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GREENHOUSE GASES EMISSION OF COMMUNITY COMPOSTING OF AGRICULTURE AND AGRO-INDUSTRY AGED WASTES

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ABSTRACT

This study investigated the greenhouse gas emission of compost products from community composting plants. Aged wastes from agricultural and agro-industrial sources used as raw materials for composting with intermittent forced aeration static pile composting application. Investigation of two types of compost products, including powder and granular shapes, revealed that the powder composting process emitted CO_2 and CH_4 gases as 730.23 kg and 4.81 kg, respectively, during the composting process, while the granular composting process emitted 784.38 kg CO_2 and 3.39 kg CH_4. An additional liquid mixture for granular formation contributed to higher emissions of CO_2 and CH_4 compared to the powder composting process. These data are useful for conducting life cycle assessments to evaluate and improve the environmental performance of community composting systems.

Keywords: aged waste, greenhouse gas emissions, community composting, agricultural and agro-industrial wastes.

1. INTRODUCTION

Composting defines as a controlled aerobic, biological conversion of organic wastes into a complex and stable material. The final product has several beneficial uses, most commonly for agriculture and landscaping [1]. This product is useful as an organic amendment or growing medium, which improves soil physical properties for water retention and for the supply of essential nutrients [2]. The application of organic fertilizer has proven to result in lesser emissions of greenhouse gases into the environment compared to chemical fertilizers [3].

The Thai government has promoted composting technology to develop community participation and community economy by producing organic fertilizer through the program One District One Composting Plant [4], and also to overcome problems created by a massive amount of agricultural and agro-based industrial waste as the consequence of agricultural development activities [5], and to support sustainable agriculture in Thailand.

Greenhouse gases define as gases that trap heat in the atmosphere. The most important greenhouse gases emissions of human activities are carbon dioxide (CO_2) and methane (CH_4), beside nitrous oxide (N_2O) and other fluorinated substances. Although CO_2, CH_4, occurs naturally in the atmosphere, the concentration of these gases changes because of human activities. The CO_2 concentration in the atmosphere was 403 ppm in 2016, while methane was 1.843 ppm [6]. In last decade emission of greenhouse gases from solid waste management technology has become exciting topics to be studied, its varied from composting [7],[8], anaerobic digestion [9], recycling unit [10], incineration [11] and also from landfill practices [12].

Recent studies on the composting system and process had described emissions of gases from composting, such as CO_2, CH_4, N_2O, ammonia (NH_3), hydrogen sulfide (H_2S), nitrogen oxides (NOx), and volatile organic compounds (VOCs) [13]. CO_2, CH_4, and N_2O are the leading gases generated by microbial degradation of organic matter (OM) during composting [14]. These studies related to full scale and home scale composting with several composting methods, including windrows composting, tunnel composting, and composter, which mainly uses various raw materials consisting of various green waste. Moreover, these studies reported variations of gases emitted into the environment during the composting process [15], [16], [2], [17].

Furthermore, the studies observed raw materials of composting processes which mostly come from municipal solid waste as organic fraction of municipal solid waste (OFMSW), yard/garden wastes, leftover raw fruit and vegetables (LRFV), pruning wastes, and organic household waste (OHW) [18], [15], [2], [16], [3]. Other types and sources were pig manure and corn stalks, and feedlot cattle manure and wheat straw which by-product of animal farming activities and vegetable plantation [19], [20]. From these studies could be concluded that the composting process with various raw materials, different type, and aeration technology, would contribute a different amount of gaseous emission.

During the composting process, the organic matter in the feedstock is decomposed, formed compost, and gaseous emissions consist of water (H_2O) and CO_2, and partly of CH_4 and N_2O. In this process, aerobic microbial mineralized organic carbon (C) into CO_2, whereas the significant phase of waste reduction (dry mass). Carbon makes up 35-50% of the total solids content of source-separated organic household waste [21], [22], [23], and more than 80% of this carbon will degrade and emitted as CO_2 along composting process [24], [23]. The CO_2 emission of the composting process considered biogenic because it comes from organic material and considers as neutral in terms of global warming potential [25], [23]. The CO_2 emission of composting studies aims to allow better GHG accounting [26], [23]. Methane emission from composting has different ranges of production rates, from very low, near the detection limit of the equipment in industrial composting [16], [23], to the highest as 12% of initial carbon on static pile composting [27], [23].

The present study aimed to investigate greenhouse gas emissions. It includes CO_2 and CH_4 that produced during the composting process in community composting, using agricultural wastes from animal manure and agro-industrial wastes from palm oil mill factories and rice mill factories (decanter cake, rice husk, and rice bran). These wastes were kept at the generation sources for a few weeks and were dried to reduce the moisture content before being sent to the community composting plant. Therefore, such waste was not fresh but was pretreated to be aged before being used as raw material for composting. The investigation located at the selected community composting plant. It is essential to conduct this study, since composting processes with typical types and sources of raw materials, life cycles, composting techniques, and operating machines would have different impacts on the environment [5]. This investigation is used to understand the profile of gaseous emission rates during the composting process, which afterward can be used to assess the impacts of composting processes on the environment.

2. METHODOLOGY

2.1 Investigated composting plant and composting process

The selected community composting plant used in this study was located at Rattaphum District in Songkhla Province in southern Thailand, as shown in Figure-1. It composted raw materials from agricultural and agro-industrial wastes collected from animal farms and industries from both local and surrounding areas of the neighbouring provinces of Patthalung and Satun. The compost production capacity was 150 tons per year and can apply to rubber, oil palm, and fruit plantations.

In the composting plant, raw materials consisting of the aged waste of goat manure, chicken manure, bat manure, rice husk, rice bran, decanter cake from palm oil mill factories, and phosphate rock mixed with a liquid mixture containing water, liquid organic fertilizer, molasses, and seeds. The composting process was carried out in static piles in channels along 20 days, with intermittent forced air aeration for one hour a day for 15 days using a blower. The product of this process was then crushed to produce a powder product, while to produce the granular product, the process was continued by mixing with the additional liquid mixture, forming the granules, and dry the product for more than four days and up to 24 days. No leachate produced and no technology applied for air emission reduction. The compost product can use in oil palm and rubber plantations, and also in fruit farms, the composting process diagram is presented in Figure-2.

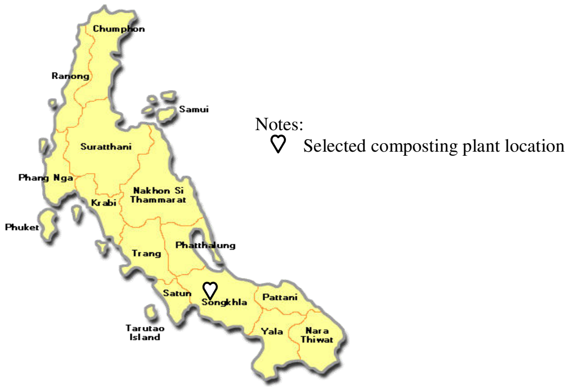

Figure-1. Location of studied community composting.

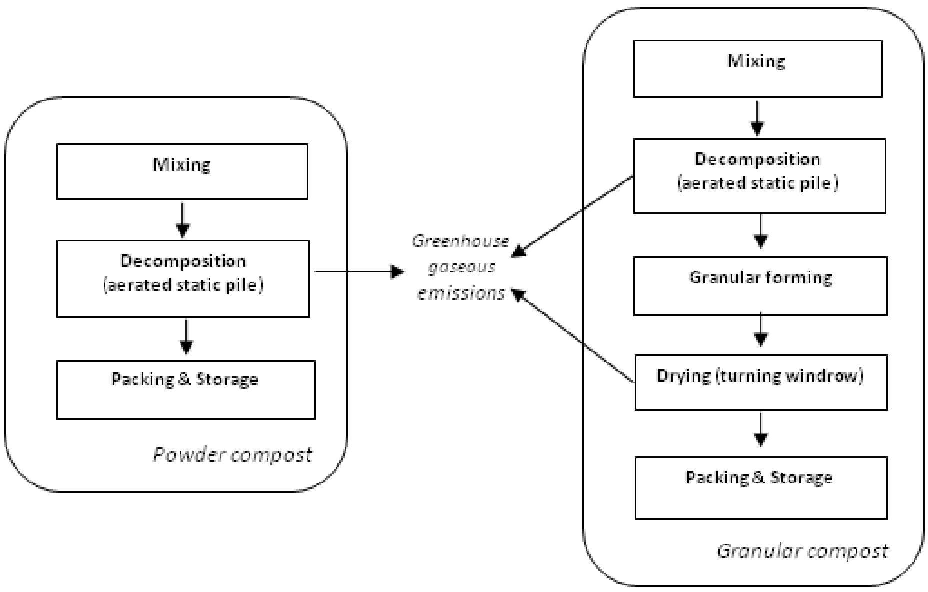

Figure-2. Powder and granular composting processes.

2.2 Sample collection and analytical methods

In general, for sampling spots, the dimension of composting piles in channels had to be considered, and there were 1.5 m high x 2.8 m long x 1.8 m wide. There was 1 sample spot for greenhouse gases emission sampling, and 3 sample spots in total as composite compost samples used to determine compost quality, as seen in Figure-3.

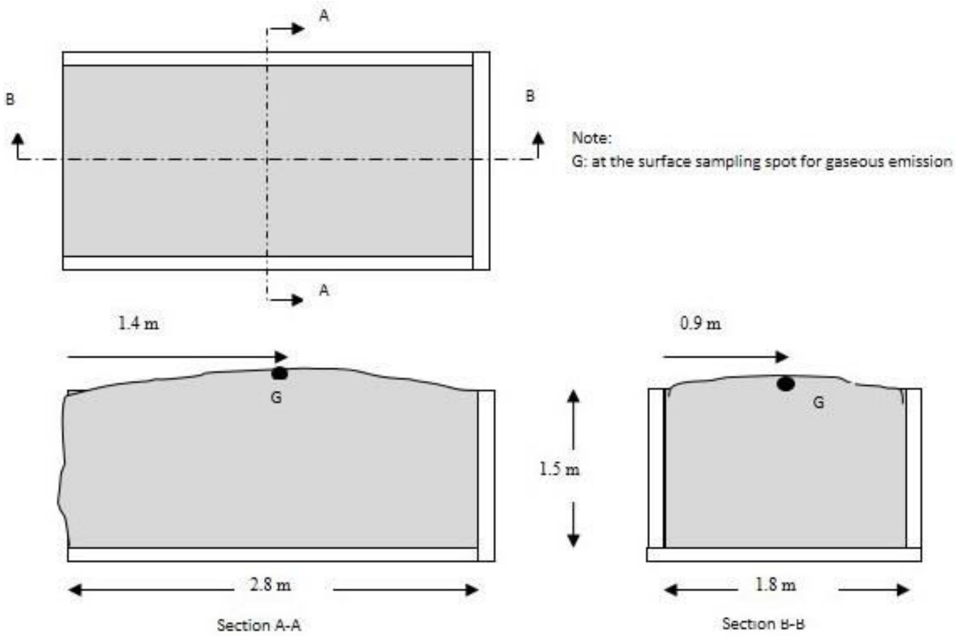

Figure-3. Sampling spots for compost product and gaseous emissions.

Sampling and measurement before 20 days of the composting time were done on composting piles in channels, while after 20 days it did in a granular compost drying station. Samples of gas emissions were collected by the static flux chamber method, which has been widely used for collecting greenhouse gas fluxes from soils [28], [29], landfills [30] and composting piles [17]. Gas fluxes (F_{flux}) on the top of composted material was determined by the change in the concentration of gases linearly inside the flux chamber over time (dC_{gas}/dt) at dimensions of the chamber ($V_{chamber}/A_{chamber}$), were formulated as [17]:

$$F_{flux} = \rho_{gas} \text{ x } dC_{gas}/dt \text{ x } V_{chamber}/A_{chamber} \quad (1)$$

where F_{flux} is the flux of greenhouse gases, in g $m^{-2}s^{-1}$; ρ_{gas} is density of specific greenhouse gases, in g m^{-3}; C_{gas} is greenhouse gas concentrations; in %, dt is the time interval of measurement, in seconds; $V_{chamber}$ is the volume of greenhouse gases trapped in the chamber, in m^3; and $A_{chamber}$ is area covered by a chamber, in m^2.

The static flux chamber that used was a modified static chamber made of PVC (Poly Vinyl Chloride) pipe, which 0.25 m in diameter and 0.25 m in height. Gas samples were taken from the sample port every 5 minutes during 30 minutes in every sampling day, including days 1, 5, 7, 10, 15, and 19. Gas samples were sucked from the sampling port using a 60 mL syringe, injected into 6 mL sample-tubes, and stored in the sample box. In addition, for granular composting, gas sampling for 22 and 24 days of composting periods were continually collected using the same method mentioned before. A sample spot for gas emissions located in the central part of the pile surface.

Gas samples were analyzed in The Scientific Equipment Centre, the certified laboratory in Prince Songkla University, Thailand. Gas emissions analysis only for the emission of carbon dioxide and methane only, Dinitrogen monoxide was excluded from this study by consideration of limited gas analyses provided by the certified laboratories. Gas samples analyzed by gas chromatography with a thermal conductivity detector (GC-TCD) using HP-PLOTQ column, 30 m x 0.53 mm ID. X film thickness 40 µm, with condition column flow rate 9 psi @ split 1:2; inlet temperature 250^{o}C; oven isothermal temperature 60^{o}C hold 3 min; detector temperature 250^{o}C; make up flow 2 mL/min; and reference flow 16 mL/min.

3. RESULTS AND DISCUSSIONS

3.1 Gas concentrations

Gaseous concentrations of CO_2 and CH_4 during the composting process present in Table-1.

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Table-1. CO_2 and CH_4 concentrations during the composting process.

Composting Time (day)	CO_2 (mL/L)	SD	CH_4 (mL/L)	SD
1	13,800.00	±8,614.91	363.29	± 39.87
5	6,925.00	±4,784.26	371.25	± 97.63
7	8,700.00	±6,211.28	388.00	± 30.08
10	6,287.71	±3,575.06	362.29	± 132.92
15	8,859.43	±4,694.44	299.57	± 21.69
19	4,943.83	±3,262.03	275.17	± 32.85
22	2,696.67	±1,563.06	413.33	± 64.70
24	4,426.67	±874.86	283.33	± 46.76

Table-1 revealed that in the powder composting process (represented by data of day 1 until day 19) concentrations of CO_2 during the sampling time ranged from 4, 943.83 to 13, 800.00 mL/L which started at the highest concentration and ended at the lowest concentration, while CH4 concentrations showed slight variations around 275.17 to 388.00 mL/L which fluctuated along the sampling time. During more extended composting periods (from day 1 to day 24) for the granular composting process, concentrations of CO_2 reached the lowest value at 2, 696.67 on the 22nd day. They ended in the range of concentration of the previous process. Otherwise, concentrations of CH_4 reached their highest value at 413.33 on the 22nd day. They ended at the same concentration as at the end of the powder composting process.

3.2 Gases flux

The determination of gaseous emissions was based on the gaseous flux analyzed from samples collected. By following Equation 1, the flux of gas for each sampling day shows in Table-2.

Table-2. CO_2 and CH_4 fluxes during the composting observation.

Composting time (day)	Powder composting		Granular composting	
	CO_2 (g/m^2/s)	CH_4 (g/m^2/s)	CO_2 (g/m^2/s)	CH_4 (g/m^2/s)
1			0.59	0.002
5	0.59	0.002	0.66	0.001
7	0.66	0.001	0.69	0.002
10	0.69	0.002	0.31	0.004
15	0.31	0.004	0.36	0.002
19	0.36	0.002	0.20	0.002
22	0.20	0.002	0.10	0.004
24			0.07	0.003

The flux of CO_2 rose continuously from the initial day at 0.59 g/m^2/s to the highest flux at 0.69 g/m^2/s on the 7th day of composting time. On the other days, flux dramatically declined on the 10th day and decrease ended on the 19th day after slightly increasing on the 15th day. As the granular forming process continued, CO_2 flux kept decreasing until the end of the process as 0.07 g/m^2/s on the 24th day. Table-2 shows that CO_2 flux reached the highest emissions on the 7th day or at the one-third period of the composting process. This pattern showed similar conditions with related studies on composting of cattle deep litter [31], dairy manure [32], and agro-industrial waste [14].

Meanwhile, CH_4 flux, as presented in Table-2, was dropped on the 5th day, moving gradually higher on the 7thday, and on the 10th day reached the highest flux at 0.004 g/m^2/s. The flux reduced thereafter and ended at 0.002 g/m^2/s on the 19th day after slightly moving up from the 15th day. Table-2 shows that the highest methane flux was at the halfway point of the composting process. This finding is also in line with related studies on composting of cattle deep litter [31], dairy manure [32], and agro-industrial waste [14], where the peak of emission reached the half period of the composting process. Meanwhile, as granular forming continued, by addition of liquid mixture, CH_4 flux was increased and reached its highest point on the 22nd day at 0.004 g/m^2/s and fell to 0.003 g/m^2/s on the last day of the process.

This condition can be caused by the repetition of the process on the 7th day, where the input of new microorganisms and substrate of carbon source from molasses in the liquid mixture had activated the degradation activity and produced methane. The increased CH_4 flux indicated that the additional liquid mixture for granular forming of compost contributed more to CH_4 emissions.

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3.3 Gas emissions during the composting process

Gas emissions during the composting process were calculated by multiplying gas flux with composting process time and comparison of the area covered by the flux chamber with the surface area of the composting pile. By summing all emissions of gases during the composting days of the powder process resulted in a total emission of gases, including 730.23 kg CO_2 and 4.81 kg CH_4 during the composting time, as shown in Figure-4. Meanwhile, for the granular composting process, CO_2 was emitted as 784.38 kg and CH_4 as 3.39 kg during the composting process.

Emissions of CO_2 and CH_4 in the percentage of each sampling day were shown in Figure-4. As for the powder compost, CO_2 emission on the initial day was only 3.5% of total emission and rose rapidly to the highest emission on the 5th day at 29.8% of the total emission or as 217.568 kg. Afterward, the emission fluctuated and ended at 13.3% of total emissions on the last day after it dropped from 19.7% of emissions on the 15th day. Meanwhile, the movement of the CH_4 emission profile exhibited that on the initial day, it was only 2.1% of the total, as moving fluctuated and reached the peak emission on the 15th day at 37.0% of total emissions or as 1.255 kg. Then, after emissions dropped until the end day, it contributed to 21.6% of the total emission.

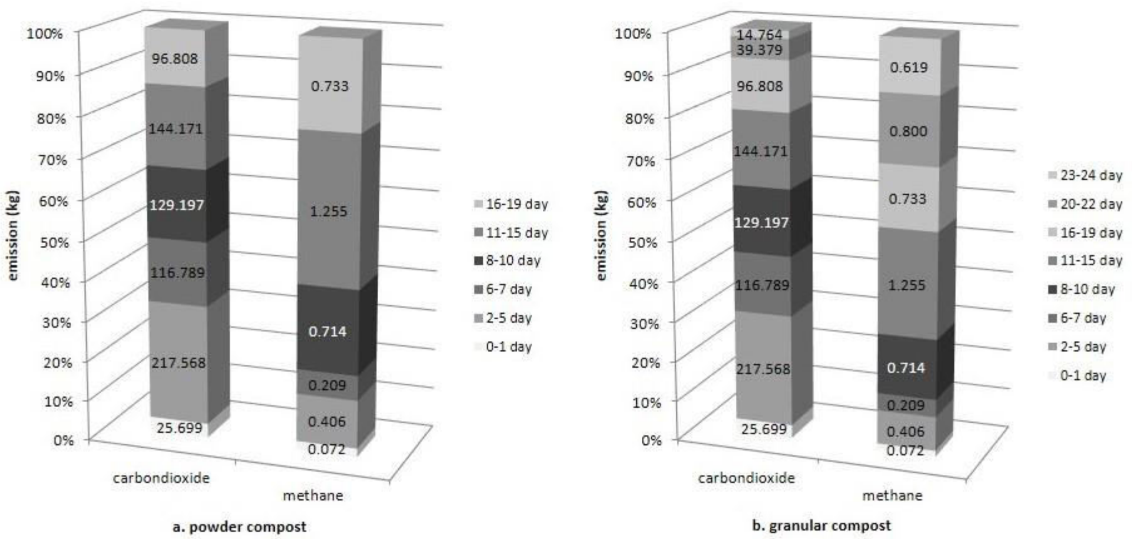

Figure-4. CO_2 and CH_4 emissions during composting days.

About granular compost, CO_2 emission on the initial days was only 3.3% of total emissions and rose rapidly to the highest emissions on the 5th day at 27.7% (1.255 kg) of the total. Afterward, the emissions fluctuated and ended at 1.9% of the total on the 24th day after it dropped from 18.4% on the 15th day. Meanwhile, the movement of CH_4 emission profile exhibited that on the initial day it was only 1.5% of total emission, as moving fluctuated, and it reached the peak emission on the 15th day at 26.1% (128.94 kg) of the total emission and ended at 12.9% of the total emission.

3.4 Gas emission of one ton of waste to be composted

Gas emission of each ton of waste to be composted was obtained by dividing gaseous emissions during the composting process by tons of waste that processed on the composting pile. Emissions of CO_2 and CH_4 per one ton of waste to be composted are exhibited in Table-3.

Table-3. Greenhouse gaseous emissions per one ton of composted wastes.

Products	Unit	CO_2	CH_4
Powder	kg/ton waste to be composted	94.53	0.44
Granular	kg/ton waste to be composted	101.54	0.62

It can be observed that emissions of CO_2 were 215 times higher than CH_4 emissions in powder composting, while on granular composting, CO_2 was 163 times higher than CH_4. Moreover, CO_2 emissions during granular composting were 1.07 times higher than on powder composting, while CH_4 emissions during granular composting were 1.42 times higher than on powder composting. This difference was attributed to different phases of the production process, although they had similar primary raw materials. In granular compost production, there was an additional step that not applied to powder compost production, which was the additional mixing of a liquid mixture to form the granular shape. In this step, the compost mixture was mixed with water, bio-activator, molasses, and liquid fertilizer, resulting in a new, further biological process that emitted more CO_2 and CH_4, indicated by an increase of temperature.

In comparison with related studies, CO_2 emissions observed in the present study were higher than in composting of feedlot cattle manure with passive aeration that emitted 73.8 kg/ton and composting of feedlot cattle manure with active aeration at 168.0 kg/ton [19]. In consideration of the intermittent aeration method of the present study, it was placed higher than passive and active aeration of feedlot cattle manure as reported by Hao *et al.*, [19]. Similar comparisons had shown that when it was compared with windrows composting of manure, present study results were higher than bovine specified risk materials and mortalities that released CO_2 at 31.2 kg/ton [33]. However, it was lower than the composting of mixed paper, yard waste, and food waste, which emitted 150, 220, and 370 kg/ton, respectively [34].

Meanwhile, CH_4 emission in the present study for powder and granular products were higher than windrow composting of yard waste, organic fraction of municipal solid waste (OFMSW) and pruning wastes (PW) by home composter, leftover raw fruit and vegetables (LRFV) and PW by home composter. Present study emitted 0.44 kg/ton and 0.62 kg/ton, while other studies emitted 0.000023 kg/ton [18], 0.158 kg/ton [16], and 0.3 kg/ton [2]. Whilst in the range of composting of organic household waste (OHW) by home composter that produced 0.4-4.2 kg/ton [17], and lower than composting of feedlot cattle manure with passive and active aeration that emitted 6.3 kg/ton and 8.1 kg/ton, respectively [19].

By these comparisons, it can be observed that composting of manure emitted more methane than organic wastes (OFMSW, PW, LRFV, and OHW), while organic wastes (mixed paper, yard waste, and food waste) emitted more carbon dioxide than manure. Moreover, the application of aeration emitted more CO_2 and CH_4 than windrows composting. These comparisons exhibited that different raw materials composted using different composting technology would emit different amounts of CO_2 and CH_4.

In order to justify the emission measurement, mass balance calculation has performed with consideration of organic matter parameter of physicochemical properties of compost mixture as 33.13% for powder compost and 30.10% for granular compost. It showed that on powder compost, 73.01% of carbon became compost product, 22.16%, and 0.11% released as CO_2 and CH_4 emission, while the rest (4.72%) as other emissions or losses. Meanwhile, on granular compost, 68.08% of carbon where in compost product, 24.01%, and 0.16% as CO_2 and CH_4 emission, while 7.75% as other emission or losses.

4. CONCLUSIONS

In order to support sustainable agriculture in Thailand, sufficient organic fertilizer supplies are needed. By promoting the program One District One Composting Plant, the government has stimulated community participation in achieving the goals while improving the community's economic status. Through investigation of a sample one community composting plant in the Rattaphum District of Songkhla Province in Southern Thailand, it found that the powder composting process emitted 730.23 kg CO_2 and 4.81 kg CH_4, while the granular composting process emitted 784.38 kg CO_2 and 3.39 kg CH_4 along composting process.

For future study, finding a better combination of raw materials and composting methods that emit lower CO_2 and CH_4 would be interesting, in order to reduce harmful gaseous emissions from composting processes. Moreover, the present data results can be used to assess the environmental impact of this composting system in order to find a better one, the environmentally friendly one. Life cycle assessment is a reliable tool to be applied to perform it.

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