JARQ 26, 238-246 (1993)

Quality of Compost Produced from Animal Wastes

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Abstract
The characteristics of animal waste composts produced in Japan were summarized. Animal waste composts are useful for supplying nutrients to plants and for improving the soil properties. The contents of nutrients in the composts were in the order of poultry > swine > cattle. Thus, the effectiveness as fertilizer followed the same order. The contents of heavy metals in the animal waste composts were studied. The content of copper was very high in the swine waste composts, and the content of zinc was also high in those from swine and poultry. Such high contents of heavy metals are caused by the addition of these elements to feeds. The objectives of composting were summarized. One of the objectives is to convert the raw animal wastes into products which are easy to handle and safe to health. Another objective is to convert the animal wastes into organic fertilizers which are safe for plant and soil. The maturing process of composting was characterized. Poultry wastes were more easily decomposed than cattle and swine wastes, and the decomposition rate of cattle wastes was almost similar to that of swine wastes. Maturity is an important factor related to the quality of the compost. The detection of nitrate by diphenylamine, the determination of cation-exchange capacity (CEC), and the germination test are recommended as methods of estimating the degree of maturity.

Discipline: Soils, fertilizers and plant nutrition/Animal industry
Additional key words: degree of maturity, maturing process, nutrients, organic fertilizer, recycling, soil conditioner

Introduction

Along with the enlargement of the scale of livestock farms, the management of wastes has become a serious problem in Japan. From the viewpoints of recycling as resources and prevention of environmental pollution, adequate application of animal wastes to croplands is needed. Animal wastes are very important resources for agriculture, because they contain many nutrients and improve the chemical, physical, and biological properties of soil. However, raw animal wastes are not generally suitable as organic fertilizers or soil conditioners, because they cannot be handled readily and their application to croplands may cause adverse effects on plant and soil. Composting can eliminate the problems to some extent, and is an effective way to promote the agricultural utilization of animal wastes. Quality control of the composts is very important to promote the recycling of animal wastes. The qualities required for the utilization of animal waste composts are

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Table 1. Quality of composts

A: Ease of handling
  1) Adequate moisture content
  2) No offensive odor
  3) Safety to health

B: Safety to plant and soil
  1) Low easily decomposable organic matter
  2) Low C/N ratio
  3) No phytotoxic substances
  4) No harmful elements
  5) No plant pathogens
  6) No weed seeds

C: Effectiveness to plant growth and as soil amendment
  1) High nutrient contents
  2) Effective for improving the chemical properties of soil
  3) Effective for improving the physical properties of soil
  4) Effective for promoting the biological activities of soil

Table 2. Mineral composition of raw animal wastes[11]

		Moisture (%)	N (%)*	P_2O_5 (%)*	K_2O (%)*	CaO (%)*	MgO (%)*	Total C (%)*	C/N
Layer	Feces	78	6.18	5.19	3.10	10.98	1.44	34.7	5.6
Broiler	Feces	78	4.00	4.45	2.97	1.60	0.77	-	-
Swine	Feces	75	3.61	5.54	1.49	4.11	1.56	41.3	11.4
	Urine	98	32.5	-	-	-	-	-	-
Cattle	Feces	80	2.19	1.78	1.76	1.70	0.83	34.6	15.8
	Urine	99.3	27.1	tr	88.6	1.43	1.43	-	-

* % on dry weight basis.

Table 3. Mineral composition of animal waste composts[11]

Compost		Moisture (%)	N (%)*	P_2O_5 (%)*	K_2O (%)*	CaO (%)*	MgO (%)*	Total C (%)*	C/N
Layer	+ Sawdust	54.1	1.94	3.74	2.44	7.13	0.85	32.6	16.8
Broiler	+ Sawdust	43.6	4.00	4.77	2.79	5.47	2.53	34.0	8.5
Swine	+ Sawdust	57.2	2.22	3.25	1.53	3.00	0.97	39.9	18.0
	+ Rice straw	69.7	2.92	5.95	4.74	1.38	0.87	-	-
	+ Rice hull	39.5	2.27	3.67	1.21	4.00	1.16	38.8	17.1
Cattle	+ Sawdust	65.5	1.71	1.79	1.96	2.96	0.70	39.9	23.3
	+ Rice straw	77.6	2.16	2.15	2.31	2.31	0.96	36.0	16.7
	+ Rice hull	72.6	1.35	5.59	1.92	0.95	0.74	38.0	28.1
	+ Hay	75.2	2.30	1.38	2.17	2.06	0.81	38.2	16.6

* % on dry weight basis.

listed in Table 1. The characteristics listed in the A and B sections can be obtained by the maturation of compost, except for the presence of harmful elements. The degree of maturity is very important in terms of the quality of the compost. The characteristics listed in C indicate the effectiveness of the compost. It has been recognized that animal waste composts act as organic fertilizers and also as soil conditioners. The nutrient contents are important for the quality of the compost, since their effect as fertilizer is determined by the contents and availability of nutrients. However, various aspects on the relationship between the effect of compost as soil conditioner and the quality of the compost remain to be clarified.

In this paper, various studies on the quality of animal waste composts are reviewed in terms of nutrient contents, heavy metal contents, and the degree of maturity of the composts.

Nutrients in animal waste composts

The nutrient contents in raw animal wastes and animal waste composts are listed in Tables 2 and 3, respectively. These data were collected from several agricultural and livestock experimental stations throughout Japan.

The contents of nutrients such as nitrogen, phosphorus, potassium, calcium, and magnesium in the raw animal wastes and the composts are generally in the order: poultry > swine > cattle. Thus, the effectiveness as fertilizer follows the same order.

Quality standards for animal waste composts have not been defined in Japan, though the quality standards for bark compost have been established by the Japan Bark Compost Association and the National Bark Compost Industry Association (Table 4). The establishment of such quality standards is also desirable for the animal waste composts. Although quality standards are needed for maintaining and improving the qualities of the products and promoting their utilization, it is very difficult to establish them, because the contents of nutrients in these composts vary widely depending on the kinds of animals, kinds and mixing ratios of bulking agents, and types of composting. However, unless the nutrient contents

Table 4. Quality standards established by the Japan Bark Compost Association[8)]

Item	Standard
Organic matter	> 70%
Total N	> 1.2%
C/N ratio	< 35
P_2O_5	> 0.5%
K_2O	> 0.3%
pH	5.5–7.5
CEC	> 70 meq/100g
Moisture	60 ± 5%
Seedling experiment*	acceptable

* Tomato, cucumber or radish seeds.

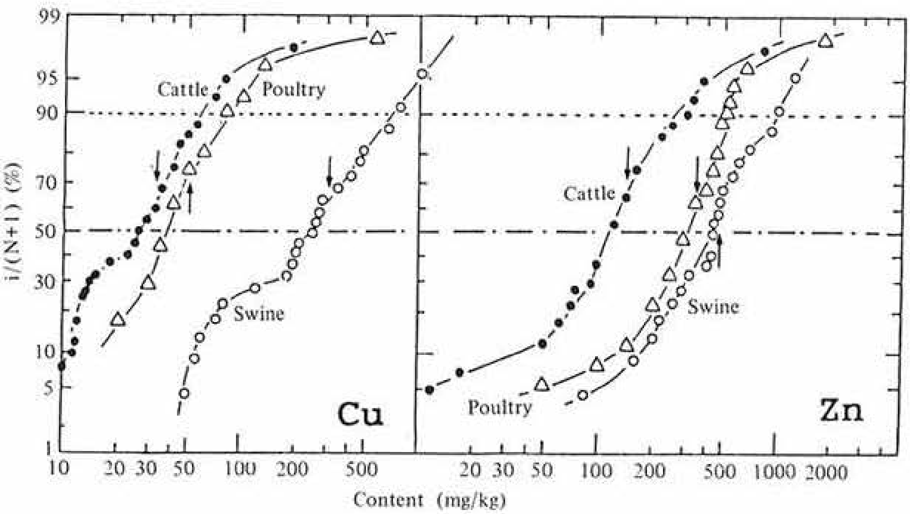

Fig. 1. Contents of copper and zinc in animal manures and composts[9)]

Table 5. Minor elements in feed and feces of pig[13]

(mg/kg)

		Zn	Cu	Fe	Mn	Cd
Milk for suckling pig	Feed	182	152	498	71	0.7
	Feces	823	897	2,469	371	1.3
Feed for suckling pig	Feed	174	161	372	72	1.0
	Feces	680	854	2,205	280	1.5
Feed for growing pig	Feed	133	139	528	75	0.8
	Feces	473	677	2,205	293	1.2
Feed for fattening pig	Feed	103	53	283	72	0.8
	Feces	436	400	1,566	259	1.4
Feed for breeding pig	Feed	119	19	292	88	0.7
	Feces	376	101	1,770	282	1.6

in the composts are determined, planning of fertilizer application is very difficult. When the composts are sold, the qualities need not be indicated outside the bags or any other containers at present, although these requirements will be necessary in future. If the qualities should be indicated, such problems could be solved, even though the quality of compost cannot be controlled by regulation standards.

Heavy metals in animal waste composts

The contents of copper and zinc in animal waste composts and dried manure registered as special fertilizers are shown in Fig. 1. These data were collected from fertilizer and feed inspection stations in Japan.

The copper contents were less than 100 mg/kg (dried matter) in 90% of the cattle and poultry manures and composts, while high copper contents over 100 mg/kg were detected in about 70% of the swine manures and composts. The zinc contents were less than 200 mg/kg in 90% of the cattle manures and composts, but high zinc contents over this concentration were detected in 80% of the poultry manures and composts and in 90% of the swine manures and composts. Thus, the content of copper was very high in the swine manures and composts, and the content of zinc was also high in those from swine and poultry.

Such high contents of heavy metals are caused by the addition of these elements to feeds. The contents of mineral elements including copper and zinc in the feeds and swine feces were studied at each stage of development (Table 5). The mineral contents in the swine feces were higher than those in feeds; the contents of copper and zinc in the feces were 4.9 to 7.6 times and 3.2 to 4.5 times those in feeds, respectively. The contents of these elements in the feeds and feces were in the order of suckling pig > growing pig > fattening pig > breeding pig. It was also shown that the contents of copper and zinc in the milk for suckling pig were about 8 times and 2 times, respectively, those in the feed for breeding pig.

Although the contents of copper and zinc in composts have not yet been regulated by law in Japan, the restriction of the addition of these elements to feeds will be necessary to promote the agricultural utilization of swine and poultry wastes.

Maturation of animal waste composts

1) Objectives of composting

One of the major objectives of composting is to convert the raw animal wastes into products which are easy to handle and safe to health. The raw animal wastes are not suitable for utilization, because their odor is offensive and they are dirty, and sticky, but the offensive odor can be attenuated and the difficulties in handling alleviated mostly during the

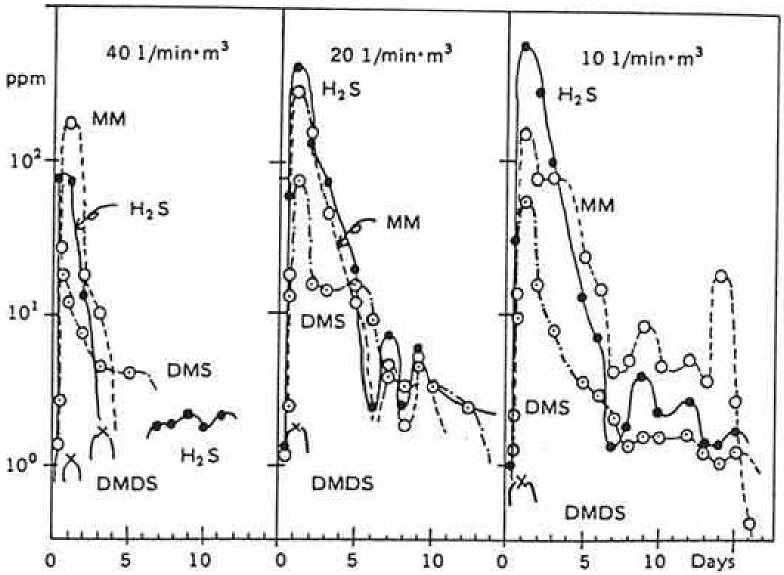

Fig. 2. Changes in the composition of odorous sulfuric compounds in gas emitted during the composting of swine waste[1)]
H_2S: Hydrogen sulfide, MM: Methylmercaptan,
DMS: Dimethylsulfide, DMDS: Dimethyldisulfide.

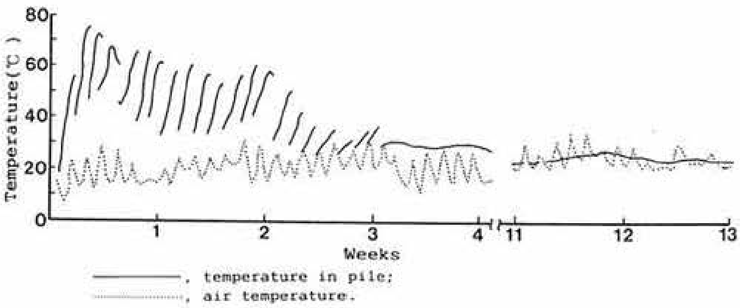

Fig. 3. Changes in the temperature during the composting of cattle waste[5)]

composting process. The changes in the composition of the odorous compounds emitted during the composting of swine wastes were studied (Fig. 2). The odorous fumes contained sulfur compounds such as hydrogen sulfide, methylmercaptan, and methyl sulfides. These sulfur compounds were present in large quantities at the initial stage of composting, but their amount decreased rapidly with maturation. It is important to maintain aerobic conditions during composting, since these compounds are emitted under anaerobic conditions. The animal wastes may contain pathogens, parasites, and weed seeds. When the aeration is adequate, the temperature in the pile usually increases to more than 60°C. The temperature profile during the composting of cattle waste is shown in Fig. 3. The temperature rise is necessary, not only for accelerating the decomposition of organic constituents, but also for inactivating harmful organisms. Pathogens, parasites, and weed seeds are all generally killed during composting at temperatures of 60°C or higher (Tables 6 and 7).

Another objective of composting and maturing is to convert the animal wastes into organic fertilizers which are safe for plant and soil. The adverse effects

Table 6. Lethal temperatures for pathogens and parasites[7]

Species	Common name	Temperature, Time
Salmonella typhi	Typhoid bacillus	55–66°C, 30 min
Salmonella spp.	Salmonella	55°C, 1 hr, or 60°C, 20 min
Shigella spp.	Shigella	55°C, 1 hr
Escherichia coli	Coliform bacillus	55°C, 1 hr, or 60°C, 20 min
Entamoeba histolytica	Amoebic dysentery	68°C
Taenia saginata	Beef tapeworm	71°C, 5 min
Trichinella spiralis	Trichinosis	50°C, 1 hr, or 62–72°C
Necator americanus	American hookworm	45°C, 50 min
Brucella abortus or *suis*	Brucellosis	61°C, 3 min
Micrococcus pyogenes var. *hominis*		50°C, 10 min
Streptococcus pyogenes		54°C, 10 min
Corynebacterium diphtheriae	Diphtheria bacillus	55°C, 45 min
Ascaris lumbricoides, ova	Ascaris	50°C, 50 min or 60°C, 20 sec
Anchylostoma, ova	Hookworm	60°C

Table 7. Effect of temperature within the compost pile on the germination of weed seeds[12]

Species	Germination rate (%)		
	On surface of pile (<50°C for 11–14 days)	Within pile (60°C for 2 days)	Control
Digitaria adscendens	96	0	74
Panicum villosum	72	0	87
Cyperus microiria	56	0	30
Chenopodium album	26	0	16
Polygonum nodosum	8	0	53
Portulaca oleracea	85	0	91
Amaranthus blitum	68	0	70
Acalypha australis	7	0	51
Fotoua villosa	26	0	19
Oryza sativa	75	0	98
Hordeum vulgare	16	0	96

on plant and soil caused by the application of raw or immature animal waste composts and objectives of maturing are indicated in Table 8.

The animal wastes contain large quantities of easily decomposable organic matter. When they are applied in large amounts to croplands, the soil may undergo excessive reduction, the concentration of inorganic nitrogen may increase excessively, and phytotoxic substances such as phenolic acids and volatile fatty acids may be produced under the reduced conditions. When composts whose C/N ratio is too high due to the mixing of crop residues such as rice straw or wheat straw are applied to soil, nitrogen starvation may occur in crop plants as a result of substantial nitrogen immobilization. Furthermore, straws and woody materials which are used as bulking agents may contain phenolic acids such as p-hydroxy benzoic acid, p-coumaric acid, and vanillic acid[8,10]. When such materials are applied to soil, the growth of the crops may be inhibited by these phytotoxic substances. Therefore, it is essential that the easily decomposable organic matter and phytotoxic substances be degraded and the C/N ratio decrease during the composting process before application.

2) Maturing process of composting

The organic matter is decomposed and becomes stabilized during composting. Changes in the contents of ash, total carbon, total nitrogen, and the C/N ratio of cattle wastes are shown in Fig. 4. Organic matter decomposition leads to a relative increase in the ash content. The content of total carbon decreases while that of total nitrogen increases so that the C/N ratio falls. Marked changes in the

Table 8. Adverse effects on plant and soil of the application of raw or immature compost and objectives of maturing[2)]

Raw materials	Bulking agent*	Source of adverse effects	Objectives of maturing
Animal wastes	–	• Excessive concentration of inorganic nitrogen • Soil reduction • Phytotoxic substances	• Degradation of easily decomposable organic matter in animal wastes • Degradation of phytotoxic substances
Animal wastes + Crop residues	Low	• Excessive concentration of inorganic nitrogen • Soil reduction • Phytotoxic substances	• Degradation of easily decomposable organic matter in animal wastes • Degradation of phytotoxic substances
	High	• Nitrogen immobilization • Phytotoxic substances • Soil reduction	• Decrease in C/N ratio • Degradation of phytotoxic substances • Degradatioin of easily decomposable organic matter in crop residues and animal wastes
Animal wastes + Woody materials	Low	• Excessive concentration of inorganic nitrogen • Soil reduction • Phytotoxic substances	• Degradation of easily decomposable organic matter in animal wastes • Degradation of phytotoxic substances
	High	• Phytotoxic substances • Nitrogen immobilization • Soil reduction	• Degradation of phytotoxic substances • Decrease in C/N ratio • Degradation of easily decomposable organic matter in woody materials and animal wastes

* Mixing rate of bulking agent (crop residues or woody materials).

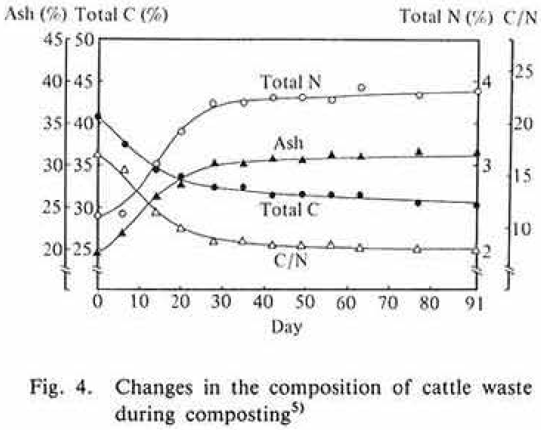

Fig. 4. Changes in the composition of cattle waste during composting[5)]

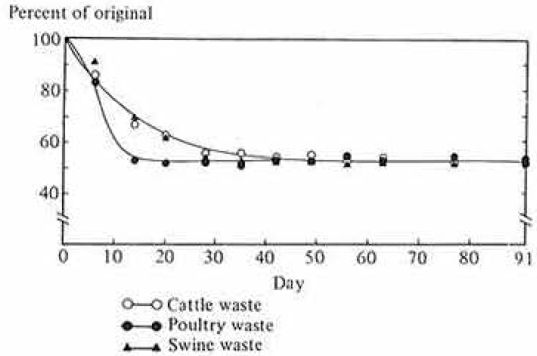

Fig. 5. Changes in the residual rates of organic matter during composting

chemical composition become attenuated after about five weeks, and thereafter the constituents change only gradually.

The decomposition of organic matter during the composting process is characterized by changes in the residual rate (percentage of organic matter which remains compared to the original amount) (Fig. 5). The organic matter content can be roughly estimated by ignition loss (i.e. the amount of material lost when the wastes are burnt). Fig. 5 indicates that poultry wastes are more easily decomposed than cattle and swine wastes, and the decomposition rate of cattle wastes is almost similar to that of swine wastes.

Table 9. Methods and indexes for estimating the degree of maturity

A: Estimation based on microbial activity
  1) Biochemical oxygen demand (Haga and Harada, 1984)
  2) Chemical oxygen demand (Lossin, 1971)
  3) Enzymatic activity (Godden et al., 1986)

B: Biological estimation
  1) Germination test (Fujiwara et al., 1980, Zucconi et al., 1981, Osada et al., 1985)
  2) Seedling experiment (Kawada, 1981)
  3) Pollen tube culture (Konishi et al., 1986)

C: Physical estimation
  1) Temperature in pile (Golueke, 1972)
  2) Odor emission (Haga et al., 1978)
  3) Color change (Sugahara et al., 1979)

D: Chemical estimation
  1) C/N ratio of solid phase (Poincelot, 1975, Golueke, 1981)
  2) C/N ratio of water extract (Chanyasak and Kubota, 1981)
  3) Ratio of carbon in reducing sugars to total carbon (Inoko et al., 1979)
  4) Detection of nitrate (Harada, 1983, Finstein and Miller, 1985)
  5) Absence of ammonia (Spohn, 1978, Mori and Kimura, 1984)
  6) Gel chromatography of water extract (Yoshida and Kubota, 1979)
  7) Cation-exchange capacity (Harada and Inoko, 1980)

E: Estimation based on humic substances
  1) Circular paper chromatography test (Hertelendy, 1974, Inoko, 1979)
  2) Content of humic compounds (Watanabe and Kurihara, 1982)

Estimation of maturity

Compost should be well matured before it is applied, because the application of immature compost to soil may cause severe damage to plant growth as described previously. Therefore, a method of estimating the degree of maturity of compost is required. Many methods and indexes for estimating the degree of maturity have been proposed (Table 9).

1) Detection of nitrate by diphenylamine

In the earlier stage of composting, ammonium is produced by the decomposition of nitrogenous compounds such as protein. Ammonium is oxidized into nitrate by the action of ammonium-oxidizing bacteria and nitrite-oxidizing bacteria with the progress of maturation. Consequently, nitrate accumulates as the compost matures. The presence of nitrate can be detected qualitatively with diphenylamine. Diphenylamine solution dissolved in concentrated sulfuric acid is added to the water extract from the compost: if nitrate is contained in the extract, the solution turns blue. This method can be used to test the maturity of cattle waste compost, but not that of swine and poultry waste composts, because a very small quantity of nitrate is produced even in mature composts made from swine and poultry wastes[2].

2) Determination of cation-exchange capacity

The negative charge, i.e. the cation-exchange capacity (CEC), of organic matter increases as the compost matures[4]. We developed a simple method to determine the CEC of composts[3]. Highly significant correlations were observed between the CEC and C/N ratio ($r = 0.992^{***}$), total carbon ($r = -0.968^{***}$), total nitrogen ($r = 0.995^{***}$), and ash content ($r = 0.992^{***}$) in composted cattle wastes[6]. Thus, since the CEC reflects the changes in the constituents during maturation, it is a useful parameter for estimating the degree of maturity of the compost.

3) Germination test

Immature 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 detected by a germination test[2]. Twenty to 50 seeds of winter rape (*Brassica rapa*) are placed on a filter paper in the petri dish (9 cm in dia.), 10 m*l* of water extract from the compost is added, and the seeds are then incubated at 20°C under dark conditions. The germination rate is measured after 24 hr. The germination rate is low when samples of the raw materials or those from anaerobic portions of the pile are used, and increases as the materials mature[6].

Conclusion

Quality control of the composts is very important to promote the recycling of animal wastes. The quality of the composts can be evaluated on the basis of the contents of nutrients and heavy metals and the degree of maturity.

The regulation of the nutrient content in the composts based on quality standards is difficult. However, since the indication of the nutrient content on the labels is necessary for the planning of fertilizer application, such a procedure should become compulsory.

High concentrations of copper and zinc in swine and poultry wastes are very important factors in the prohibition of utilization of composts. The contents of copper and zinc in the composts are not regulated at present, although the concentrations of arsenic, cadmium, and mercury in the composts are limited by law in Japan. Limitations on the concentrations of these elements in soils are being considered from the viewpoint of environmental protection. Restriction in the addition of copper and zinc to feeds will be necessary to promote the agricultural utilization of swine and poultry wastes in future.

Maturity is an important factor related to the quality of the composts. Although the estimation of maturity is relatively easy for producers of the composts, it is difficult for the users to estimate the maturity of the composts, whose raw materials and the process of composting are unknown to them. Although many methods and indexes have been proposed for estimating the degree of maturity of composts, a more practical and reliable method is still needed. The indication of the qualities on labels on the bags or containers of the composts may also be necessary when the composts are sold.

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(Received for publication, September 21, 1992)