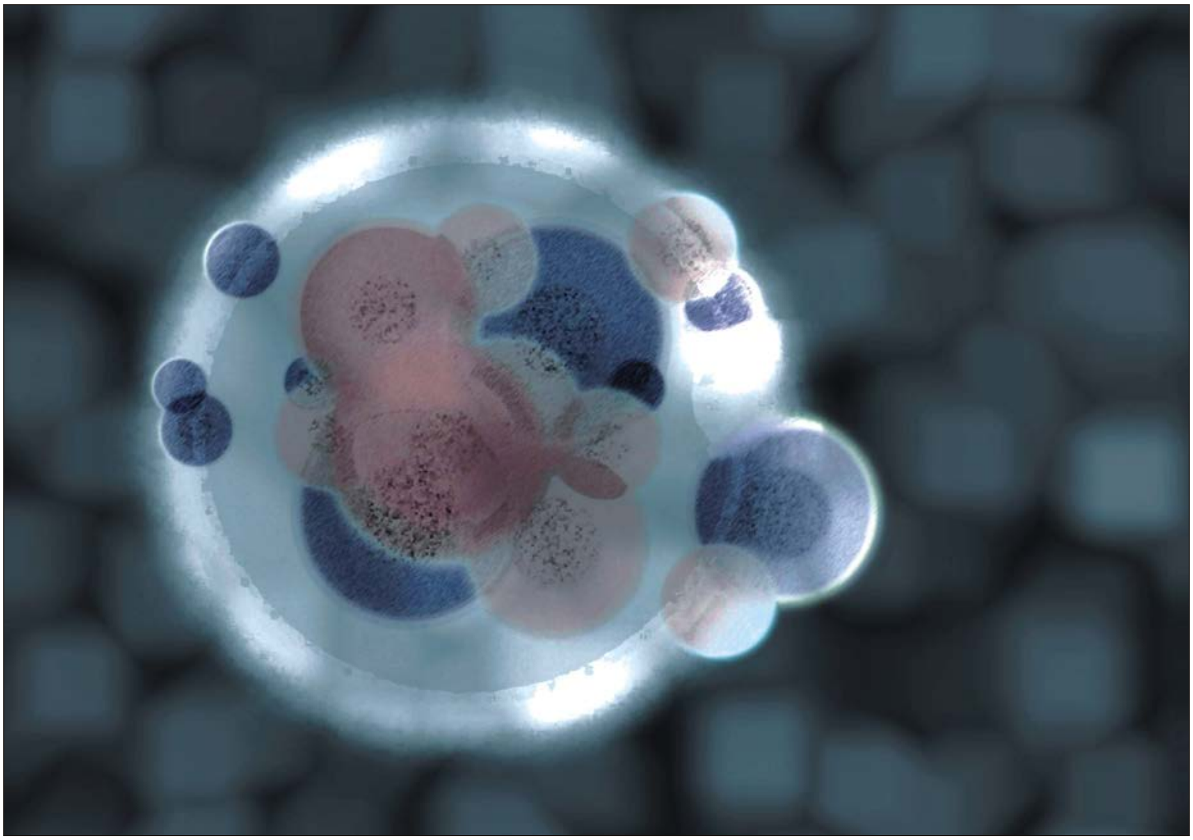

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Precise Optimization of Cattle Manure Composting using an Experimental Small-scale Instrument

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Abstract: Ordinary manure composting requires a large amount of material to be processed and it is difficult to compost manure uniformly and repeatedly. The objective of this study was to determine optimal conditions for composting cattle manure using a Kaguyahime unit, an experimental small-scale instrument. The instrument was filled with 7 kg cattle manure from breeding adult beef cows, which grazed on bahiagrass (*Paspalum notatum* Flügge) pasture and were fed Italian ryegrass (*Lolium multiflorum* Lam.) hay during shortage of grazing herbage. The manure was dried under sunlight to adjust moisture content or left undried and sawdust was used as a subsidiary material at different ratios. The maximum temperature during the first 7 days of composting occurred when the moisture content of materials was over 60% and the ratio of manure to subsidiary material was 17.5. Under these conditions, the maximum temperature was over 60°C, ranging from 63.4-72.4°C within 4 days after composting and a temperature above 60°C continued for 33.5-48.5 h. The pH and electric conductivity of manure after 20 days of composting remained at a level safe for use with plants.

Key words: Cattle manure, composting, small-scale instrument, subsidiary material, temperature

INTRODUCTION

In Japanese animal husbandry, the number of small-scale livestock farmers has been decreasing due to shortage in labor and aging of the farmers, leading to an increase in abandoned forage fields occupied by farmers who have stopped farming. On the other hand, large-scale producers tend to be dependent on imported herbage due to an increase in livestock number. The domestic self-sufficiency of herbage in Japan has decreased to 26% on the basis of total digestible nutrients in 2011 (MAFF, 2013) which is inferior to other developed Western countries.

While livestock waste is decreasing due to the decrease in number of livestock, the 85 million tons of waste are larger than the waste derived from the food and wood industries. Animal waste has two opposite effects on the environment. If the waste is piled outside without prompt treatment or stored underground without protection, groundwater and surface-water pollution and generation of bad odors occur. In contrast, prompt treatment of animal waste produces organic fertilizer which has a role in soil amendment (Hasyim *et al*., 2013). In Japan, improper treatment of livestock waste is prohibited by law and production of animal manure under proper treatment has increased (MAFF, 2005).

Understanding of the manure composting process and its effectiveness in herbage production is necessary for building societal awareness of resource recycling. Manure composting requires two steps: the first is to produce safe and easily handled products for producers and the second is to make sure animal manure is fermented perfectly and that the fermented manure is safe for cultivated crops (Cobo *et al*., 2002; Kajiya *et al*., 2013). The ordinary manure composting process which piles cattle manure under an open-shed manure composting site, is easily affected by environmental factors, requires a large amount of manure and proceeds without uniformity, leading to compost that shows low reproducibility. In an experimental approach for improving the process, a small-scale instrument has been applied to composting swine manure (Zhu, 2006; Koyama, 2012). The stability and maturity of composting livestock manure are affected by aeration rate, carbon to nitrogen ratio and moisture content of the composting mixture (Guo *et al*., 2012).

Therefore, the objectives of this study were to determine optimal conditions for composting cattle manure using an experimental small-scale instrument.

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MATERIALS AND METHODS

Small-scale manure composting instrument: In this study, a small-scale manure composting Kaguyahime instrument (Fujihira Co. Ltd., Tokyo) was used to maintain uniformity of a small amount of sample material for manure composting (Koyama, 2012). The instrument has a cylindrical tank accommodating a maximum of 12.3 L when filled. An air inlet for ventilation is located at the base of the tank and the air flow rate is regulated by a flow meter; an outlet for exudate is also located at the base. A temperature sensor can be inserted into the upper part of the tank for monitoring the temperature profile in the tank which is sealed with a heat retaining box.

Layout of manure composting methods: The instrument was filled with 7 kg cattle manure produced by breeding adult beef cows which grazed on bahiagrass (*Paspalum notatum* Flügge) pasture and were fed additionally with Italian ryegrass (*Lolium multiflorum* Lam.) hay during shortage of grazing herbage. The manure was dried under sunlight to adjust the moisture content or was left undried and sawdust was used as a subsidiary material at different ratios, following Kajiya *et al*. (2013). The flow rate of air during composting was determined by the performance of the instrument. The composting period was limited to 7 days to obtain the peak maximum temperature (max temp), pH, Electrical Conductivity (EC) and moisture content of the mixture in one experiment (Exp. 1).

In experiment 2 (Exp. 2), manure was composted under the optimal conditions obtained in Exp. 1 and every 4 days, the mixture was turned by hand and samples were taken. When a rise of temperature in the tank was no longer observed after turning, monitoring was terminated after the mixture was sampled for chemical analysis.

Chemical analysis: Moisture content of the mixture was determined by an MB45 halogen moisture analyzer (Ohaus Corp., Tokyo). The temperatures of the mixture in which the sensor was inserted to the center and of the room where the instruments were set, were recorded every 30 min by a TR-71U thermo recorder data logger (T and D Corp., Tokyo). After air-drying, the manure was ground to put it through a 2 mm sieve for chemical analyses, as described in Hasyim *et al*. (2013). After 5 g manure was put into a plastic tube with 50 mL distilled water and shaken reciprocally, the pH and EC of the solution were determined by an F-15 pH meter (HORIBA Ltd., Kyoto) and CM-40S EC meter (DKK-TOA Corp., Tokyo), respectively. After 5 g manure was shaken reciprocally with 100 mL distilled water at room temperature for 30 min, the slurry was filtered through No. 3 filter paper (Advantec Ltd., Tokyo), 10 mL of the extract was used to assess the germination percentage of Japanese mustard spinach (*Brassica rapa* var. *perviridis*) and 10 mL distilled water was used as a control. Germination percentage was determined on the 7th day after incubation in the dark at 20°C.

RESULTS AND DISCUSSION

Experiment 1: Optimum manure composting conditions in the initial 7 days: The materials used for manure composting for the 8 treatments in Exp. 1 are shown in Table 1. The moisture content of the composted materials in treatments 1-4 was higher than 77% due to not drying them before composting, while the pre-dried treatments were the lowest in moisture content at 59.2% for treatment 8, followed by 71.8% for treatment 7, even though an insufficient drying period led to a moisture content as high as about 79% in both treatments 5 and 6. The cattle manure to sawdust ratio was the lowest at 4.7 in treatments 1 and 2, followed by 9.3 in treatments 3 and 4, 14.0 in treatments 5 and 6 and the highest at 17.5 in treatments 7 and 8. The initial pH and EC values of the mixture used for composting and the max temp in the first 7 days after composting are shown in Table 2. The initial pH values ranged from 8.3 to 9.2 and the EC values ranged from 1.2 to 2.1 across all 8 treatments. Although the max temperature reached only 34-49°C in treatments 1-6, treatments 7 and 8 had a peak temperature of the composted manure over 60°C which is judged as the lethal temperature for pathogens, parasites and weedy seeds and temperatures above 60°C in the hemophilic

Table 1: Materials for manure composting in experiment 1 (Exp. 1)

		Treatment							
Raw material	Item	1	2	3	4	5	6	7	8
Cattle manure	Fresh weight (kg)	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	Moisture content (%)	86.80	86.80	87.40	87.40	82.20	82.20	74.60	59.10
Sawdust	Fresh weight (kg)	1.50	1.50	0.75	0.50	0.50	0.50	0.40	0.40
	Moisture content (%)	55.40	55.40	46.90	46.90	16.30	16.30	12.00	9.10
Composted mixture	Manure to dust ratio	04.70	4.70	9.30	9.30	14.00	14.00	17.50	17.50
	Moisture content (%)	77.40	79.40	84.00	84.10	78.50	78.80	71.80	59.20
	Bulk density (kg L^{-1})	0.61	0.58	0.56	0.64	0.54	0.54	0.44	0.33
	Flow rate (L min^{-1})	00.69	0.71	0.65	0.58	0.67	0.69	0.72	0.77

Table 2: Initial pH and Electrical Conductivity (EC) of the manure mixture used for composting and the maximum temperature (Max temp) of the mixture in the first 7 days after composting (Exp. 1)

	Treatment							
Attribute	1	2	3	4	5	6	7	8
pH (H_2O)	8.3	8.7	8.4	8.8	8.9	9.0	9.2	8.7
EC (mS cm^{-1})	1.5	1.2	1.4	1.7	1.4	1.6	1.2	2.1
Max temperature (°C)	41.4	40.7	38.9	33.6	48.8	44.8	68.0	72.1

phase continued for 46.5 h in treatment 7 and 73.5 h in treatment 8. These temperature profiles were the same as obtained by Koyama (2012) using the same Kaguyahime instrument.

Moisture content in the range 65-75% and a C/N ratio of 15-21 did not significantly affect the temperature of swine manure composted with corn stalks (Guo *et al*., 2012). However, the same swine manure with corncob did not reach the set temperature (60°C) when it had an initial moisture content of 80%, as reported in Zhu (2006), a result corresponding with the present treatments 1-6.

The relationships between bulk density, cattle manure to sawdust ratio, moisture content at composting and the max temp in the first 7 days after composting are shown in Fig. 1. With an increase in bulk density of the mixture, the max temp decreased linearly and was negatively correlated with bulk density ($r = -0.956$, $p < 0.01$). The max temp also had a significant negative correlation with moisture content ($r = -0.914$, $p<0.01$) and a significant positive correlation with manure to sawdust ratio ($r = 0.799$, $p<0.05$). This suggests that the rise of temperature in the composting process was affected by the bulk density, manure to sawdust ratio and moisture content.

The conclusions from Exp. 1 were that optimum conditions for cattle manure composting were a manure to sawdust ratio over than 17.5 and a moisture content of the mixture below 70% at the start of composting.

Experiment 2: Suitable manure compost composition for 20 days of composting: Materials for manure composting for the 3 trials in Exp. 2 are shown in Table 3. The manure to sawdust ratio was fixed at 70 and the moisture content of the mixture averaged 65.2% which was lower than the critical moisture content of 70% based on Exp. 1. Moisture content during composting was maintained around 70% in these 20 day trials (data not shown). Temperature profiles of the composted mixture in the first 20 days after composting are shown in Fig. 2. All of the trials showed a max temp above 60°C in the thermophilic phase within 4 days of composting and continued to show a marked rise in temperature after turning on the 4th and 8th days of composting, while no significant rise appeared on the 16th day, even after turning the mixture. The max temp in

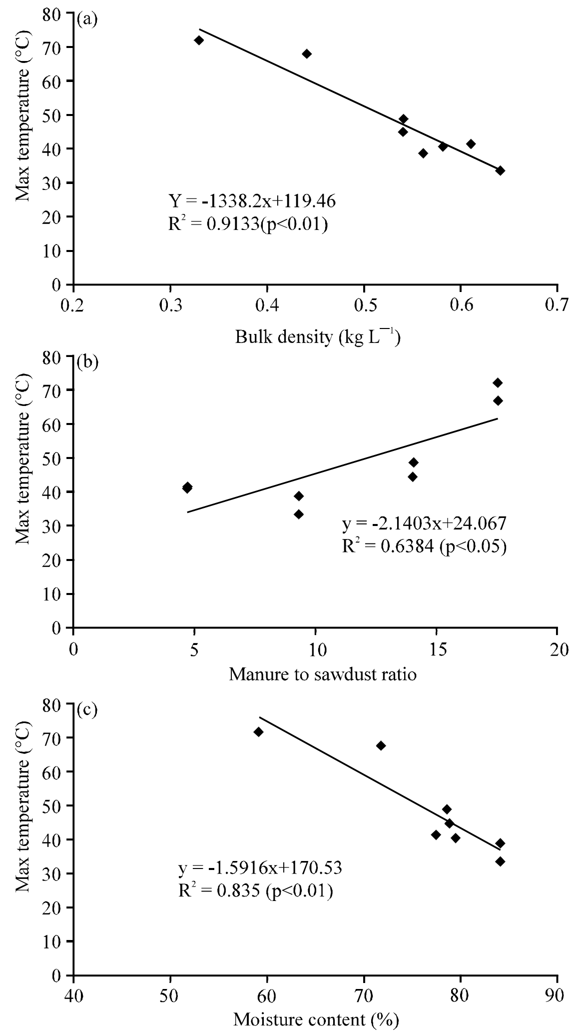

Fig. 1(a-c): Relationship between (a) bulk density of the compost mixture, (b) Manure to sawdust ratio and (c) Moisture content of compost mixture and maximum temperature of the mixture in the first 7 days after composting (Exp. 1)

these 3 trials ranged from 63 to 72°C (average 69°C) and the thermophilic phase above 60°C continued for 34-49 h (average 43 h) which met the sanitary standard (Zhu, 2006).

Changes in pH and EC of the compost mixture in the first 20 days of composting are shown in Fig. 3. The pH value in the compost mixture during the 20 days of trials was relatively stable at 8.0-8.3 within the range of 6.0-9.0 recommended for rapid composting (Ogunwande and Osunade, 2011) and EC tended to increase up to 2.4 mS cm^{-1} after the 8th day, below the upper limit of 4.0 mS cm^{-1} considered tolerable by plants with medium sensitivity (Ogunwande and Osunade, 2011).

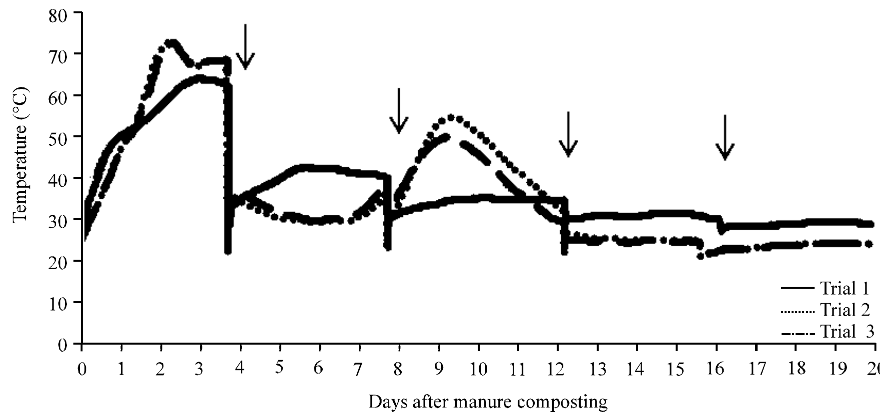

Fig. 2: Change in temperature of compost mixture in the first 20 days after composting (Exp. 2)

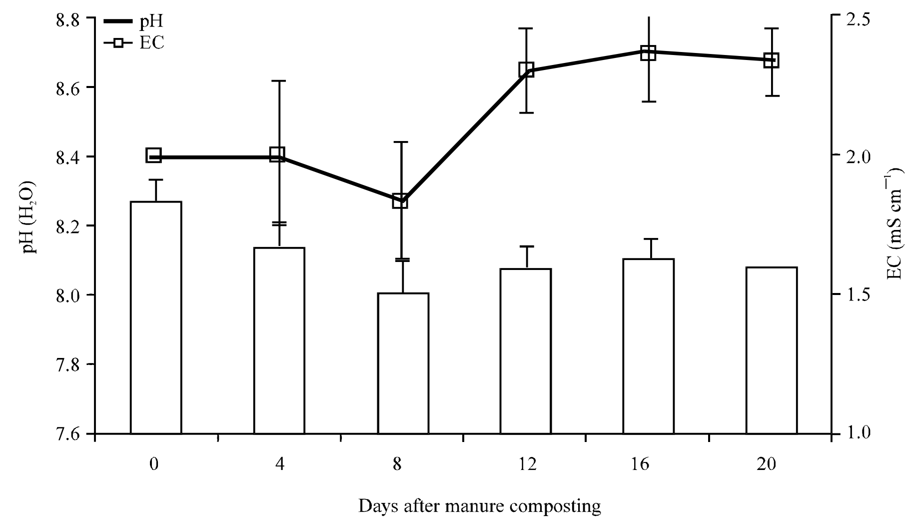

Fig. 3: Changes in pH and Electrical Conductivity (EC) of compost mixture in the first 20 days after composting (Exp. 2) Mean±Standard deviation

Table 3: Materials for manure composting in experiment 2 (Exp. 2)

		Trial			
Raw material	Item	1	2	3	Average
Cattle manure	Fresh weight (kg)	7.00	7.00	7.00	7.00
	Moisture content (%)	74.40	66.10	66.10	65.90
Sawdust	Fresh weight (kg)	0.10	0.10	0.10	0.10
	Moisture content (%)	16.50	11.30	11.30	13.90
Composted mixture	Manure to dust ratio	70.00	70.00	70.00	70.00
	Moisture content (%)	73.10	62.30	62.30	65.90
	Bulk density (kg L^{-1})	0.52	0.48	0.48	0.50
	Flow rate (L min^{-1})	0.68	0.74	0.73	0.72

The germination percentage of Japanese mustard spinach on the compost liquid was determined on the 7th day after incubation. Germination percentage in the composted manure was 94.7%, compared with 100% in the control which suggested that no phytotoxic substances were produced during composting.

CONCLUSION

Based on temperature profile and pH and EC values during the manure composting process and on seed germination percentage, the composted manure could be utilized safely as an organic fertilizer. In small-scale experiments with the Kaguyahime instrument, the optimum conditions for composting were a cattle manure to sawdust ratio over 17.5 and a moisture content at the start of composting less than 70%.

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