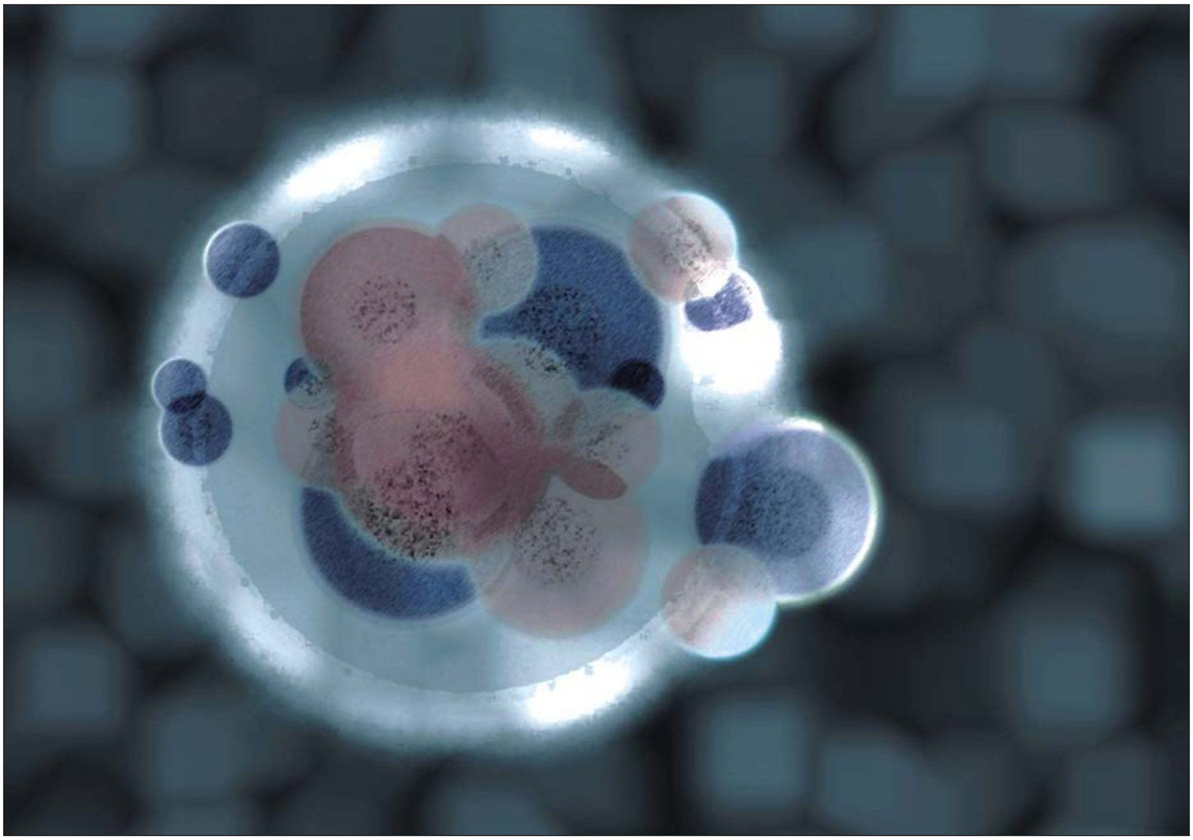

Journal of Biological Sciences

ISSN 1727-3048

Journal of Biological Sciences 15 (1): 40-44, 2015
ISSN 1727-3048

ansinet
Asian Network for Scientific Information

RESEARCH ARTICLE OPEN ACCESS

DOI: 10.3923/jbs.2015.40.44

Precise Optimization of Poultry Manure Composting Using an Experimental Small-Scale Apparatus

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ARTICLE INFO
Article History:
Received: April 01, 2015
Accepted: May 02, 2015

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ABSTRACT
Ordinary stacked composting from bovine and poultry manures requires large amounts of materials and it is difficult to conduct uniform and repeated processing. While precise optimization using bovine manure and an experimental small-scale apparatus (Kaguyahime) has already been accomplished, poultry manure has readily decomposable components compared to bovine manure. The objective of this study was to determine the precise optimization of poultry manure composting using the same small-scale apparatus, filled with 7 kg of manure that was dried under sunlight and different amounts of sawdust as subsidiary material. In the preliminary experiment, the maximum temperature for the first 7 days of composting reached over 60°C when the moisture content of the mixture decreased below 65%, while the manure-to-sawdust ratio negligibly affected the temperature increase. Under the preliminary conditions, the maximum temperature of poultry manure mixed with sawdust was over 70°C within 2 days after composting and the thermophile phase above 60 and 55°C continued for an additional 27 and 18 h, respectively. The pH and electrical conductivity of poultry manure composted for 32 days remained at 9.1 and 6.6 mS cm^{-1}, respectively, which indicates the manure is safe for land application.

Key words: Poultry manure, composting, small-scale apparatus, subsidiary material, temperature

INTRODUCTION

In Japan, improper treatment of livestock wastes is prohibited by law and proper processing and utilization of animal manure has increased (MAFF., 2005). In southern Kyushu, Japan, where there is a high concentration of bovine and poultry farms, livestock wastes are processed into solid and liquid manure and/or burnt for bioenergy production.

Poultry wastes dried in the plastic house have been used in boilers to warm poultry houses, while nowadays, because of the Japanese National Act on Special Measures Concerning Countermeasures against Dioxins, large-scale incinerators have been introduced to protect against dioxin generation. Poultry wastes from large-scale broiler industries are burned to produce bioenergy in both Miyazaki and Kagoshima Prefectures located in southern Kyushu.

Since almost the same composition of concentrates are fed to laying hens (layers), the total nitrogen content of the poultry manure is maintained at approximately 55-60 g kg^{-1} (Ogunwande and Osunade, 2011; Koyama, 2012). Since most of the materials to produce chemical fertilizers are imported, the price of the fertilizer depends on that of the imported materials and consequently influences the cost of domestic herbage production. Therefore, wastes from layers should be used not only for soil amendment and as bioenergy material, but also for animal manure that contains high contents of nitrogen, phosphorus and potassium (Cobo *et al*., 2002).

Manure composting is required to secure the thermophile phase and avoid the risk of spreading manure pathogens (Millner *et al*., 2014) and weedy seeds possibly contaminating imported concentrates (Nishida *et al*., 1999; Utamy *et al*., 2012). Ordinary stacked composting from livestock and poultry manures requires large amounts of materials and it is difficult to conduct uniform and repeated processing. The authors (Kajiya *et al*., 2014) have already established precise optimization for bovine manure using an experimental small-scale apparatus that is negligibly affected by the external environment.

The objective of this study was to determine the precise optimization of poultry manure composting using the apparatus and to compare the conditions between poultry and bovine manure composting.

MATERIALS AND METHODS

Small-scale manure composting apparatus: A small-scale manure composting apparatus (Kaguyahime, Fujihira Co., Ltd., Tokyo) was used to maintain the uniformity of a small amount of sampled materials for the livestock manure composting, as in a previous study (Kajiya *et al*., 2014). The apparatus has a cylindrical tank with a maximum volume of 12.3 L. An air inlet with a flow meter is located at the base of the tank to regulate ventilation and an outlet for exudates is also located at the base. A temperature sensor for monitoring internal temperature profiles can be inserted into the upper part of the tank, which is sealed within a heat-retaining box. An outlet at the top of the apparatus can be used to check the odor and composition of ventilated gasses.

Methods for composting poultry manure: The apparatus was filled with 7 kg of fresh manure from Boris Brown layers, which were fed with compound feed for layers, rice bran and rice hulls, in an open poultry farm in Miyakonojo City, Miyazaki, Japan. Poultry manure was dried under sunlight or wetted with water to adjust the moisture content to 51 and 70% and different amounts (0.50, 0.75, 1.00 and 1.50 kg) of sawdust from Japanese cedar was mixed as subsidiary material to prevent the inhibition of seed germination due to a low carbon-to-nitrogen ratio (Guo *et al*., 2012), following Kajiya *et al*. (2013). The flow rate for the manure composting was 50 L min^{-1}, corresponding to 1 m^3 of manure.

This study included both preliminary and main experiments. In the preliminary experiment, seven treatments were set depending on the moisture content and the amount of sawdust and the composting period was limited to the initial 7 days without turning of the mixture to obtain the peak maximum temperature (Max temp), pH, Electrical Conductivity (EC) and moisture content of the mixture.

In the main experiment, manure composting was repeated in triplicate under the optimal conditions obtained during the preliminary experiment. The mixture for the main experiment was manually turned every 4 days and samples were taken at each turning for chemical analyses. When no increase in temperature was observed after turning, the mixture was sampled a final time for chemical analyses and the monitoring was terminated.

Chemical analyses: The moisture content of the mixture was determined using halogen moisture analyzers (MB45, OHAUS Corp., Tokyo). A data logger (Thermo recorder, TR-71U, T and D, Nagano) recorded temperatures every 30 min from sensors placed in the room and in the center of the mixture. After air-drying, the manure was ground and passed through a 2 mm sieve for chemical analyses (Hasyim *et al*., 2014). Five grams of manure was placed into a plastic tube containing 50 mL of distilled water and the mixture was shaken reciprocally for 30 min. The pH and EC of the solution were then determined using a pH meter (F-15, HORIBA Ltd., Kyoto) and EC meter (CM-40S, DKK-TOA Corp., Tokyo), respectively. Subsequently, 5 g of manure in 100 mL of distilled water was eluted at room temperature for 30 min using a reciprocal shaker and filtered using No. 3 filter paper (ADVANTEC Ltd., Tokyo). The extract (10 mL) was used to test the germination percentage of Japanese mustard spinach (*Brassica rapa* var. *perviridis*, cultivar Kiyosumi) and 10 mL distilled water was used for control. The germination percentage was determined from the number of germinated seeds among 50 seeds sown on the 4th day and incubated in the dark at 20°C.

RESULTS

Preliminary experiment: Optimal poultry manure composting conditions during the initial 7 days: Materials for the poultry manure composting and seven treatments in the preliminary experiment are shown in Table 1. The moisture content of the composted mixture should be 55-75% for optimal fermentation and the moisture content of the poultry manure at sampling was 58.5%, so the manure was not dried under sunlight. However, the moisture content of the mixture can drop to as low as 17% after mixing with sawdust. Thus, in 3 treatments 1-3, water was added to the poultry manure to achieve moisture contents of 68.2, 65.3 and 64.6%, respectively. In treatments 4-7 without adding water, the

Table 1: Materials for poultry manure composting in the preliminary experiment

		Treatment						
Raw material	Item	1	2	3	4	5	6	7
Poultry manure	Fresh weight (kg)	7.00	7.00	7.00	7.00	7.00	7.00	7.00
	Moisture content (%)	73.60	70.70	70.70	51.10	51.10	51.10	51.40
Sawdust	Fresh weight (kg)	0.50	0.75	1.00	0.50	0.75	1.00	1.50
	Moisture content (%)	17.20	17.30	17.30	16.50	16.50	16.50	17.20
Composted mixture	Manure-to-sawdust ratio	14.00	9.33	7.00	14.00	9.33	7.00	4.67
	Moisture content (%)	68.20	65.30	64.60	47.70	46.30	47.40	45.70
	Bulk density (kg L^{-1})	0.91	0.73	0.69	0.58	0.55	0.56	0.54
	Flow rate (L min^{-1})	0.39	0.49	0.54	0.61	0.67	0.67	0.75

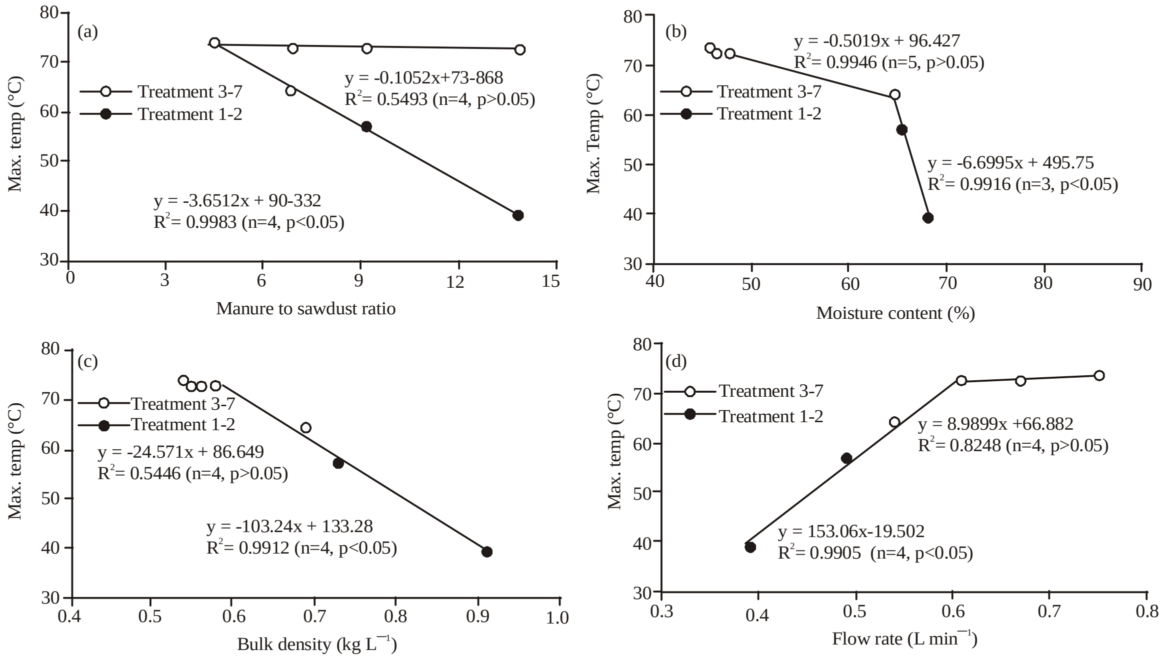

Fig. 1(a-d): Relationships between (a) Manure-to-sawdust ratio, (b) Moisture content of composted mixture, (c) Bulk density of the composted mixture and (d) Flow rate and the maximum temperature (Max temp) of the mixture during the first 7 days after composting in the preliminary experiment

Table 2: pH and Electrical Conductivity (EC) of the mixture during composting and the maximum temperature (Max temp) of the mixture during the initial 7 days after composting (Preliminary experiment)

	Treatment						
Attributes	1	2	3	4	5	6	7
pH (H_2O)	9.7	9.5	9.4	9.3	9.4	9.2	9.3
EC (mS cm^{-1})	3.5	3.4	3.3	3.7	3.6	4.1	3.1
Max temp (°C)	39.1	57.0	64.0	72.6	72.7	72.7	73.8

moisture content of the mixture was 45.7-47.7%, which was lower than the critical 55%. The mixing ratios of poultry manure to sawdust were 14.0, 9.3 and 7.0 in treatments 1-3, respectively, with the addition of water, while the ratios were 14.0, 9.3, 7.0 and 4.7 in treatments 4-7, respectively, without the addition of water.

The pH and EC of the mixture and the Max temp during the initial 7 days after composting are shown in Table 2. The pH and EC values were 9.2-9.7 and 3.1-4.1 mS cm^{-1}, across the seven treatments. Although the Max temp reached below 60°C in treatments 1 and 2, treatments 3-7 showed a peak temperature of composted manure over 60°C, which is the lethal temperature for pathogens, parasites and weedy seeds. The thermophile phase above 60°C continued for 22, 53, 54.5 and 48 h, respectively. These temperature profiles were the same as those in Koyama (2012) using the same Kaguyahime apparatus.

Relationships between the mixing ratio of poultry manure to sawdust, moisture content, bulk density, flow rate and the Max temp of the mixture are shown in Fig. 1. The mixing ratio of the manure to sawdust did not affect the Max temp (r = 0.518, p>0.05), as shown in Fig. 1a. On the other hand, the moisture content of poultry manure mixed with sawdust and the bulk density were negatively correlated with the Max temp of the mixture at the probability levels of 5% (r = -0.872, Fig. 1b) and 1% (r = -0.992, Fig. 1c), respectively. The flow rate of the apparatus was positively correlated with the Max temp of the mixture (r = 0.928, p<0.05), as shown in Fig. 1d. Thus, the Max temp of the mixture after composting was affected by moisture content, bulk density and flow rate, but was not significantly affected by the mixing ratio of poultry manure to sawdust.

Results from the preliminary experiment suggest that the temperature during the composting process was mainly affected by a moisture content below 65%, which should be fitted to the main experiment.

Main experiment: Suitable manure composting during the 32 days of composting: Materials for poultry manure composting for the three conditions in the main experiment are shown as averages in Table 3. The poultry manure-to-sawdust ratio was fixed at 70. Since the moisture content of poultry manure was as high as 75.1%, the manure was dried under sunlight to decrease it to 56.5%. The average moisture content of the mixture was 55.5%, which was in the optimal range below 65%, as obtained in the preliminary experiment. The moisture content in the manure composting process did not change considerably, reaching 53.1% during the 32 days of composting. Temperature profiles of the composted mixture

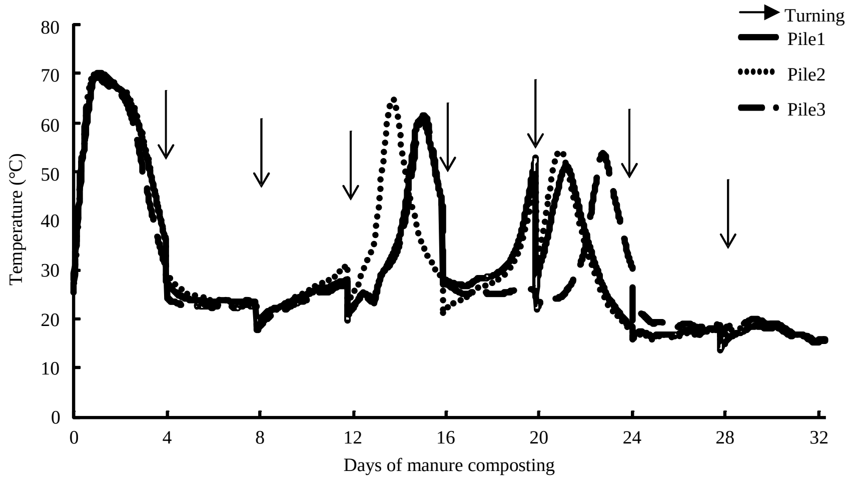

Fig. 2: Changes in temperature of poultry composted mixture during the first 32 days after composting in the main experiment

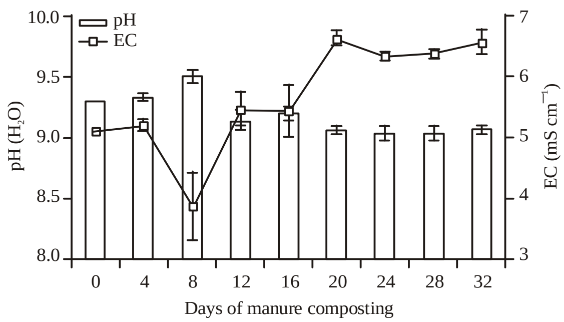

Fig. 3: Changes in pH and Electrical Conductivity (EC) of composted mixture during the first 32 days after composting in the main experiment. Mean±Standard deviation

Table 3: Materials for poultry manure composting in the main experiment

Raw material	Item	Average
Poultry manure	Fresh weight (kg)	7.0
	Moisture content (%)	56.5
Sawdust	Fresh weight (kg)	0.10
	Moisture content (%)	11.2
Composted mixture	Manure-to-sawdust ratio	70.0
	Moisture content (%)	55.5
	Bulk density (kg L^{-1})	0.54±0.01
	Flow rate (L min^{-1})	0.65±0.01

during the 32 days after composting are shown in Fig. 2. All of the replications showed a Max temp above 60°C in the thermophile phase within 2 days of composting, which then decreased to below 40°C when the first turning of the mixture was conducted on the 4th day of composting. There was a significant increase in temperature between the 8th and 20th days of composting. There was no significant increase in temperature after the 24th day, even after turning the mixture and the experiment was terminated on the 32nd day. The average Max temp in these three replications was 69.8°C. The thermophile phase above 55°C lasted 73.5-80 h (average: 77.2 h) and that above 60°C lasted 57-66.5 h (average: 60°C for 60.8 h).

The changes in the pH and EC of the composted mixture during the 32 days are shown in Fig. 3. The pH peaked at 9.5 on the 8th day and had decreased slightly to 9.1 by the 32nd day. The EC value was relatively stable, at 5.1-5.5 mS cm^{-1}, during the initial 16 days, except for the 8th day, but had increased up to 6.6 mS cm^{-1} by the 32nd day. The germination percentage of Japanese mustard spinach on the 4th day after manure treatment was 98%, which nearly matched the 99% for controls.

DISCUSSION

It was found during the preliminary experiment that the moisture content of poultry (layers) manure mixed with sawdust should be less than 65% but the ratio of manure to sawdust does not affect the increase in temperature after composting. These findings are clearly different from those for bovine manure composting, which revealed that both a manure-to-sawdust ratio above 17.5 and moisture content below 70% were essential for optimal manure composting. Compared to bovine manure composting, the peak temperature in the present poultry manure composting was also 70°C but the thermophile phase above 60 and 55°C lasted an additional 27 and 18 h, respectively. The differences in the temperature response were a result of easily decomposable organic substances. In the present study, the poultry manure from layers fed with mainly maize concentrates should have higher contents of easily decomposable organic substances than the bovine fibrous manure from beef-producing cows that are fed herbaceous plants. In general, the temperature increase during composting is mainly due to the respiratory heat produced by microorganisms that breakdown organic substances in the manure. Thus, the higher content of easily decomposable organic substances in poultry manure leads to a longer thermophile phase from catabolic activity even under the higher mixing ratio of poultry manure to sawdust.

The primary requirement for using composted manure as organic fertilizer is safety for the soil and cultivated crops. If poor-quality composted manure, containing weedy seeds and pathogenic bacteria, is applied to arable lands, weeds may flourish and the consumption of harvested raw vegetables may cause food poisoning. In the present study, the maximum temperature during the composting period was 68.3°C and the thermophile phase above 55 and 60°C continued for 77.2 and 60.8 h, respectively. These temperatures are satisfactory for achieving the lethal thermophile phase at a temperature above 60°C for 30 h that is necessary to kill 10 species of Japanese noxious weeds (Nishida *et al*., 1999). Millner *et al*. (2014) showed that temperatures above 45°C continued for more than 3 days reduces the number of *Escherichia coli* O-157, *Salmonella enterica* and *Listeria monocytogenes*. The pH at the end of the present composting was 9.1, which was higher than the pH values when composting bovine manure (Kajiya *et al*., 2014) and swine manure (Zhu, 2006). However, the higher pH of the composted poultry manure will likely not be harmful to the acidic Japanese soil. The EC of the poultry manure at 6.6 mS cm^{-1} was higher than the recommended EC value (5.0 mS cm^{-1}) and requires careful attention during application. The germination percentage of Japanese mustard spinach at 98% nearly matched that of the control (99%), which suggested the absence of any substances that would inhibit the germination or growth of cultivated crops.

CONCLUSION

Based on temperature profile, pH, EC values and germination percentage during the poultry (layers) manure composting process, composted poultry manure could be utilized safely as organic fertilizer. Unlike bovine manure, the optimal condition for composting poultry manure mixed with sawdust was a moisture content of less than 65%.

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