30. TN losses during composting process were approximately -7.3%, 41.9%, and 43.2%, respectively, for

piles 1, 2, and 3. Although the TN losses of treatments 2 and 3 were apparently higher than that of treatment 1, TN content in the final compost of treatment 2 was significantly higher than that of treatment 1 ( $p < 0.05$ ).

The lowest nitrogen loss was observed for treatment 1 whose C/N ratio was 30, due to the high initial C/N ratio of composting mixtures which favored the microbial growth and, at the same time, enhanced immobilization of inorganic nitrogen Liang et al. (2006), therefore, reducing TN losses in the form of  $N-NH_3$  Dias et al. (2010). In contrast, high nitrogen losses were evident for both treatments 2 and 3, approximately 41.9% to 43.2% of the initial N (Figure 5), suggesting higher loss of nitrogen as ammonia under the low initial C/N ratio Tiquia and Tam (2000). High organic matter degradation generally leads to high TN losses Dias et al. (2010) due possibly to high degree of mineralization through high ammonia volatilization and, in turn, regulates the concentrations of  $NH_4^+$  available in the compost pile. The degrees of TN loss found for both treatments 2

**Table 2** Parameter of the first-order equation describing OM and nitrogen degradation

Treatment	OM loss			N loss		
	A (%)	k (day <sup>-1</sup> )	R <sup>2</sup>	A (%)	k (day <sup>-1</sup> )	R <sup>2</sup>
Pile 1 (C/N ratio of 30)	33.57	0.10	0.85	-14.14	3.75	0.38
Pile 2 (C/N ratio of 25)	59.63	0.31	0.95	41.19	0.18	0.96
Pile 3 (C/N ratio of 20)	55.95	0.08	0.95	38.58	0.07	0.75

A, maximum degradation; k, rate constant.

**Table 3** TN changes during coir pith composting

Composting time (day)	Total nitrogen (%)		
	30 (Pile 1)	25 (Pile 2)	20 (Pile 3)
0	1.27 ± 0.08 c	1.79 ± 0.08 b	1.90 ± 0.26 a
14	1.79 ± 0.07 b	2.23 ± 0.05 a	2.15 ± 0.06 a
35	2.17 ± 0.14 a	2.15 ± 0.28 a	2.13 ± 0.31 a
60	1.82 ± 0.09 a	2.18 ± 0.03 a	2.13 ± 0.32 a
120	1.80 ± 0.02 b	2.35 ± 0.02 a	2.00 ± 0.19 ab

Values of the same row followed by the same letter are statistically insignificant at  $p > 0.05$  according to the LSD test ( $n = 3$ ).

**Table 4 Qualities of coir pith compost prepared at various initial C/N ratios (35 days)**

Parameter	Pile 1	Pile 2	Pile 3	Organic compost standard (2005)
	(C/N ratio of 30)	(C/N ratio of 25)	(C/N ratio of 20)	
Nitrogen (%)	2.17 ± 0.10 a	2.15 ± 0.30 a	2.13 ± 0.30 a	>1.0
Phosphorus (%)	0.16 ± 0.002 c	0.240 ± 0.002 a	0.18 ± 0.002 b	>0.5
Potassium (%)	2.49 ± 0.30 b	3.03 ± 0.30 a	2.32 ± 0.10 b	>0.5
pH	7.10 ± 0.00 b	7.30 ± 0.00 a	6.90 ± 0.00 b	7.0 to 8.0
Organic matter (%)	66.20 ± 3.40 a	67.90 ± 1.40 a	63.70 ± 0.10 a	25 to 50
C/N ratio	17.00 ± 0.90 ab	17.60 ± 0.40 a	16.40 ± 0.20 b	0 to 20:1

Multiple comparison was performed within a row for mean value (±SD) of which different letters indicate statistically different at 95% confidence interval (n = 3).

and 3 were similar to those obtained by Martin and Dewes (1992) who reported that 37% to 54% of the initial TN was lost during the co-composting of rice straw and cattle manure under the low initial C/N ratios ranging from 12.9 to 14.4. Further, Barrington et al. (2002) also reported that approximately 85% of initial TN available was degraded, whereas 70% of C was lost during immobilization process under low initial C/N ratio composting of approximately 20.

#### Compost maturity and quality

Several indices have been employed to assess the state of composting including color, odor, temperature, and C/N ratio Zmora-Nahum et al. (2005). According to the physico-chemical changes as well as compost qualities (Figures 1,3,5), compost prepared with initial C/N ratio of 25 reached maturity faster, approximately 1 week, than those prepared with initial C/N ratios of 20 and 30. By the end of composting, qualities of compost (Table 4) conformed well to that specified by the Thai standard for organic compost Department of Agriculture of Thailand (2005). Furthermore, the efficacy, in terms of maturity, of composting process using the natural aeration under low C/N ratio for co-composting of coir pith in this study was comparable to those reported by Ghosh et al. (2007) who composted coir pith fortified with edible oyster mushroom and urea in a multilayer heap fashion given that perforated PVC pipes were employed for the purpose of aeration. The authors found that the multilayered heap composting of coir pith led to compost maturity within 21 days. Results found in this study indicated that forced aeration during composting of coir pith was not necessary if coir pith was fortified with cow manure, rice bran, and coconut juice and operated under low C/N ratio; however, maturity was reached at 35 days post-composting.

#### Conclusions

Co-composting of coir pith supplemented with cow manure, coconut juice, and rice bran under comparatively low initial C/N ratios, i.e., 20, 25, and 30, was investigated in this study. For the three compost piles, physical changes in

terms of color, odor, and texture, and pH appeared to be of similar trend and reached maturity within 1 month. Further, initial C/N ratios posed significant influence on the composting performance assessed in terms of temperature evolution, OM degradation, and TN loss. The OM and TN losses observed for all compost piles fitted well to the first-order kinetic. Pile 2 with the initial C/N ratio of 25, on the one hand, showed the fastest biodegradation rate during the initial (bio-oxidative) phase of composting and, on the other hand, led the highest TN losses during an entire composting process. Pile 1 with the initial C/N ratio of 30 allowed optimal composting process in that minimal TN loss and utilization of larger quantity of coir pith were accomplished.

#### Competing interests

The authors declare that they have no competing interests.

#### Authors' contributions

All authors, ST, KP, SK, and SA, have made adequate effort on all parts of the work necessary for the development of this manuscript according to his/her expertise. All authors read and approved the final manuscript.

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