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Degradation of Organic Matter in Cattle Manure Composting by Aeration and Turning in a Packed-Bed Reactor

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Abstract

A mixture of cattle manure and sawdust was composted using an 18.8 L reactor at aeration rates of 0.05, 0.15, and 0.50 L/min.kgdm, employing three turning patterns (no turning, full turning, and turning with position change of the layers). The maximum temperatures for aeration were 64.3℃ at 0.05 L/min.kgdm, 73.2℃ at 0.15 L/min.kgdm, and 70.8℃ at 0.50 L/min.kgdm. An aeration rate of 0.50 L/min.kgdm effectively accelerates composting in the early stage. A combination of aeration and the turning operation were found to resulting in different composting process patterns. Organic matter reduction in forced aeration composting can be enhanced with turning and its reduction in composting with full turning was somewhat greater than that for turning with a position change. We propose major composition changes in compost material by aeration and turning in a fabricated packed-bed reactor.

[Keywords] aeration, cattle manure composting, packed-bed reactor, turning pattern

I Introduction

Waste from animal husbandry remains environmental problems. The total animal waste in Japan in 2004 was 88.7 million tons (60.9 million tons of excrement and 27.8 million tons of urines), with 60.2% from dairy and beef cattle (Anonymous, 2005). This excessive solid waste from animal husbandry results in an unpleasant odor that draws complaints from the community. Composting is a simple and low-energy solution. Unidentified phenomena occur during composting operations in a composting facility. The effect of aeration and turning operations in composting are unclear. The optimal products in aerobic biomass decomposition are water (vapor), CO_2, and energy. Moisture content, oxygenation, pH, and the C/N ratio contribute to the composting process (Zucconi and De Bertoldi, 1987 ; Kreith, 1994). Temperature changes within the compost materials result from the heat balance within the reactor (Kimura, 2003). Wide ranges of aeration rates from 0.25 to 2.75 L/min.kgdm were found to result in higher temperature compost material (Kimura, 2003). Kimura and Shimizu (1981) reported on three regions of aeration rates (low, medium, and high). Increasing from a low aeration rate of 0–1 L/min.kgdm increased the maximum temperature, dry matter loss, and total weight loss. Significant total weight loss and dry matter loss were observed at the middle range (1–5 L/min.kgdm), but the composting temperature was less than that of the low range. Fermentation was slow at a rapid aeration rate (more than 5 L/min.kgdm). One major difficulty with a forced aeration system is inefficient diffusion of air throughout the entire pile, resulting in temperature and moisture content fluctuations and other problems, including the formation of channels in the pile.

The aeration mechanisms involved in providing oxygen can be categorized into three broad groups : agitation, forced aeration, and turning (Kreith, 1994). A combination of these mechanisms may also be used. Turning or mixing during composting is usually performed to minimize the heterogeneity associated with temperature, oxygen, and moisture gradients in the system (Haug, 1993 ; Vandergheynst and Lei, 2003). Microorganisms can function efficiently if a good mix is developed, and air will flow through the material more uniformly due to a breakdown of the short-circuit effect.

There is little available data regarding the turning pattern effects on the composting process. Therefore,

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it is important to clarify the roles of the aeration and turning pattern. The research objective was to determine the aeration and turning pattern effects on the composting characteristics (temperature distribution, moisture content, and degradation) from cattle manure composted using a packed-bed reactor.

II Materials and method

1. Materials

Fresh beef cattle manure and sawdust were collected from the Nippon Agricultural Research Institute (Tsukuba, Ibaraki Prefecture). The initial moisture contents of the fresh manure and sawdust were 78% to 80% and 12% to 18% (w.b.). The organic matter contents of the manure and sawdust were 88% and 99%. The cattle manure and sawdust were mixed to adjust the moisture content to ±65% (w.b.), a suitable initial moisture content to begin composting (Torisu et al., 1980 ; Kimura and Shimizu, 1981). Raw materials were collected for every run, and the manure was stored in the laboratory for one day before the experiment to measure the initial moisture content.

2. Compost reactor apparatus

A self-heating operation mode was adopted for this experiment as illustrated in Fig. 1. The compost reactor was 60 cm high, with 18.84 L total capacity and was fabricated using 20 cm-diameter polyvinyl chloride (PVC) pipe, made by stacking four 15 cm high layers on top of each other. The bottom layer contained a plenum chamber. Each layer had wire mesh (1 x 1 mm) at the bottom. The advantage of the wire mesh is that it facilitates sampling without mixing with the other layers. The reactor received forced aeration from an air pump (Sinku-Kiko DAP-30) with a 30 L/min capacity through a 5 mm-diameter flexible pipe. We used an air flow meter (Kolfoc) with a capacity of 0.5 and 2.0 L/min. The outer surface and bottom of the compost reactor were insulated with 10 cm thick wool fiberglass to reduce heat loss. The temperatures were measured with a thermocouple (T type) inserted through a 4 mm-diameter hole in the PVC pipe in each layer. Temperature data were recorded with a data recorder (Keyence NR 1000) at 30 min intervals. A personal computer was connected for data acquisition, to display the temperature, and for recording onto a hard disk.

3. Experimental design

The experiments were conducted from March to July 2005, and the ambient temperatures were 18 to 31℃. About 8 kg of mixed cattle manure and sawdust was placed in the compost reactor, each layer holding 2 kg of raw material. The aeration rate ranges were selected based on previous research (Kimura and Shimizu, 1981). Three aeration rates (0.05, 0.15, and 0.50 L/min.kgdm) were applied to facilitate high-temperature composting. Three turning patterns (types A, B, and C) were applied. Type A compost underwent no turning, while type B compost each layer was mixed, turned and divided into four layers. The compost material for pattern type C was removed from each layer, turned, and then replaced in the same vessel. The positions of the layers were reversed from the previous period. The compost was turned every 120 h and samples were collected before turning. Table 1 lists the experimental elements in this study. A schematic diagram of the turning methods is provided in Fig. 2.

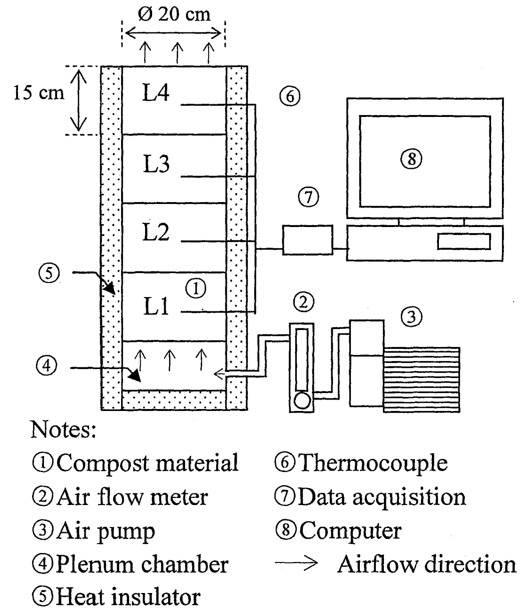

Fig. 1 Compost reactor setup

Table 1 Experimental design with two factors (aeration rate and turning pattern) for composting cattle manure

Turning method	Aeration rate (L/min.kgdm)		
	0.05	0.15	0.5
A	0.05A	0.15A	0.50A
B	0.05B	0.15B	0.50B
C	0.05C	0.15C	0.50C

4. Measurements

The weight of compost of each layer was measured with a balance at the initial, each turning period and the end of composting. The moisture content of the raw materials and composting mixtures was determined by drying the samples at 105℃ for 24 h. Ashes were obtained by placing 4 g of dry sample in a furnace at 600℃ for 3 h, and the organic matter was calculated as the difference between the ash and dry weights. Degradation of the compost material was calculated using Eq. 1.

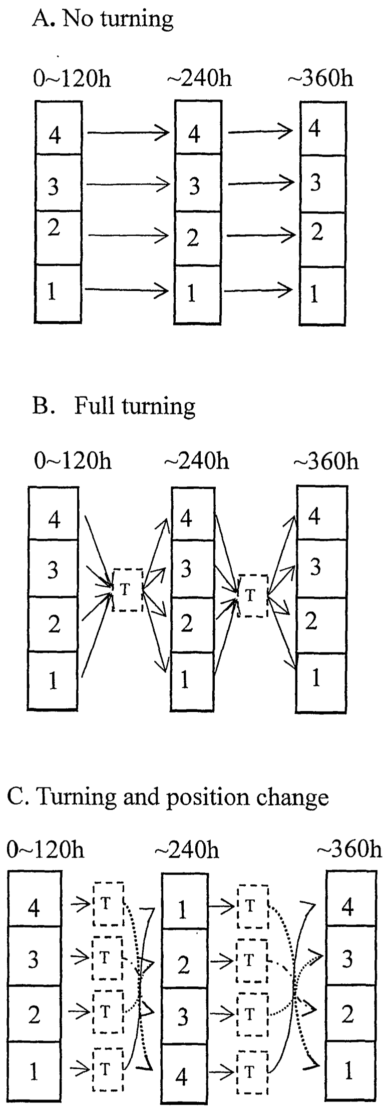

Fig. 2 Schematic diagram of the turning patterns for runs A, B and C

$$\text{Degradation}(\%)=\left\{1-\frac{(100-OM_i)}{(100-OM_f)}\right\}\times 100 \qquad (1)$$

OM_i : Initial organic matter (%)
OM_f : Final organic matter (%)

III Results and discussion

1. Temperature distribution

To determine a suitable range for aeration rates for high temperature composting, various rates were applied to the compost reactor. Figure 3 depicts the average temperature of the compost material at aeration rates of 0.025, 0.050, 0.100, 0.150 and 0.200 L/min.kgdm. From the graph, aeration of 0.100 L/min.kgdm indicates that there was high temperature composting where the average temperature of over 60℃ was held for about 48 h. However, at an aeration rate of 0.025 L/min.kgdm the temperature failed to reach a thermopilic phase, most likely because of the lack of oxygen. In this case, passive aeration was not facilitated because the construction of reactor did not allow for an air source other than the air pump to flow from the bottom. As well, saw dust as bulking agent has little effect on the void space compared to rice straw (Harada, 1998).

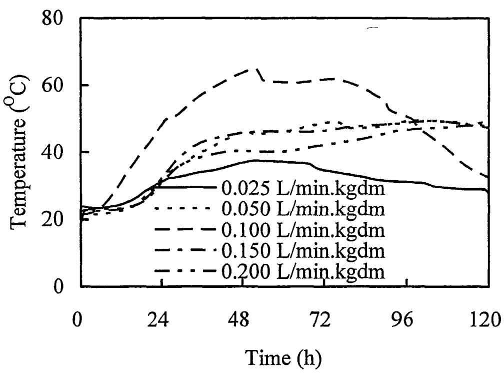

Fig. 3 Effect of aeration rates on average temperature of compost material during 120 h of composting

We recorded the maximum temperatures for all runs within the first five days of composting, as shown in Fig. 4. The temperature increase after the first turning for both turning pattern types was less than in the first period. The maximum temperatures at aeration rates of 0.05, 0.15, and 0.50 L/min.kgdm were 64.0, 73.2, and 70.8℃ respectively. Increasing the aeration rate from 0.05 to 0.15 L/min.kgdm revealed a positive correlation with heat production from biological activity. Heat production from respiration could not suppress the heat removal resulting from aeration at 0.50 L/min.kgdm ; thus, the temperature was lower than with aeration at 0.15 L/min.kgdm.

The times required to reach the maximum temperature at aeration rates of 0.05, 0.15, and 0.50 L/min.kgdm were 54.9 to 120.0 h, 52.0 to 70.0 h, and 14.5 to 25.0 h, respectively, after commencing composting. The maximum temperature was reached in a shorter time using a higher aeration within our aeration rate ranges. From Fig. 4 the maximum temperatures in runs 0.05B, 0.15B and 0.50B can be seen as occurring in the second and third layers. It is also evident that the aeration rate had an effect on the position of the layer with the maximum temperature. A similar result was found by Wu et al. (1990).

Three aeration rates indicated three temperature profiles. Temperature profiles at an aeration rate of 0.05 L/min.kgdm led to an oxygen deficiency on L3 and L4, while aeration at 0.50 L/min.kgdm resulted in excess aeration. In the case of an aeration rate of 0.50 L/min.kgdm, the temperature profile of the compost layers on the entrance side fall, affected by the air

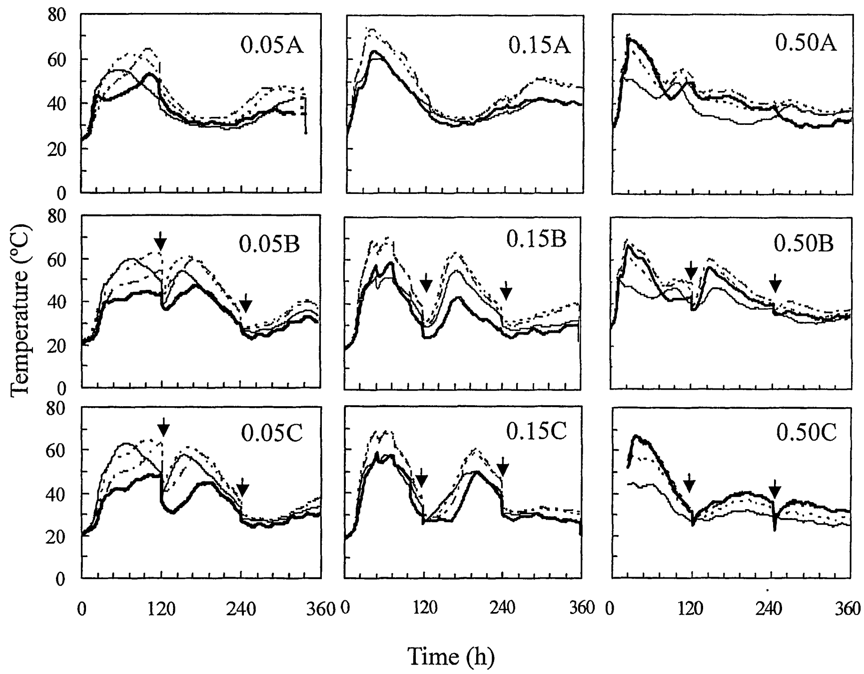

Fig. 4 Effect of aeration rates and turning patterns on the temperature distribution of compost materials (—— : L1; ······ : L2; -·-·- : L3; ▬ : L4; —— : ambient temperature; ➞ : turning)

Table 2 Organic matter loss and heat production at different aeration rates and turning patterns

Turning method	Organic matter loss (kg)			Heat production (Calorie)		
	Aeration (L/min.kgdm)			Aeration (L/min.kgdm)		
	0.05	0.15	0.50	0.05	0.15	0.50
A	0.204	0.317	0.518	816	1268	2072
B	0.112	0.279	0.649	448	1116	2596
C	0.048	0.257	0.612	192	1028	2448

temperature. However on the exit side, fermentation temperatures tend to rise more than that in the case of an aeration rate of 0.15 because of the supply of oxygen. In the case of an aeration rate of 0.15 L/min. kgdm the lower layer (entrance) is not so affected by the air temperature and the temperature of the layer rises ; whereas in case of an aeration rate of 0.50 L/min.kgdm the entrance is affected, with the rise and fall of L1 and L4, respectively, reversing each other, and the middle layers L2 and L3 are relative higher, while the temperature of the upper layer rises.

The heat of the fermentation was calculated based on organic matter reduction ; assuming 3000–5000 calories (average 4000) were produced from 1 kg of organic matter loss. Aeration rates of 0.05, 0.15 and 0.50 L/min.kgdm produced fermentation heats equivalent to 192–816, 1028–1268 and 2072–2596 calories, respectively, as shown in Table 2.

A high temperature was obtained only in the first stage of composting without turning (runs 0.05A, 0.15 A and 0.50A). The most easily degradable material (such as sugars, protein, lipid etc) on the surface of compost matrix was decomposed during this period. The temperature increase after turning (runs 0.05B and 0.05C) indicated that decomposition increased again due to the availability of fresh substrate from the breakdown of the compost material structure during turning. Turning after a temperature decrease restructured the compost material and returned it to a high temperature state due to increased microbial activity brought by exposure to fresh organic matter not yet consumed in the ongoing composting process. Turning continued to affect the temperature increase at aeration rates of 0.15 and 0.50 L/min.kgdm. The temperature increase after full turning was more rapid than after turning with a position change. This may have been due to the uniformity of fresh material throughout the vessels. Oxygen was obtained mainly from the air supplied by an air pump, with very little diffusion of free air to the top layer. Very little oxygen is obtained by way of ambient air diffusion into the outer layer of the windrow (Kreith, 1994).

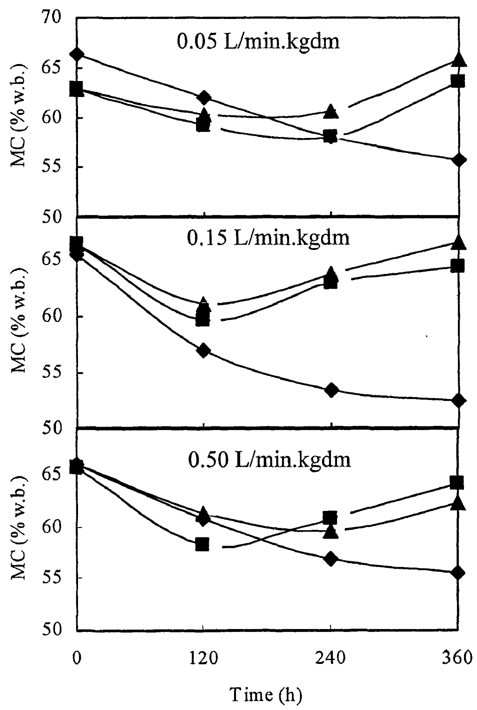

Fig. 5 Moisture content changes during 360 h of composting with different aeration rates and turning patterns (—◆— : A; —■— : B; —▲— : C)

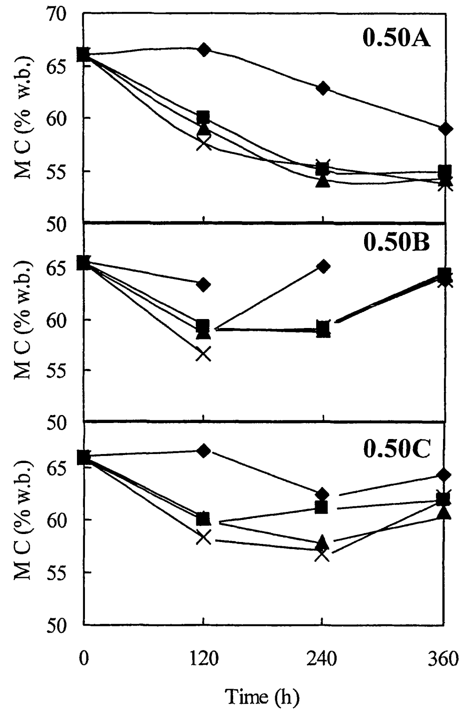

Fig. 6 Moisture content changes of layers for aeration of 0.50 L/min.kgdm (runs 0.50A, 0.50B, and 0.50C)
(—×— : L1; —▲— : L2; —■— : L3; —◆— : L4)
Note : All the plots for case of 0.50B start from the average MC values every after full-turning treatment.

2. Moisture content and organic matter

The initial moisture content varied from 62.8% to 66.4% (w.b.). Figure 5 indicates the moisture content changes during 360 h of composting. The moisture content of the compost material for all runs decreased in the early stage of composting (120 h). The moisture content decreased during 360 h of composting in runs 0.05A, 0.15A, and 0.50A. In contrast, the moisture content in both runs B and C slightly increased in the second and third periods. In the case of composting without turning, decomposition slowed when the easiest degradable material decreased on the compost aggregate surface. The reason is the slow diffusion of oxygen penetrating the solid material. Moisture transfer still occurred via aeration without turning. In the composting with turning method, decomposition continued when the material particles became smaller after turning. Breaking the compost matrix exposed fresh material and facilitated microbial growth and material decomposition, producing water. Runs 0.50A, 0.50B and 0.50C produced 390, 469 and 420 g water, by assuming water generated per 1 kg of dry matter loss was 0.57 kg as represented by the oxidation reactions $C_6H_{12}O_6$ and $C_6H_{12}O_5$ (Kimura and Shimizu, 1989). The moisture content increased when the water generated by the reaction surpassed the amount vaporized (Bach et al., 1987).

The moisture loss rate at aeration rates of 0.05, 0.15 and 0.50 L/min.kgdm were 5.5%, 10.4% and 8.7% after 120 h of composting. The moisture loss rates were higher (15.9%–19.7%) in composting without turning than in the composting with turning method at 360 h, most likely due to low water production.

Figure 6 depicts the moisture content change in the layers at an aeration rate of 0.50 L/min.kgdm during 360 h of composting. The moisture content recordings in the first, second, third, and fourth layers at 360 h of composting in run 0.50A were 53.7%, 54.3%, 54.9%, and 59.1% in run 0.50A. There was a moisture content gradient in the treatment without turning. The moisture content in run 0.50B became more uniform at the end of composting. The moisture content for all layers in run 0.50C decreased up to 240 h, except for the 3rd layer. Finally, the moisture content of the layers increased at the end of composting (360 h). Reverse water flow occurred in composting with turning type C. Shimizu et al. (1989) indicated that temperature is an important factor for decreasing moisture. The moisture transfer here was due to the different temperatures of the compost material, assuming water vapor pore saturation.

The initial organic matter content of the mixture of cattle manure and saw dust varied from 92.0% to 94.0%. Increasing aeration from 0.05 to 0.50 L/min.kgdm increased the rate of organic matter loss from 1.2% to 2.1% for composting without turning. The oxygen supply is the most influential factor in the decomposition process. At an aeration rate of 0.50 L/min.kgdm, oxygen was distributed evenly throughout the vessel. Hence, the availability of oxygen facilitated enhanced decomposition. The degradation and rate of organic matter losses were almost same level in composting with or without turning at an aeration rate of 0.05 L/min.kgdm. Oxygen penetrated compost pores well after breaking large particles during turning. Exposing this fresh material to lower oxygen levels did not help to increase the decomposition in comparison to composting without turning.

Both turning methods produced greater degradation at aeration rates of 0.15 and 0.50 L/min.kgdm compared with no turning. The degradation in runs 0.50A, 0.50B, and 0.50C were 24.7%, 30.1%, and 29.3% at 360 h of composting. Compared to composting without turning, the turning methods increased the rate of organic matter loss from 1.8% to 2.6%-2.8% at an aeration rate of 0.15 L/min.kgdm and from 2.1% to 2.6%-2.9% at an aeration rate of 0.50 L/min.kgdm. The appropriate combination of aeration and turning yielded the highest rate of organic matter loss (2.6%-2.9%). The organic matter loss rate in full turning was little higher than turning with position change because the material in full turning was more uniform than in turning with position change. The initial organic matter compositions were not the same due the different composition of manure and sawdust. The percentages of degradation for all runs during composting are illustrated in Fig. 7, which shows the highest decomposition rate occurring in the first period for aeration 0.50 L/min.kgdm. The degradation rate for aeration rate 0.15 L/min.kgdm was nearly steady during composting most likely due to the availability of substrate and oxygen for microbial activity.

3. Weight loss

Weight reduction creates a financial advantage with respect to transportation costs. Figure 8 indicates the accumulated weight loss in 360 h of composting. The accumulated weight loss was 204 g in the first, 154 g in the second, 84 g in the third, and 422 g in the fourth layers after 360 h of composting in run 0.05A. There was a weight loss gradient in a vertically upward direction, except in the top layer. The weight loss from the top layer was affected by aeration and ambient conditions.

The percentages of weight loss in the early stage of composting (120 h) to the total weight loss during composting at aeration rates of 0.05, 0.15, and 0.50 L/min.kgdm were 43.3% to 51.5%, 40.8% to 57.0%, and 51.1% to 61.6%. This demonstrates that the temperature in the early stage of composting is an important factor for mass transfer during composting. Composting reduced the mass of compost material using energy from the decomposition process. After 360 h of

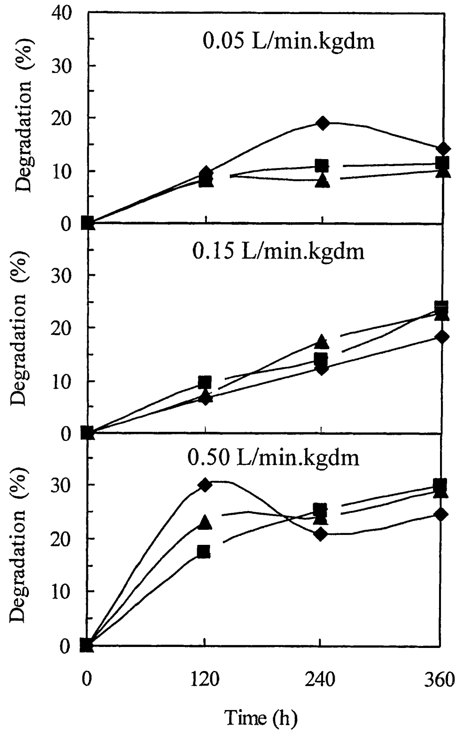

Fig. 7 Degradation of organic matter during 360 h of composting with different aeration rates and turning patterns (—◆— : A; —■— : B; —▲— : C)

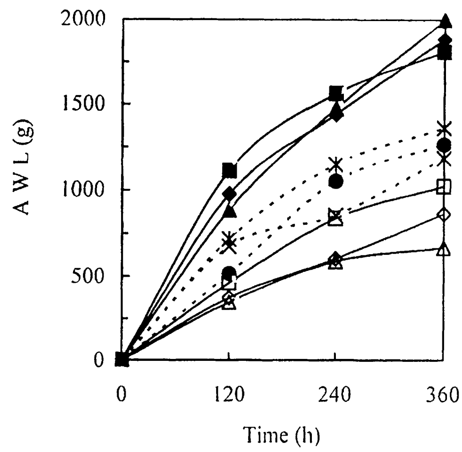

Fig. 8 Accumulated weight loss (AWL) during 360 h of composting with different aeration rates and turning patterns (—◇— : 0.05A; —□— : 0.05B; —△— : 0.05C; - ✕ - : 0.15A; - ✳ - : 0.15B; - ● - : 0.15C; —◆— : 0.50A; —■— : 0.50B; —▲— : 0.50C)

composting the percentages of total weight loss at aeration rates 0.05, 015 and 0.50 L/min.kgdm were 8.3% to 12.7%, 14.8% to 17.2% and 23.1 to 25%. Kuroda et al. (1996) reported that total weight loss after fourteen days was 45% for a mixture of swine manure and corrugated cardboard (using a 48.8 L reactor). Elwell et al. (2001) reported that the total weight loss after 400 h of swine manure composting was 41.4% to 53.2% (using a 205 L reactor). The final weight observed in our results was lower compared with both Kuroda and Elwell due to the different raw material composition and reactor types.

The primary component of weight loss is water, although some volatiles also evaporate during composting. Figure 9 depicts the relationship of the moisture content with the weight loss in runs 0.50A and 0.50C. The relationship between weight loss and moisture loss was most likely linear in run 0.50A. In contrast, the relationship of weight loss and moisture content was different in run 0.50C in terms of the balance between water production and water transfer, resulting in a moisture content change. Turning had the effect of greater decomposition and produced more water than treatment without turning. Turning changed the structure of the compost material, making it more compact due to the uniform matrix of the mixed cattle manure and sawdust. Water removal brought by the aeration rate was likely steady since the compost structure did not change without turning.

4. Effect of aeration and turning on compost material composition

Figure 10 depicts the composition changes of compost during composting. It was calculated by assuming that the ash content was uniform throughout the composting. The organic matter reduced from 2607 g to 1922 g for run 0.50A, and from 2563 g to 1740 g for run 0.50B, while the water decreased from 5375 g to 4174 g for run 0.50A, and from 5224 g to 4161 g for run 0.50B during 360 h of composting. The composition change within the compost material was different in composting with turning as compared to composting without turning, in which organic matter decreased more for composting with turning methods rather than in composting without turning. Organic matter reduction with full turning was somewhat greater than that for turning with a position change. For all aeration rates, organic matter reduction consistently decreased in composting with full turning most likely due to material uniformity. The aeration rate affects organic matter reduction, water transfer and the total weight loss. Interaction between aeration and turning

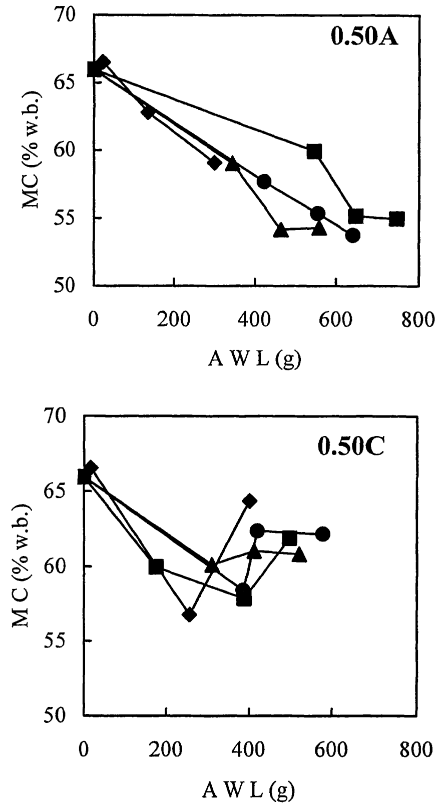

Fig. 9 Relationship between accumulated weight loss (AWL) and moisture content change (—●— : L1; —▲— : L2; —■— : L3; —◆— : L4)

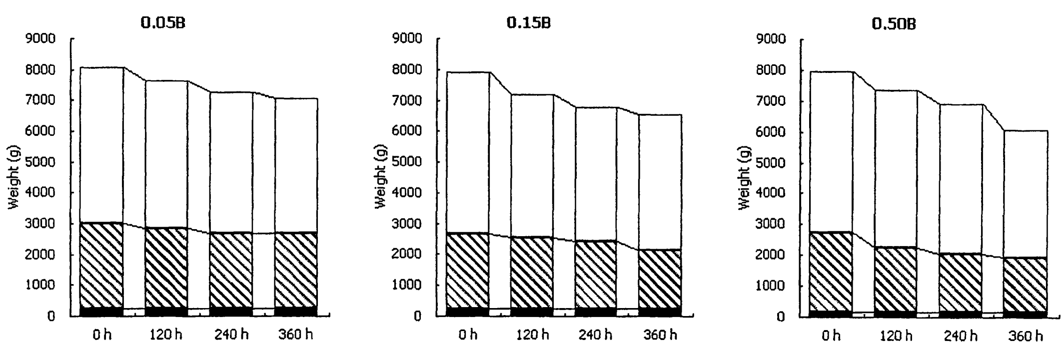

Fig. 10 Composition of water, organic matter, and ash in compost material during 360 h of composting (□ : water; ▧ : organic matter; ■ : ash)

methods results in different pattern composition, in which increasing aeration tends to reduce total mass, while turning tends to decrease organic matter.

IV Conclusion

The effects of aeration and the turning pattern on decomposition of organic matter in cattle manure composting were determined in this research. Increased aeration rates from 0.05 to 0.50 L/min.kgdm increased the maximum temperature and reduced the time required to achieve a high temperature in the early stage of composting. The moisture content reduction was higher in composting without turning than with turning methods. The losses of dry matter and total weight were most likely affected by an increase in the aeration rate. Organic matter degradation was the same level in composting with turning or without turning at low aeration (0.05 L/min.kgdm). This research confirmed that degradation in forced aeration composting can be increased with a combination of full turning or turning with a position change at aeration rates of 0.15 and 0.50 L/min.kgdm. Composition changes within compost material are also affected by aeration and turning. Our results suggest that a combination of an aeration rate of 0.50 L/min.kgdm and full turning provides the greatest degradation as well as total mass reduction.

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「技術論文」

牛ふんのコンポスト化における有機物分解に及ぼす通気と切り返しの影響

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要　旨

容量18.8 Lの反応槽を使用して，牛ふんのコンポスト化を3つの通気量（0.05，0.15，0.50 L/min.kgdm）と3つの切り返し（層の位置の入れ替えによる切り返し，全体の切り返し，切り返しなし）の条件で行った。最高温度は通気量0.05 L/min.kgdmで64.3℃，0.15 L/min.kgdmで73.2℃，そして0.50 L/min.kgdmで70.8℃であった。通気量0.50 L/min.kgdmで，効果的にコンポスト化初期過程における分解が促進された。切り返しをしない場合に比べ，切返しをする場合は有機物の分解が促進されることが明らかになった。通気量0.50 L/min.kgdmによる15日後の分解率は，切り返しなしの場合で24.7%，全体の切り返しをした場合で30.1%，そして層の位置を入れ替えた切返しでは29.3%であった。通気量の増加によってコンポスト化材料の総重量減は増加した。

［キーワード］通気，牛ふんコンポスト化，充填床反応層，切り返しパターン

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