

COMPOSTING AND LAND APPLICATION OF ANIMAL WASTES

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Summary

As the livestock production in Japan is industrialized, a tremendous amount of animal wastes is being produced annually, resulting in serious environmental pollution problems. Animal wastes could be pollutants, but they are also important sources of fertilizer nutrients and organic matter. Composting is an effective way of promoting the increased utilization of animal wastes. The characterization of maturing process during composting is important in order to improve the composting technology and to develop an efficient method to estimate the degree of maturity. The rise and fall in temperature, and changes in the constituents of the compost, reflect the maturing process and may serve as indicators for maturation. In addition, the detection of nitrate by diphenylamine, the determination of cation-exchange capacity (CEC), and the germination test, are also recommended as the methods of estimating the degree of maturity. The heavy applications of animal manure and compost may cause an adverse effect on soils and crops. When excess manure is applied, the nitrogen will be accumulated in soil, resulting in accumulation of nitrate in crops and pollution of the groundwater. Guidelines for application rates are recommended, to maintain soil productivity and quality of crops, and to prevent the environmental pollution.

(Key Words: Composting, Animal Wastes, Manure, Recycle, Application)

Introduction

The application of organic matter is very important in maintaining high and stable crop yields. However, the amount of organic matter applied to fields in Japan has been gradually decreasing, since farmers have become dependent on the use of chemical fertilizers as labor has become scarce. A decline in soil fertility has now been noticed, and the importance of increasing soil fertility by the application of organic matter is again being recognized.

The total production of animal wastes in Japan is estimated to be about 75 million mt/year (Harada, 1985). These animal wastes contain many nutrients such as nitrogen, phosphorus, potassium, and other minerals. The total amount of nitrogen contained in animal wastes has been estimated at 720 thousand mt/year (Miwa and Iwamoto, 1987) in Japan. It was more than the total

consumption of nitrogen in chemical fertilizer (680 thousand mt/year). In addition to the supply of the nutrients, the application of animal wastes also improves the chemical, physical, and biological properties of soil. Thus, the animal wastes are very important as organic fertilizers and as soil conditioners.

At present, however, animal wastes are not utilized so effectively. As the number of animals kept by a farmer is increased year by year, it becomes more difficult for farmers to recycle all of the animal wastes onto crop land, and the management of wastes is becoming a very serious problem. For the poultry and swine growers who do not hold sufficient crop land, this trend is especially remarkable.

In order to promote the use of animal wastes in agriculture and to prevent environmental pollution, many difficulties must be overcome. Raw animal waste is not generally acceptable as an organic fertilizer, because it has an offensive odor and is insanitary and unstable, although it is a useful resource for crop production. Furthermore, heavy application of raw animal wastes may cause damage to crop plants as a result of excess ammonium, reduction of soil, and

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the presence of phytotoxic substances. Avoidance of these problems can be achieved to a greater or lesser extent by composting.

In this paper, studies on the composting of animal wastes and their application in crop land are summarized.

Composting of Animal Wastes

1. Definition and objectives of composting

Composting is defined as follows: Composting is a method of solid waste management whereby the organic component of the solid waste stream is biologically decomposed under controlled conditions to a state in which it can be handled, stored, and/or applied to the land without adversely affecting the environment (Golueke, 1977).

The raw animal waste is offensive, dirty, and sticky. Besides, it contains readily decomposable organic matter. When it is applied heavily to the crop land, the soil may be reduced too much and the phytotoxic substances such as phenolic acids and volatile fatty acids may be produced. Furthermore, it may contain pathogens, parasites, or weed seeds. Therefore, the objectives of composting are to reduce the offensive odor, to resolve the difficulties in handling due to the stickiness, to inactivate the pathogens, parasites, and weed seeds, to stabilize the organic constituents, and thus to produce a uniform organic material suitable for land application.

The crop residues such as rice hull and straw, and the wood material such as sawdust and woodchip are admixed usually as bulking agents in composting to secure fast stabilization. Such admixtures may contain phytotoxic substances (Kusano and Ogawa, 1974; Yoshida, 1975). Therefore, it is another objective to decompose phytotoxic substances when such material is mixed with animal wastes.

2. Maturing processes of composting

The characterization of maturing processes during the composting is important in order to improve the method of composting and to develop the method to estimate the degree of maturity.

(1) Changes in temperature during composting

When the sufficient air is supplied, the temperature usually rises to higher than 60°C during composting. If the air supply is insufficient, however, the temperature does not so rise. Therefore, such temperature rise is a useful index for assessing whether composting is proceeding well or not. The temperature profile during the composting of cattle waste is shown in figure 1 (Harada and Haga, 1983).

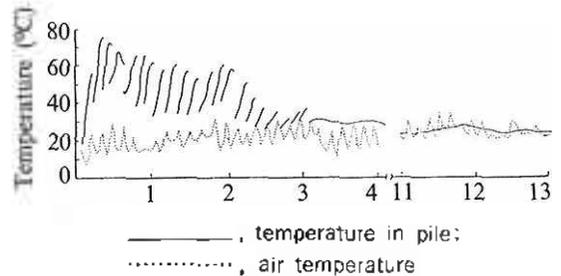


Figure 1. Changes in temperature during the composting of cattle waste.

The temperature rise is necessary not only for accelerating the decomposition of organic constituents, but also for the inactivation of noxious organisms. Pathogens, parasites, fly larvae, and weed seeds have been killed during the composting at temperature of 60°C and higher (Gotaas, 1956; Poincelot, 1975; Burge et al., 1977; Takabayashi et al., 1978).

(2) Decomposition of organic matter

The organic matter is decomposed and stabilized during the composting. The changes in ash, total carbon, total nitrogen, and C/N ratio of cattle waste are shown in figure 2 (Harada and Haga, 1983). Organic matter was decomposed and the content of ash increased relatively. The content of total carbon decreased, total nitrogen increased relatively; thus C/N ratio decreased. The remarkable changes in chemical composition were leveled off until about 5 weeks, and thereafter these constituents changed gradually.

The decomposition of organic matter during the composting was characterized by the changes in residual rate (the rate of residual amount to the initial amount, %) of organic matter (figure 3). The organic matter was roughly estimated by the ignition loss. The decomposition of organic matter with time can be represented by the fol-

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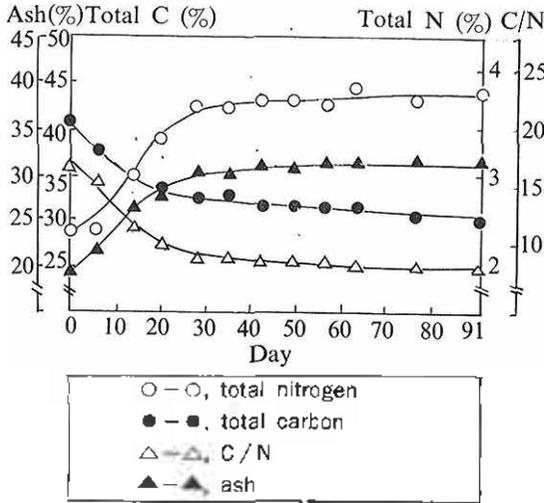


Figure 2. Changes in constitution of cattle waste during the composting.

lowing equation; $Y = A \cdot \text{EXP}(k \cdot X) + B$, where X is period of composting (day), Y is residual rate of organic matter (%), k is exponential constant, and A and B are constants. The changes in the residual rate of organic matter during the composting were expressed as follows:

$$Y = 49.02 \text{ EXP}(-0.0775X) + 52.3 \text{ (Cattle waste)}$$

$$Y = 49.54 \text{ EXP}(-0.136X) + 52.8 \text{ (Poultry waste)}$$

These equations indicate that poultry waste is more easily decomposed than cattle waste.

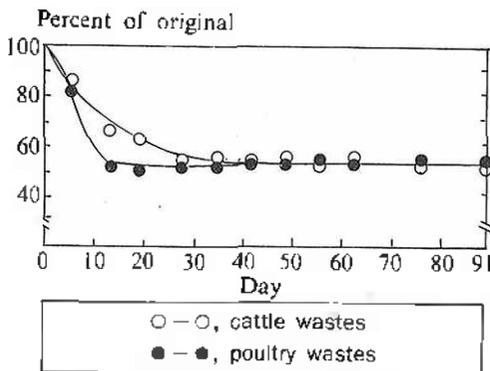


Figure 3. Changes in residual rates of organic matter during the composting of cattle and poultry wastes.

(3) Changes in organic constituents

The changes in organic constituents during

the composting of cattle waste are shown in figure 4 (Harada et al., 1985). The contents of hemicellulose and cellulose decreased rapidly till about 5 weeks; thereafter little change was noticed. The content of lignin increased gradually till the end of composting.

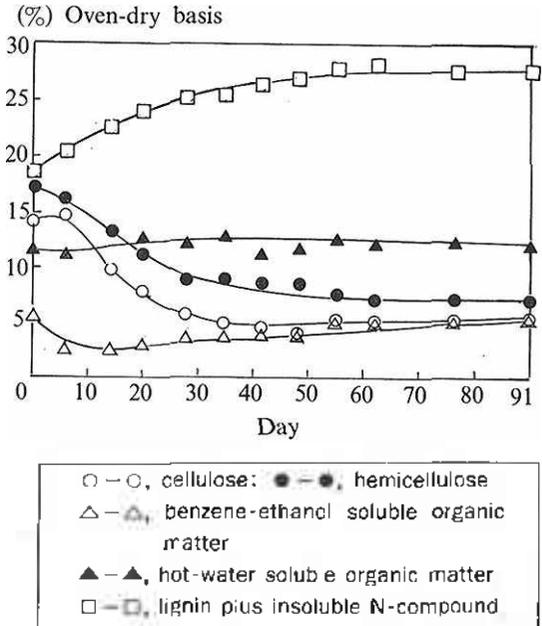


Figure 4. Changes in organic constitution of cattle wastes during composting.

Various microbes participate in the composting, and the microfloral population changes successively during the composting. The succession of microflora and the sequence of degradation of composting material are as follows (Poincelot, 1975): In the earlier stage of composting, mesophilic bacteria and fungi are dominant, and consume the sugar, starch, and protein. As the temperature rises above 40°C , they are replaced by thermophilic bacteria, actinomycetes, and thermophilic fungi. In this stage, lipid, hemicellulose, and cellulose are decomposed. Finally, as the temperature falls, mesophilic bacteria and fungi reappear. Consequently, it is considered that sugar and starch are decomposed at first, subsequently hemicellulose and cellulose, and finally lignin, are decomposed.

The change in residual rate of each organic constituent was shown in figure 5 (Harada et al., 1985). In this study, however, the sequence

of degradation mentioned above was not so clear. The degradation of each constituent appears to be proceeding simultaneously as the whole, since the composting mass is not homogeneous and many reactions are occurring simultaneously in different micro sites.

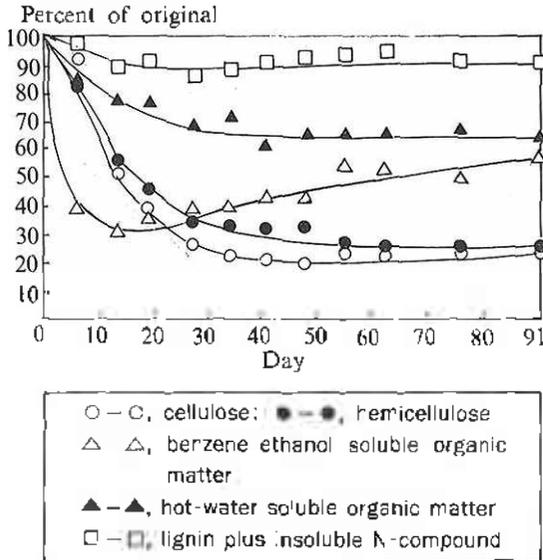


Figure 5. Changes in residual rates of organic constituents during the composting of cattle waste.

3. Estimation of maturity

The compost should be sufficiently matured before the application, since the application of immature compost to soil occasionally causes severe damage to plant growth. Therefore, the method to estimate the degree of maturity of compost is required.

(1) Temperature in composting mass

As described above, the temperature in compost piles rises with the progress of decomposition, and falls when the organic constituents has been stabilized. Therefore, the temperature in the pile can be used as an index to estimate whether composting has completed or not. However, the temperature change does not necessarily reflect the processes, but varies according to the circumstances. For instance, the temperature may lower even though the organic constituents have not been stabilized yet, when the composting mass

has been dried excessively.

(2) Constituents of composting materials

The changes in constituents reflect the maturing process. The increase of ash, total nitrogen, and lignin, and the decrease of organic matter, total carbon, hemicellulose, cellulose, and C/N ratio with time may serve as the indicators for maturation. However, the guidelines of maturity should be proposed for each raw material, since the contents of these constituents varies with material.

(3) Detection of nitrate by diphenylamine

In the earlier stage of composting, ammonium is produced by the decomposition of nitrogenous compounds such as protein. The ammonium is oxidized to nitrate by the action of ammonium-oxidizing bacteria and nitrite-oxidizing bacteria during the progress of maturation. Consequently, nitrate is accumulated in the matured compost. The nitrate is detected qualitatively by diphenylamine. The diphenylamine solution, dissolved in concentrated sulfuric acid, is added to water extract of compost, and, if nitrate is contained in the extract, blue color appears. This method can be used for the cattle waste compost, but not for the poultry compost, because the nitrate is scarcely produced during the composting of poultry waste even after the complete composting (Osada et al, 1986).

(4) Determination of cation-exchange capacity

The negative charge, namely the cation-exchange capacity (CEC) of organic matter increases as the compost matures (Harada and Inoko, 1980). The highly significant correlations were observed between the CEC and C/N ratio ($r = -0.995^{***}$), total carbon ($r = -0.968^{***}$), total nitrogen ($r = 0.995^{***}$), and ash ($r = 0.992^{***}$) for the cattle waste compost (Harada et al., 1984). Therefore, the CEC is considered to reflect the changes in constituents during the maturation, and hence it is a useful parameter for estimating the degree of maturity of the compost.

(5) Germination test

Immatured compost and anaerobically piled compost may contain phytotoxic substances such as phenolic acids and volatile fatty acids. The existence of such phytotoxic substances can be

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detected with the germination test. Fifty or 20 seeds of comatsuna (*Brassica rapa*) are placed on a filter paper in a petri dish ($\phi 9$ cm) and 10 ml of water extract from compost is added, and then it is incubated at 20°C under a dark condition. The germination rate is measured after 24 hrs. The germination rate was low with the sample of raw material and of anaerobical portions of the pile, and increased as the material matured (Osada et al., 1985).

Land Application of Animal Manure and Compost

1. Grassland and forage crop field

The large amounts of animal manure and/or compost tend to be applied to the grassland and forage crop field, because the grass and forage crops generally tolerate the high rates of plant nutrients and respond well to produce the high yield. However, when the excess manure or compost is applied, nitrogen is accumulated in soil and the concentration of nitrate in crops increases. Feeding of such crops is hazardous to ruminants. Generally, 0.22% $\text{NO}_3\text{-N}$ is considered the safety limit (dry matter basis) (Wright and Davison, 1964). Nitrate is accumulated easily in stalks of corn with heavy application of manure (figure 6). When the annual application rate exceeds 100 t/ha, nitrate content in green-cut corn and Italian ryegrass can be dangerous (Ito et al., 1982).

In addition, the heavy application of manure and compost causes the imbalance in base composition of soils and forage crops. Potassium is accumulated in soils with the heavy application, since animal manure contains high concentration of potassium. Forage crops, grown in such potassium-rich soil, take up potassium easily and accumulate it luxuriously in the aboveground parts, particularly in stalks in the case of corn. Plant uptake of magnesium and calcium is antagonistically lowered with the excess potassium in soils; thus the ratio of $\text{K}/(\text{Ca}+\text{Mg})$ in the plants increased remarkably (figure 7). When the base equivalent ratio, $\text{K}/(\text{Ca}+\text{Mg})$ in forage crops, exceeds 2.2 and the magnesium content in forage crops lowers below 0.2%, the outbreak of grass tetany of dairy cattle is increased markedly (Kemp and Hart, 1957).

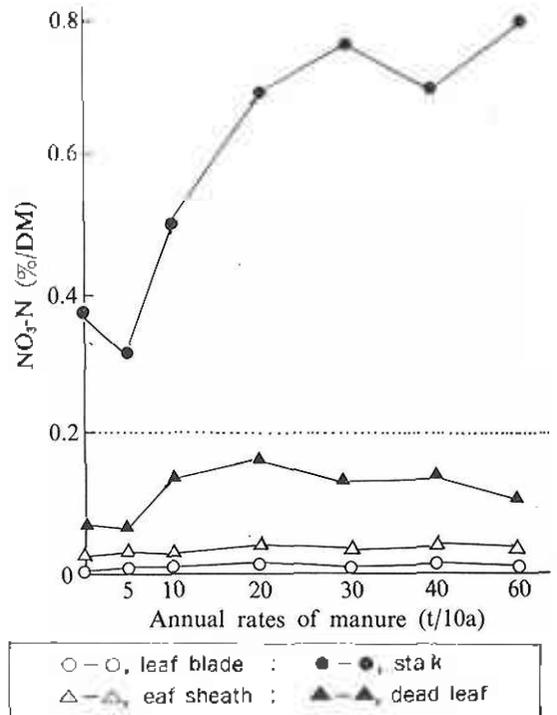


Figure 6. Nitrate concentrations in green-cut corn as affected by the manure application rates.

Therefore, the amount of manure and compost applied to the cropped land should be within the certain limit. Optimum application rates of animal manure in grassland and forage crop field are recommended as in table 1 (Kurashima, 1983). Chemical fertilizers are recommended to use together with the animal manure (table 2). Namely, the amount of potassium required by crops is applied in the form of cattle manure, and the nitrogen and phosphorus are supplemented with chemical fertilizer, since the cattle waste contains high potassium. In the cases of swine and poultry manure containing high phosphorus, the requirement of phosphorus is sufficed with manure, and the nitrogen and potassium are supplemented with chemical fertilizer.

2. Paddy field

In the paddy field, the adequate application of manure and compost maintains the soil fertility and stable high rice yield; however, the heavy application may decrease crop yield because of the excess nitrogen in soil. Furthermore, when

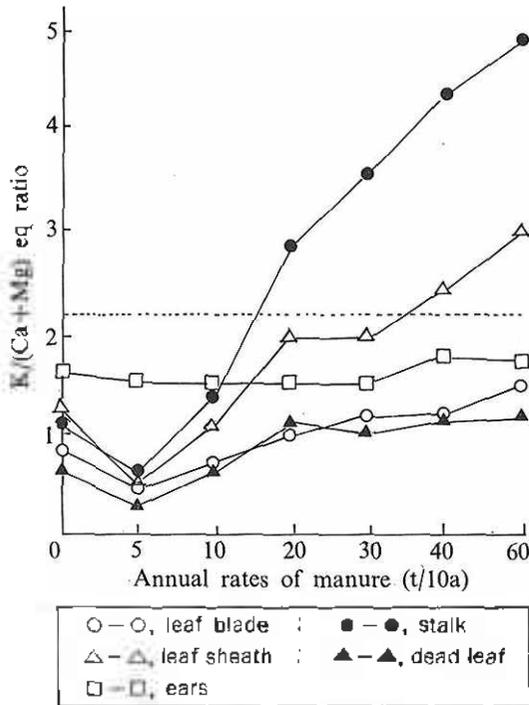


Figure 7. K (Ca+Mg) equivalent ratios in green-cut corn as affected by manure application rates.

the animal manures containing large amount of readily decomposable organic matter are applied heavily to paddy fields, soil microorganism multiplies rapidly, and the reduction of soil may occur with the consumption of oxygen. Under such soil conditions, phytotoxic substances are produced, aggravating the growth of plant root. Therefore, the application of matured compost is desirable, since the reduction is apt to occur excessively in the paddy field.

The optimum application rates of animal manure and compost in paddy field are recommended as in table 3 (Shiga, 1983). The guidelines were proposed with the consideration of the nitrogen content in manure.

However, when animal manure and compost are applied every year for a prolonged period, it must be considered that the release of nitrogen from soil increases. The changes in release of nitrogen by successive application of manure is shown in figure 8. When swine manure or poultry manure is applied successively, the nitrogen is not so much accumulated in soil, since such manures are easily decomposed. In the case of cattle manure, however, the annual decomposition

TABLE 1. RECOMMENDED APPLICATION RATES OF ANIMAL MANURE IN GRASSLAND AND FORAGE CROP LAND (t/ha)

	Target yield	Cattle manure	Swine manure	Poultry dried manure
Pasture grass	50-60	30-40	20-30	5
Mixed herbage	50-60	30-40	20-30	5
Corn	50-60	30-40	20-30	5
Italian ryegrass	40-50	30	20	4

TABLE 2. REQUIREMENT OF FERTILIZERS APPLIED TOGETHER WITH MANURE (kg/ha)

	Cattle manure			Swine manure			Poultry dried manure		
	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O
Pasture grass	140	—	—	80	—	50	80	—	80
Mixed herbage	60	—	—	—	—	50	—	—	80
Corn	140	70	—	80	—	50	80	—	80
Italian ryegrass	110	—	—	60	—	40	60	—	60

rate of manure, or the release rate of nitrogen, is as low as 30%. The rest of nitrogen in the

manure is carried over to the succeeding years, and the release of nitrogen is increasing year by

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TABLE 3. RECOMMENDED APPLICATION RATES OF ANIMAL MANURE AND COMPOST IN PADDY FIELD (t/ha)

	Cattle			Swine			Poultry
	Raw manure	Dried manure	Compost	Raw manure	Dried manure	Compost	Dried manure
Rice	20-25	10	10-20	15	7	5-15	2
Rice-Wheat	20	8	15	10	5	10	

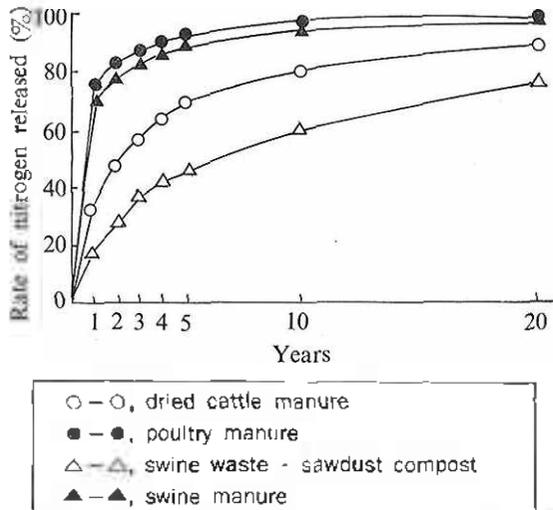


Figure 8. Increase in the rates of nitrogen released (% of nitrogen released annually of total nitrogen applied in that year) with successive manure applications.

year. In the case of compost, this trend is more remarkable.

3. Vegetable field

In the vegetable field, the application of manure and compost is important for supply of nutrients, since vegetables generally require much more nutrients. It is also important to maintain the chemical, physical, and biological properties of soil to keep high productivity in the vegetable fields. As the content of organic matter in soil increases, the CEC of soil increases with the application of manure. The negative charge of soil is an ability to retain the nutrients in the forms of cations (ammonium, potassium, calcium, magnesium and so on). The effect of the application is remarkable particularly in soils low in humus and clay. The air and water permeabilities

of soil are also improved with the application of manure. As the results, the ability of plants to take up water and nutrients is enhanced with the growth of root. Furthermore, the circulation of materials in soil is accelerated with the activation of soil organisms.

However, as in the cases with other crops, the heavy application of manure may bring the imbalance in base compositions of soils and vegetables. Kinoshita et al. (1980) reported that the concentration of calcium in the onion scaly bulb decreased with the application of swine waste compost containing sawdust. In addition, the heavy application of manure may also cause the environmental pollution. Not all of the nitrogen released from manure is taken up by crops, and the unutilized nitrogen is transformed to nitrate by nitrification. The nitrate is readily leached down to subsoils and eventually to ground water, because soils retain nitrate weakly. As application rates of manure increased, the leaching of nitrate will be increased. Ogawa et al. (1988) reported that the nitrate had been accumulated down to 200 cm of the soil after the harvest of cucumber with application of dried swine manure at a rate of 100 t/ha.

The optimum application rates of animal manure and compost in vegetable fields are recommended as in table 4 (Yumura, 1983). The guidelines were proposed with three types according to the low, medium, and high fertilizer requirements of the vegetables.

Conclusion

Composting is an effective method for promoting the utilization of animal wastes. The maturing process of animal wastes during the composting was characterized, and the conditions to accelerate the maturing process were made clear. The quality, particularly the maturity, of compost

TABLE 4. RECOMMENDED APPLICATION RATES OF ANIMAL MANURE AND COMPOST IN VEGETABLE FIELD (t/ha)

	Cattle			Swine		Poultry
	Raw manure	Dried manure	Compost	Dried manure	Compost	Dried manure
Low	20-40	4-8	10-20	3-4	10-20	2-3
Medium	30-50	6-12	13-25	4-6	12-25	3-4
High	40-60	8-15	20-40	5-8	17-35	4-5

Vegetables of low fertilizer requirement: potato, spinach, radish.

Vegetables of medium fertilizer requirement: cabbage, lettuce, tomato.

Vegetables of high fertilizer requirement: cucumber, green pepper.

is regarded important to secure the better utilization. Although many methods to estimate the degree of maturity have been proposed, more practical and reliable method is needed.

The application of animal manure and compost to crop land is beneficial to the improvement of soil productivity. However, the heavy application of manure causes adverse effect on soils and crops. Although the optimum application rates of manure and compost have been recommended tentatively, more reliable standards applicable to every region, soil, and crop are needed. Therefore, further systematic researches should be carried out to establish the recycling systems of animal wastes.

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