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FOOD & FERTILIZER TECHNOLOGY CENTER

PRODUCTION OF COMPOST FROM ORGANIC WASTES

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COMPOSTING AND APPLICATION OF ANIMAL WASTES

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FOREWORD

In the use of organic materials as fertilizers for crop production, farmers are faced with the problem that organic materials are bulky, with a low nutrient content in relation to their volume, and are often messy and smelly. Furthermore, the application of fresh organic material may reduce the soil and produce substances harmful to plant growth. This problem can be solved by composting, a process in which the organic component is biologically decomposed until the material forms a stable, inoffensive organic fertilizer.

The two papers published in this Bulletin discuss the composting process, and the application of compost to farmland for crop production. The first paper deals with the general principles of composting, and describes the most effective way to compost a range of organic materials – livestock manure, sewage sludge, municipal refuse, and bark and sawdust. The second paper deals with the composting of animal wastes, and suggests several ways in which the maturity of the compost can be accurately judged. The author also discusses important factors to be taken into account when livestock manure and compost are applied to grassland, or in rice and vegetable production.

Japan is one of the leading nations of the world in its development of nutrient recycling and the more efficient use of biological resources in agriculture. Given the strong interest in recent years in the use of organic fertilizers to reduce production costs and chemical inputs, we are sure that the Bulletin will be of considerable value to all those interested in this important topic.

Both papers were first presented by their authors at international seminars sponsored by the Center and held in 1990. Dr. Harada's paper was first presented at the 5th Animal Science Congress of the Asian-Australian Association of Animal Production Societies. The paper by Dr. Haga was presented at an international seminar on *"The Use of Organic Fertilizer in Crop Production"*, held in Suweon Korea with the co-sponsorship of the Rural Development Agency of Korea.

PRODUCTION OF COMPOST FROM ORGANIC WASTES

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(Chinese Abstract) 摘 要

有機廢物，如動物排泄物，城市廢棄物，樹皮，鋸屑等可以當作有機肥料施用於作物以維持作物產量及減少廢物的污染。在有效控制條件下可以使這些廢物製造成高品質有機肥料。在堆肥製造過程中，成熟度相當重要，成熟度的研究可以改善堆肥品質。一些化學性質如BOD，VFA，CEE，NO_3-N，還原糖比率，C／N比率，發芽率的測定均能用來表示堆肥的成熟程度；堆肥其他的性質如營養成分，重金屬及有毒含物等亦有在本文中說明，本文亦介紹如何適當施用堆肥來增加作物生長和土壤生產力。

(Japanese Abstract) 摘 要

家畜ふん尿、下水汚泥、都市ゴミ、バーク、オガクズなどの有機性廃棄物は、有機質肥料として耕地に施用すべきであり、そのことが環境汚染の防止のみならず、作物の収量を高く安定的に維持することにつながる。適正に制御された条件下でコンポスト化することによって、これら廃棄物を高品質の有機質肥料に変換することができる。コンポストの品質を改善しその腐熟度を明確にする目的で、コンポスト化における腐熟過程の特徴を把握する研究を行った。ＢＯＤ、ＶＦＡ、ＣＥＣ、硝酸態窒素、還元糖割合、Ｃ／Ｎ比などの化学的指標や、発芽試験などの生物学的指標によって、コンポストの腐熟度を表わすことができた。また、コンポストに含まれる肥料成分、重金属、作物生育阻害物質などの性質についても述べた。作物の生長や土壌の生産性を増進する一方策として、良く腐熟したコンポストを適正に施用することが勧められる。

(Korean Abstract) 초 록

가축분이나 오물찌거기, 도시의 폐기물, 나무껍질과 톱밥과 같은 유기질 폐기물은 공해방지를 위해서 뿐 아니더 안정적이고 높은 수량의 작물생산을 유지하기 위한 유기질비료로서 사용되어야만 한다. 일정한 조건을 갖춘 퇴비화의 재조공정하에서는 이러한 폐기물을 고품질의 유기질 비료로 전환시킬 수 있다. 여기에서는 퇴비화의 과정을 통해서 이들 폐기물의 품질을 개량하거나 부숙정도를 확실히 하기 위한 부숙과정의 특징이 검토되었다. BOD, VFA, CEC, 질산태질소 환원당의 비율과 C/N율과 같은 몇가지 화학적 지표와 발아검정과 같은 생물학적 지표들이 퇴비의 완숙정도를 평가할 수 있을 것이다. 퇴비의 또다른 특성들도 언급하였는데, 여기에는 영양소함량, 중금속 및 phyototoxic 물질들도 포함되어 있다. 잘 부숙된 퇴비의 적절한 시용은 작물의 생장과 토양의 생산성을 증대시키는 방법으로 추천되었다.

PRODUCTION OF COMPOST FROM ORGANIC WASTES

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ABSTRACT

Organic wastes such as livestock manure, sewage sludge, municipal refuse, bark and sawdust, should be applied onto cropland as organic fertilizers in order to maintain stable high yields as well as reduce pollution. The composting process under controlled conditions is able to convert these waste materials into high-quality organic fertilizers. Characterization of the maturing process during composting was studied, to improve the quality of compost and to make clear the degree of maturity. Some chemical indices such as BOD, VFA, CEC, nitrate nitrogen, the ratio of reducing sugar and the C/N ratio, and biological indices such as a germination test, can express the degree of maturity of the compost. Other properties of composts are also mentioned, such as the content of nutrients, heavy metals and phytotoxic substances. The appropriate application of well-matured compost is recommended as a way of increasing crop growth and soil productivity.

INTRODUCTION

The application of organic fertilizers onto cropland increases soil fertility and productivity. Most organic fertilizers are processed from organic wastes such as livestock manure, sewage sludge, municipal refuse, bark and sawdust, crop residues and so on. This kind of conversion of waste materials into useful ones is helpful in conserving fertilizer resources, as well as controlling environmental pollution. The composting process is the main method used to produce stable, high-quality organic fertilizers from organic wastes. This technique is becoming more popular, a trend likely to continue in the future. In this paper, principles and methods of composting, and of evaluating the quality of compost from various organic wastes, particularly animal wastes, are described, with special reference to the current status of research in Japan.

PRINCIPLES

Composting is a process by which organic wastes are converted into organic fertilizers by means of biological activity under controlled conditions. The objectives in composting are to stabilize the putrescible organic matter in raw wastes, to reduce offensive odors, to kill weed seeds and pathogenic organisms, and finally, to produce a uniform organic fertilizer suitable for land application.

Biological activity involves the microbiological decomposition of organic matter. Many kinds of microorganisms are involved, including bacteria, fungi, protozoa, and invertebrates such as nematodes, worms and insects. Populations of all these microorganisms fluctuate, according to whether conditions are favorable or not.

Controlled conditions are important for composting, to distinguish it from other natural biological decomposition processes such as rotting and putrefaction. Control of the composting process can shorten the period required for decomposition and stabilization of the organic matter, and can produce stable, high-quality organic fertilizer.

CONDITIONS FOR COMPOSTING

The carbon-nitrogen ratio (C/N) of waste material is an important factor in successful composting. During composting, microorganisms require carbon as an energy source and nitrogen to maintain and build body cells. A suitable C/N ratio for composting is between 20:1 and 30:1. A higher C/N ratio slows down the composting process, because there

are insufficient microorganisms due to a lack of nitrogen sources. A lower C/N ratio, on the other hand, results in nitrogen loss as ammonia volatilizes from the composting material. As composting proceeds, the C/N ratio of the waste material decreases gradually to around 15:1.

A good oxygen supply for composting materials is essential, because the composting process is an aerobic one. Oxygen can be incorporated into the compost by turning it, and/or by forced aeration, in order to maintain aerobic conditions. The oxygen requirement of compost material varies according to the kind of waste material, the organic matter content, the moisture content, the temperature and the microbiological population, but it would seem that around 100 l/min (range: 30-300 l/min) of air is required for 1 m^3 of compost material (Chûô-chikusan-kai 1987, Fukuchi and Kanai 1989, and Kimura and Shimizu 1989). In addition, particles in the compost material should be of a size suitable for aeration. Aeration efficiency is usually improved by the control of moisture content, and by the addition of bulky materials such as bark, sawdust, rice hull, rice straw etc..

The moisture content of waste material is important for maintaining suitable conditions for microorganisms to live in during the composting process. The proper moisture content is around 60%, which brings a good supply of both water and oxygen to the microorganisms. Excess water disturbs the oxygen supply to the compost material by destroying its porous structure.

Microorganisms play an important role in the decomposition and stabilization of organic matter during composting. The microorganisms mainly involved are bacteria, fungi and actinomycetes (all of which are indigenous to the organic wastes) at high enough populations (about 10^6/g) to generate the composting process. Populations increase or decline according to whether the conditions are favorable to the particular species, in terms of e.g. moisture content, substrate, aerobic or anaerobic, mesophilic or thermophilic and so on. **It is more effective to maintain favorable conditions to accelerate microbiological activity during composting, than to add some kind of inoculum to the compost material.**

The temperature of the compost material reflects the level of decomposition of the organic matter according to the microbiological activity in the compost material. When composting proceeds properly, the temperature at the initial stage rises steeply to around 70°C. This high level is maintained for a while, then falls gradually to the ambient temperature. This temperature rise and fall is the result of the rapid decomposition of biodegradable organic matter by mesophilic and thermophilic microorganisms, followed by a curing process in which mesophilic species are dominant. This pattern of temperature rise and fall is useful in monitoring the success or failure of composting (Fig. 1). In addition, high temperatures are essential in producing safe compost, since they can destroy pathogenic microorganisms, parasites and their eggs, and weed seeds.

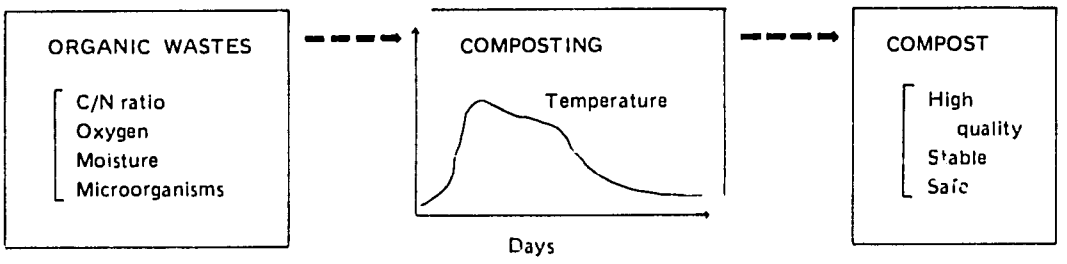


Fig. 1. Composting of organic wastes

COMPOSTING OF ORGANIC WASTES

Animal Wastes

The animal industry in Japan has expanded rapidly over the last few decades. About 90 million mt of livestock manure were produced in Japan in 1987 (Haga 1990), a quantity which is double that of night soil. These livestock wastes consist of 54 million mt/year of feces and 36 million mt of urine. About 90% of the cattle manure is used for compost, but only 30% of the pig manure (see Fig. 2). Dried poultry wastes are also a popular organic fertilizer on Japanese farms. Consequently, at least 30 million mt/year of composted animal wastes are now being used as fertilizer in Japan. The characteristics of raw animal wastes are shown in Table 1.

The moisture content of animal wastes is high, while the C/N ratio is low. It is recommended that they should be mixed with carbon-rich materials, to control both moisture content and the C/N ratio.

Dairy cattle wastes are often mixed with sawdust or perlite (an inorganic soil condi-

Table 1. Characteristics of raw animal wastes

		Production kg/day	Moisture (%)	Total N (%)*	P_2O_5 (%)*	K_2O (%)*	CaO (%)*	MgO (%)*	Total C (%)*	C/N
Poultry (layers)		0.14	78	6.18	5.19	3.10	10.98	1.44	34.7	5.6
Poultry (broilers)		0.13	78	4.00	4.45	2.97	1.00	0.77	-	-
Swine	feces	1.9	75	3.61	5.54	1.49	4.11	1.56	41.3	11.4
	urine	3.5	98	32.5	-	-	-	-	-	-
Cattle	feces	30	80	2.19	1.78	1.76	1.70	0.83	34.6	15.8
	urine	20	99.3	27.1	tr	88.6	1.43	1.43	-	-

*: % of dry matter
Source: National Grassland Research Institute 1983, and Chûô-chikusan-kai 1987

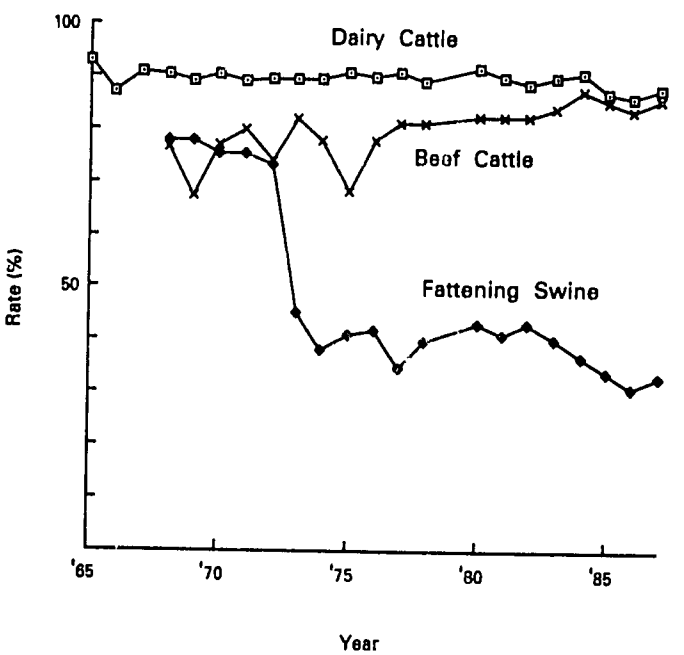


Fig. 2. Changes in the rate of utilization of composted animal wastes
Source: Haga 1990

tioner) and composted, the compost being turned mechanically once a day. The temperature rises steeply to 70°C, then stabilizes at around 60°C for 2 to 3 weeks, (including temperature changes during turning (Fig. 3)). The temperature rise represents heat generation as a result of the vigorous decomposition of organic matter. The temperature finally drops to the ambient temperature after five or six weeks have passed, and there are then no further changes in temperature after turning.

Pathogenic organisms (Table 2) and weed seeds (Table 3) can be killed by high temperatures of 60°C or higher over a sufficiently long period.

The biochemical oxygen demand (BOD) (Fig. 3), and the level of volatile fatty acids (VFA) (Fig. 4) and benzene-ethanol extracts (Fig. 5) decrease steeply after 10 to 15 days. These compounds correspond to the readily biodegradable fraction of total organic matter, and their rapid degradation may be related to heat generation during the initial stabilization of the compost.

The C/N ratio (Fig. 3), and content of hemicellulose, cellulose and lignin (Fig. 5) gradually decrease, and become almost constant at around five weeks. The cation exchange capacity (CEC) increases up to 110 me/100 g over 30 days, and finally also becomes constant (Fig. 6). Significant correlations can be observed between these factors.

Nitrate nitrogen appears after c. 30 days (Fig. 7), when most organic constitutents have become stabilized and the CEC has become constant. Thus, a qualitative test for nitrate nitrogen, such as the diphenylamine test, is useful for evaluating the maturity of cattle waste compost.

Immature compost contains phytotoxic

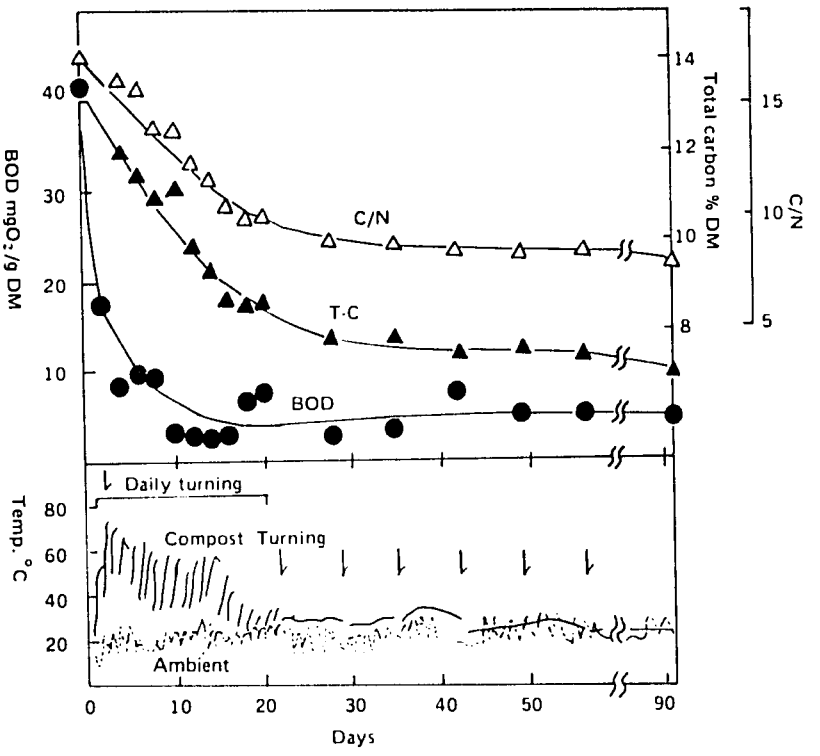


Fig. 3. Changes in temperature, BOD and C/N ratio during the composting of cattle wastes
Source: Haga and Harada 1984

substances such as volatile fatty acids (Fig. 4) and phenol carboxylic acids (Table 4). Both volatile fatty acids and phenol carboxylic acids are thoroughly decomposed during the process of aerobic composting. Germination tests using seeds of winter rape *(Brassica rapa)*, can give a good idea of the phytotoxic effect of these substances (Fig. 8).

Odor emission during composting causes secondary pollution problems. Changes in odorous compounds emitted during the composting of pig wastes were studied. The

Table 2. Lethal temperatures for pathogens and parasites

Species	(Common name)	Temperature, Time
Salmonella typhi	Typhoid bacillus	55-66°C, 30 min
Salmonella sp.	Salmonella	55°C, 1 hr, or 60°C, 20 min
Shigella sp.	Shigella	55°C, 1 hr
Escherichia coli	Coliform bacillius	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 aborutus 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

Source: Hashimoto 1958

Table 3. Effect of temperature within the compost pile on the germination of weed seeds

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
Penicum 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
Fatoua villosa	26	0	19
Oryza sativa	75	0	98
Hordeum vulgare	16	0	96

Source: Takabayashi *et al.* 1978

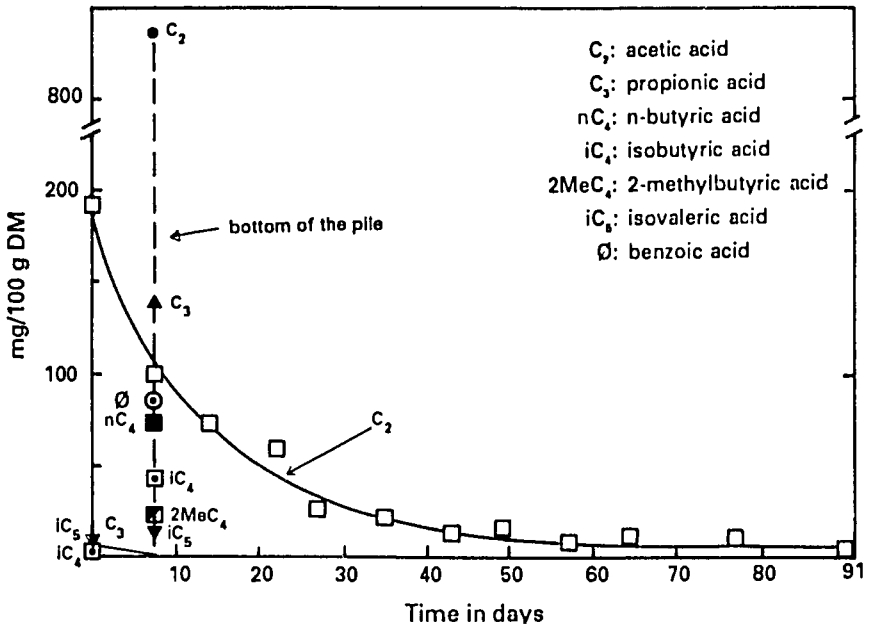


Fig. 4. Changes in volatile fatty acids during the composting of cattle wastes
Source: Haga *et al.* 1985

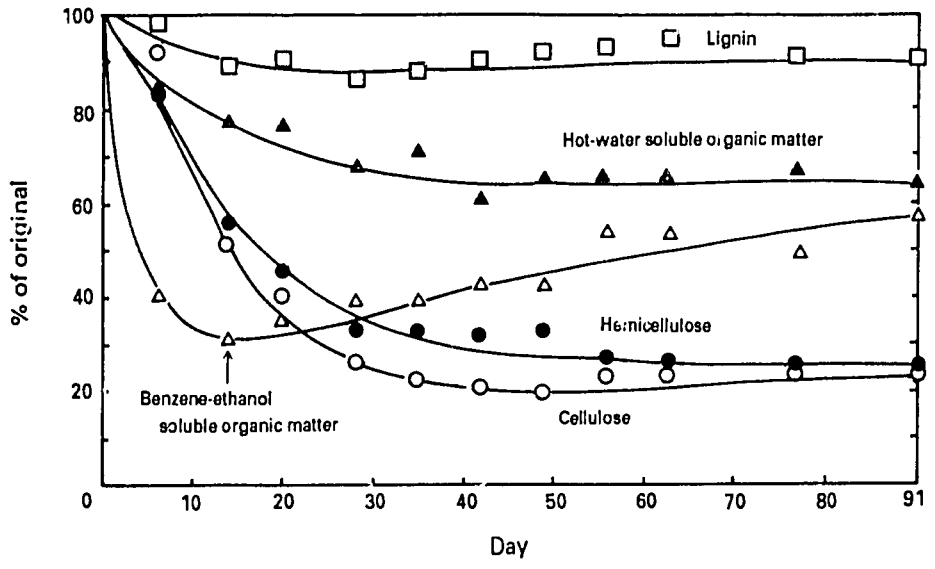


Fig. 5. Changes in the residual rates of organic constituents during the composting of cattle wastes
Source: Harada *et al.* 1985

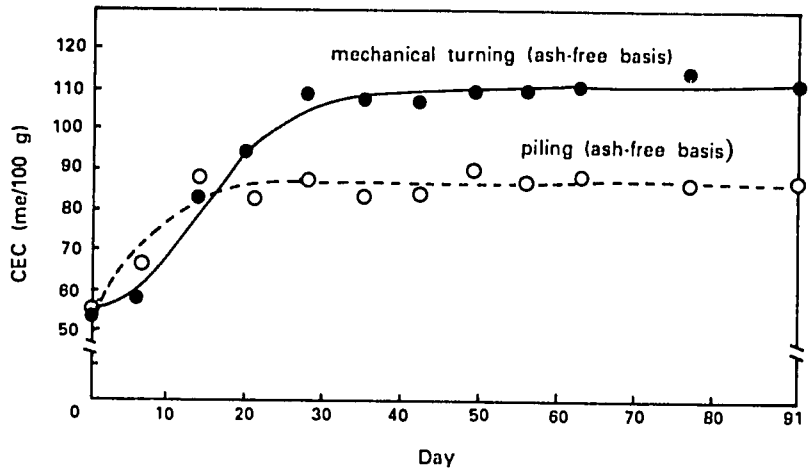


Fig. 6. Changes in the cation exchange capacity during the composting of cattle wastes

Source: Harada *et al.* 1984

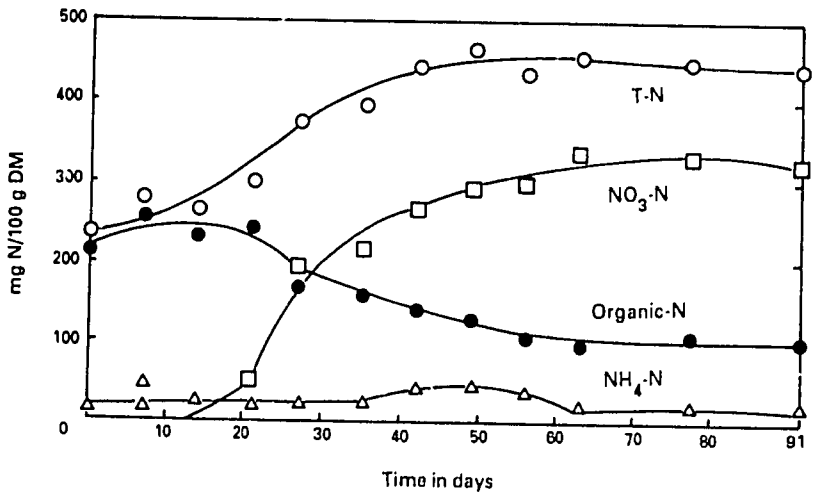


Fig. 7. Changes in the nitrogen level in hot water extract during the composting of cattle wastes

Source: Haga *et al.* 1985

odorous fumes contained sulfurous compounds such as hydrogen sulfide (Fig. 9), methylmercaptan, and methyl sulfides (Fig. 10) (Haga *et al.* 1978). They were present in large quantities under anaerobic conditions, particularly at the initial stage of poorly aerated compost. It is therefore important to maintain aerobic conditions during composting, and to remove sulfurous compounds from gas emitted.

Various types of composting facilities are being operated on Japanese farms, while there are a number of compost centers operated

Table 4. Changes in the phenolic acid content during the composting of cattle wastes

Unit: mg/100g DM

	Starting mixture	1 week			8 weeks	13 weeks
		M	P-AE	P-AN		
p-Hydroxy benzoic acid	2.7	-	tr	13.8	-	-
p-Coumaric acid	4.4	1.5	tr	3.4	tr	-
Benzoic acid	13.6	-	-	97.5	-	-

M: Mechanical turning
P-AE: Piling, Aerobic part
P-AN: Piling, Anaerobic part
Source: Haga *et al.* 1986

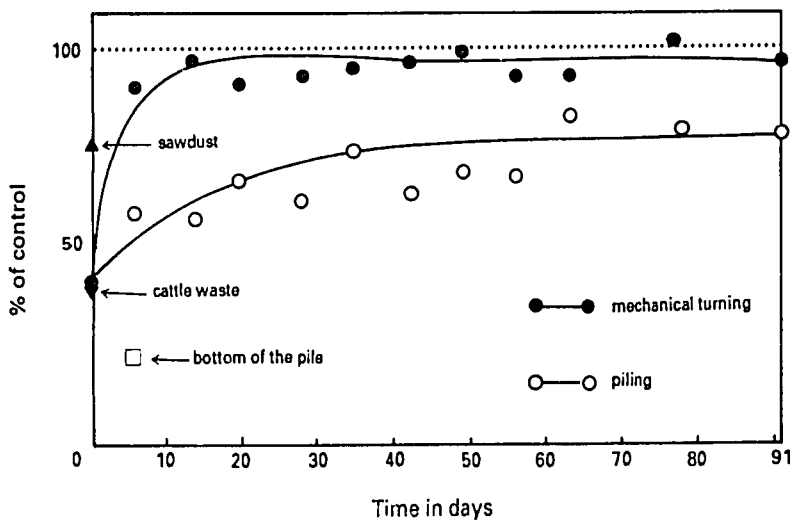


Fig. 8. Effect of hot water extracts of cattle waste compost on the germination of winter rape *(Brassica rapa)* seeds
Source: Osada *et al.* 1985

jointly by several farms. Facilities can be classified into six types; the pile type, the box type, the rotary kiln type, the enclosed vertical type, the open type with a conveyor belt for turning the compost, and the open type with a rotary turning device (Fig. 11). All these except the pile type have apparatus for forced aeration.

Characteristics of composts made from livestock wastes are shown in Table 5. These composts are variable, according to the type of animal producing the manure and the type of additional material used. Information about the application of compost to farmland is available in FFTC Extension Bulletin No. 282 (Koshino 1988).

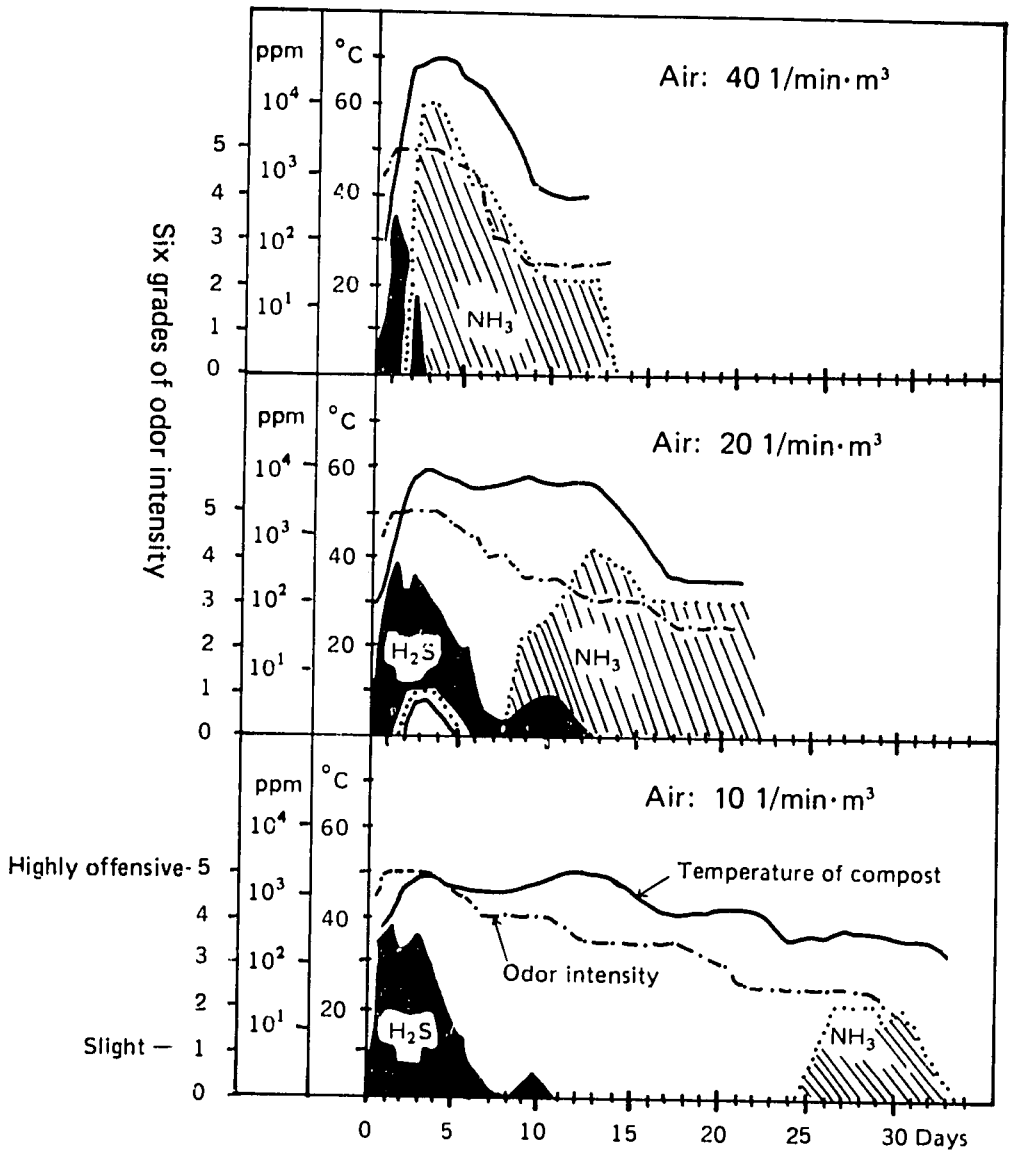


Fig. 9. Changes in odor intensity, hydrogen sulfide and ammonia in exhaust gas during the composting of swine wastes
Source: Haga *et al.* 1978

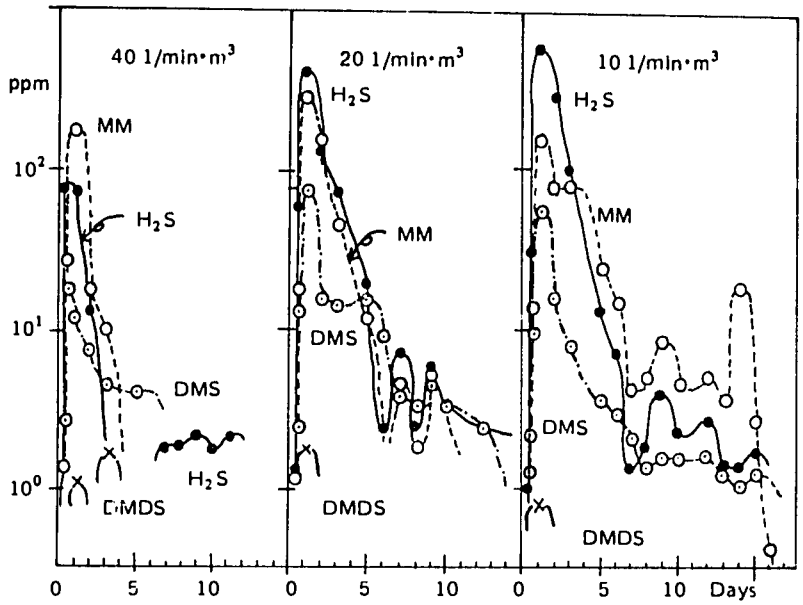


Fig. 10. Changes in odorous sulfurous componds in gas emitted during the composting of swine wastes
H2S: hydrogen sulfide
MM: methylmercaptan
DMS: dimethylsulfide
DMDS: dimethyldisulfide
Source: Haga *et al.* 1978

Table 5. Characteristics of composts made from animal wastes

	Compost	Moisture (%)	Total N (%*)	P_2O_5 (%*)	K_2O (%*)	CaO (%*)	MgO (%*)	Total C (%*)	C/N
Poultry	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

*: % of dry matter
Source: National Grassland Research Institute 1983

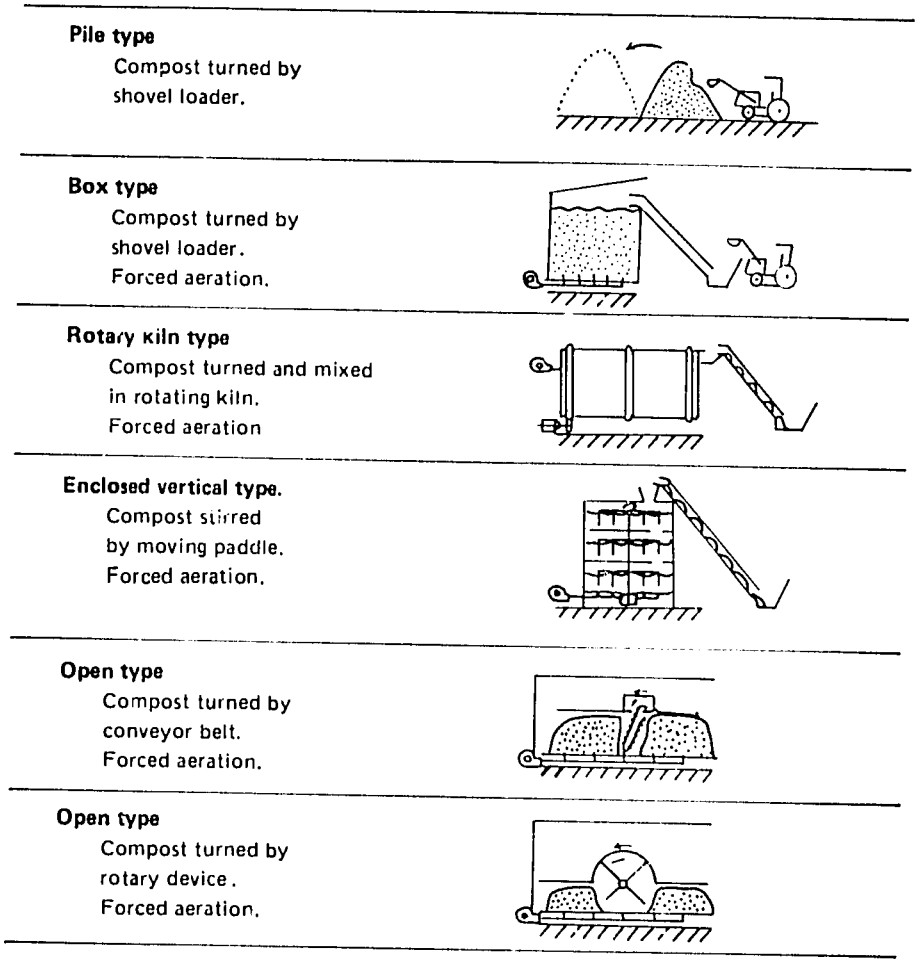


Fig. 11. Composting facilities for livestock wastes
Source: Nishimura 1990

SEWAGE SLUDGE

The amount of sewage sludge discharged from sewage treatment plants in Japan in 1983 was estimated to be about 3.6 million m^3 (moisture content: 70%). However, only 1.7% (60,000 m^3/year) of this sludge is composted, in 19 composting facilities (Hoshino *et al.* 1985).

The characteristics of dehydrated sludge before composting are summarized in Table 6. The high pH (11 to 12) is due to lime precipitation. The sludge should be mixed with bulky materials such as sawdust, bark or rice hull to improve the C/N ratio.

The sludge is composted in the first fermenter for 10 to 15 days, during which time active decomposition of the sludge and heat generation occur. The compost is then transferred into a second fermenter for curing. A longer curing period is required for compost mixed with bark or sawdust. Table 7 compares various constituents before and after composting. Composting did not produce any marked changes in these, except for the reduction of pH in lime-treated sludge.

One major concern in the quality of sewage sludge compost is the heavy metal content. The heavy metals present in sewage become concentrated in the sewage sludge,

and are retained in the compost. Table 8 shows the characteristics of compost made from sewage sludge, and shows that the heavy metal content of such compost is significantly higher than in any other compost made from organic wastes. Particular attention should be given to concentrations of zinc, copper, lead and nickel when the compost is applied to cropland.

Although heavy metals are retained in composts made from sewage sludge, the solubility of the different metals varies. Changes in the concentrations and solubility of copper, cadmium and zinc were investigated during the composting of sewage sludge with rice hull (Chino *et al.* 1983). The available copper (0.1N HCl extraction method) decreased to 10% of the total copper in around 20 days during the composting process (Fig. 12), while the level of available cadmium and zinc remained similar to the total content of each metal.

In order to measure the maturity of sewage sludge compost, either the score method or seedling germination tests can be used (Association for the Utilization of Sewage Sludge, 1980). For the first, scores are given as follows: the measured values of moisture, volatile solids, total carbon, C/N ratio, nitrate nitrogen and BOD of the compost are standardized, according to the following equation. When the score estimated from these standardized values is less than –0.1, the compost is considered to be well matured.

$$u = (x - \bar{x})/s$$

u: standardized value x: measured value
$\bar{x}$: average value s: standard deviation

Table 6. Characteristics of dehydrated sewage sludge

Sludge sample no.	Moisture (%)	Volatile solids (%*)	pH	Total C (%*)	Total N (%*)	C/N
1	68.3	54.0	11.3	22.6	3.0	7.4
2	63.0	58.4	12.1	33.5	3.9	8.6
3	77.0	55.6	6.1	30.8	3.4	9.0
4	76.5	82.6	5.7	43.8	5.3	8.3
5	63.4	48.3	11.1	24.8	3.2	7.7
6	79.5	60	8.3	30.6	4.9	6.2

*: % of dry matter
Source: Hoshino and Yamada 1985

Table 7. Comparison of various constituents before and after the composting of sewage sludges

Sludge Treatment		pH	Total C (%)	Total N (%)	C/N	NH_4-N (%)
Lime precipitation	before	10.3	18.9	1.82	10	0.36
	after	7.9	15.7	1.50	10	0.42
Polymer coagulation + Sawdust	before	6.9	31.7	1.7	19	0.37
	after	6.6	27.9	1.8	16	0.43

Source: Date 1982

Table 8. Characteristics of compost made from sewage sludge

Moisture %	pH	Total N (%*)	Total C (%*)	C/N	P_2O_5 (%*)	K_2O (%*)	CaO (%*)
27.5	7.2	2.37	25.3	10.7	8.00	0.66	21.2
Cadmium (ppm)**	**Mercury (ppm**)**	**Arsenic (ppm**)**	**Copper (ppm**)**	**Zinc (ppm**)**	**Lead (ppm**)**	**Nickel (ppm**)**	**Chromium (ppm**)**
2.15	1.39	5.74	205.5	1159.8	64.9	33.5	41.7

*: % of dry matter
**: ppm of dry matter
Source: Japanese Society for Soil Science and Plant Nutrition 1988

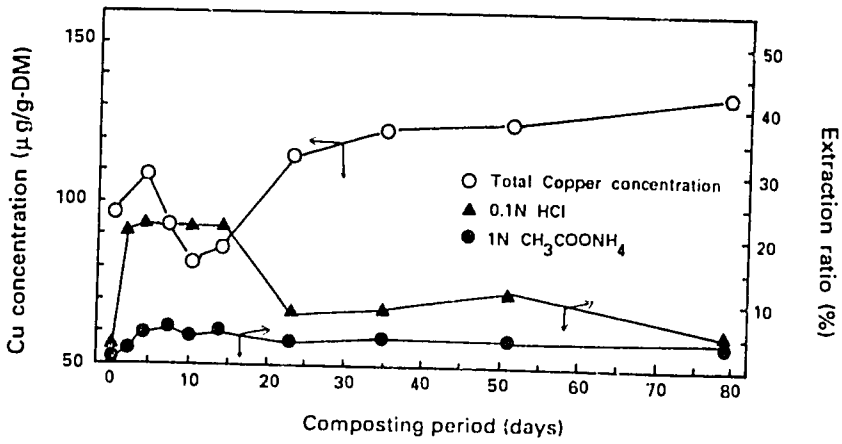


Fig. 12. Changes in the concentration and solubility of copper during the composting of sewage sludge
Source: Chino *et al.* 1983

MUNICIPAL REFUSE

About 45 million mt of municipal refuse were discarded in Japan in 1986. Most of these wastes are treated by incineration or used as landfill: only 0.1% (50,000 mt/year) are composted in 39 composting facilities (Ministry of Health and Welfare 1989).

Municipal refuse has the most complex constituents of all the organic wastes. It consists of kitchen garbage, papers, plastic, cloth, wood, glass and metal, and its constituents vary widely according to regional and seasonal conditions. The materials most suitable for composting are garbage and paper.

Table 9 shows the characteristics of or-

dinary municipal refuse compost. The content of N, P_2O_5 and K_2O ranges from 1 to 2%, while the C/N ratio was around 20 (not shown in the Table). However, the concentration of copper, zinc and lead were as high as in sewage sludge compost. The main sources of heavy metal were discarded batteries, and the metal and plastic contaminating the refuse. Pretreatment prior to composting is thus necessary to produce high-quality compost. Preferably, household garbage should be discarded separately in the kitchen, and kept separate from possible contaminants.

Fig. 13 shows changes in the constituents of municipal refuse during composting. The total carbon, the C/N ratio, the cellulose and hemicellulose content, and the ratio of the carbon in the reducing sugar to total carbon, decreased until they remained nearly constant after around five weeks. These changes in the ratio of reducing sugars and cellulose were significant, because the municipal refuse was mainly cellulosic waste consisting of garbage and paper. Consequently, an acceptable index of maturity was when the compost had a C/N ratio below 20, a total N content above 2% (on a dry matter basis), and a ratio of reducing sugar below 35% (Inoko *et al.* 1982).

Table 9. Characteristics of compost made from municipal refuse

Total N (%*)	P_2O_5 (%*)	K_2O (%*)	CaO (%*)	MgO (%*)
1.95	1.26	1.43	5.87	0.57

Cadmium (ppm**)	Mercury (ppm**)	Arsenic (ppm**)	Copper (ppm**)	Zinc (ppm**)	Lead (ppm**)	Nickel (ppm**)	Chromium (ppm**)
2.17	2.28	2.8	213	641	232	27.2	83

*: % of dry matter
**: ppm of dry matter
Source: Watanabe and Kurihara 1982

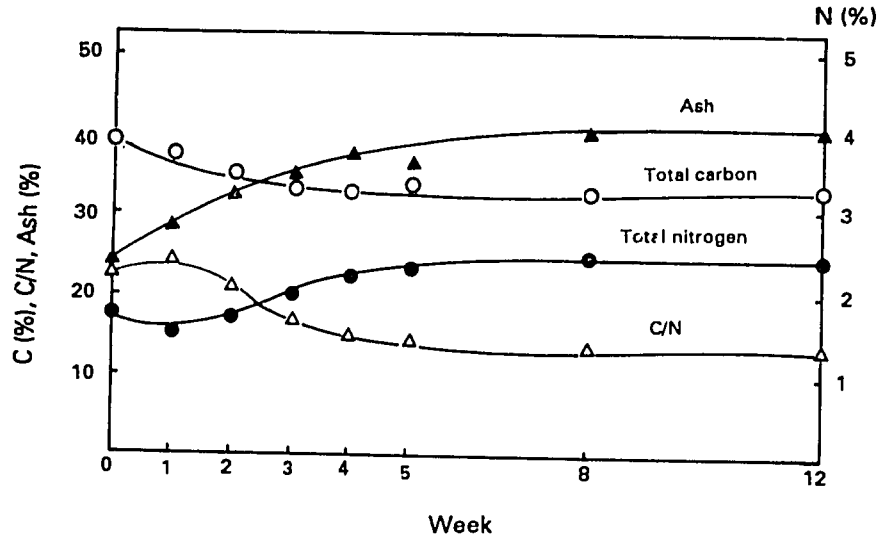
The CEC increased up to 70-80 me/100 g after 5-8 weeks, but thereafter remained almost stable (Harada *et al.* 1981). A highly significant negative correlation was noted between the CEC and C/N ratio of the compost (Harada *et al.* 1980). As shown in Fig. 14, composts were classified into four groups, according to the relationship between CEC and C/N ratio. The CEC values of mature compost made from municipal refuse were greater than 60 me/100 g of ash-free materials.

In addition, the paper chromatographic method and color change measurement methods can also be used to measure the level of maturity (Inoko *et al.* 1982).

BARK AND SAWDUST

The quantity of wood wastes produced in Japan are estimated at 14 million m^3/year. In 1981, these consisted of bark (3.6 million m^3), sawdust (5.2 million m^3), chip dust (0.9 million m^3), and miscellaneous wastes (2 million m^3) (Kawada 1982). Of these, bark is the main material used in compost, while sawdust is used for solid fuel (ogalite) and as bedding for livestock. About 0.5 million mt of bark compost was produced in 1978. To make this compost, the bark stripped from trees is pulverized, mixed with nitrogen-rich additives such as poultry wastes, urea and ammonium sulfate, and is then composted for 2-3 months with occasional turning.

The characteristics of bark compost are shown in Table 10. The nutrient content in terms of N, P_2O_5 and CaO, are relatively high. Although the C/N ratio of raw bark is 70-500, this is lowered by the addition of ni-



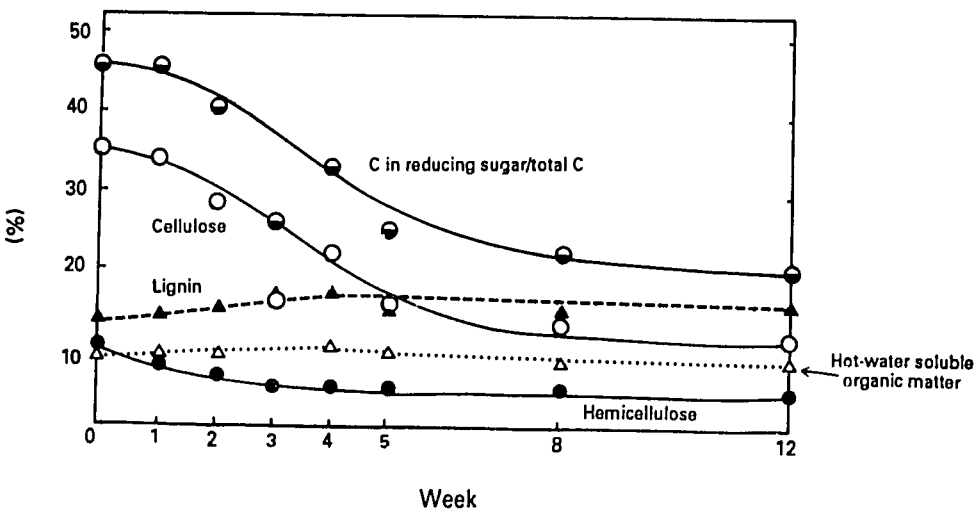


Fig. 13. Changes in constituents of municipal refuse during composting
Source: Harada *et al.* 1981

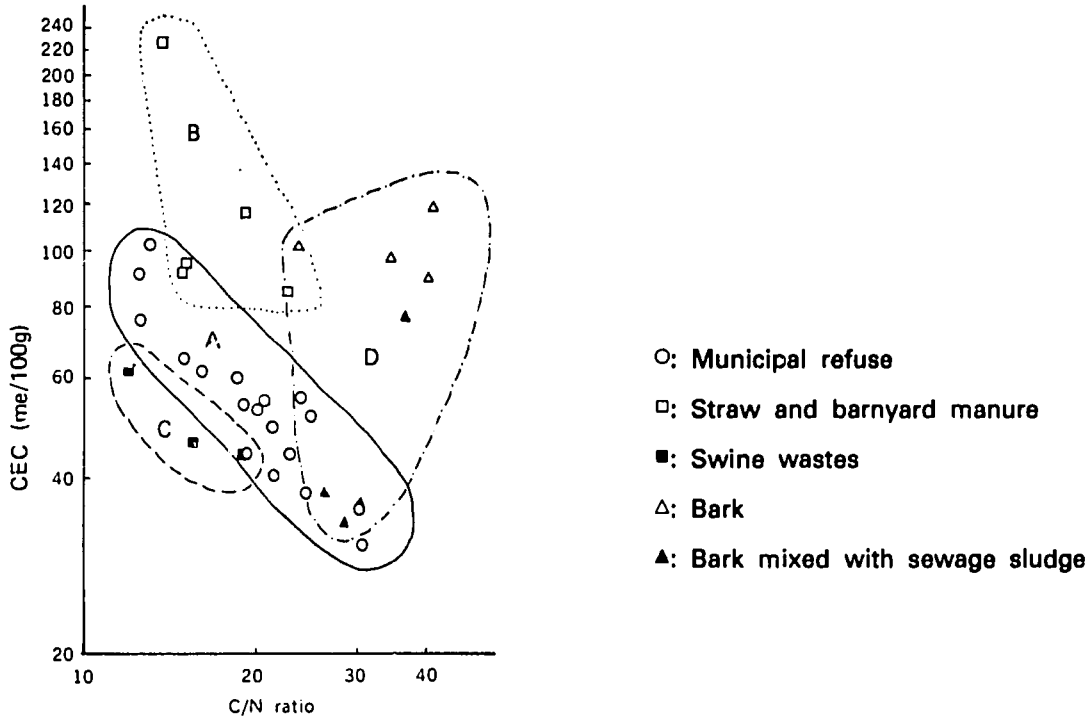


Fig. 14. Relationship between the cation exchange capacity and C/N ratio of various composts
Source: Harada and Inoko 1980

Table 10. Characteristics of bark composts

pH	Total C (%*)	Total N (%*)	C/N	CEC (me/100 g**)	P_2O_5 (%*)	K_2O (%*)	CaO (%*)
7.10	46.7	1.55	30.1	83.0	0.88	0.54	4.70

*: % of dry matter
**: milli-equivalent per 100 g dry matter
Source: Kawada 1981

trogen sources and by the composting process itself. Phytotoxic substances such as terpenoids and phenolics usually disappear when the bark is composted at high temperatures.

Quality standards for bark compost have been prepared by the Japan Bark Compost Association and the National Bark Compost Industry Association, and are shown in Table 11.

Table 11. Quality standards prepared by the Japan Bark Compost Association

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 me/100 g
Moisture	60 ± 5%
Seedling experiment*	acceptable

*: Selection of tomato, cucumber and radish seeds
Source: Kawada 1982

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COMPOSTING AND APPLICATION OF ANIMAL WASTES

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(Chinese Abstract) 摘 要

在日本，每年動物排泄物數量相當龐大，結果造成嚴重環境污染問題。動物排泄物也許是污染物，但也是肥料養分和有機物質的重要來源。將動物排泄物製成廐肥則是一個相當有效方法。

在製造過程中，成品過程是相當重要，必須找出一個有效方法來估計其成熟度。溫度上升下降，廐肥成分的改變均反應出成熟過程，都可做爲成熟的指標。除外，利用diphenylamine方法測定NO_3-N，CEC測定，發芽試驗都可用來測定成熟度。

過量施用堆肥，和廐肥對土壤、作物有害。當過量廐肥施用，氮素能累積在土壤結果造成NO_3累積在作物及污染地下水源。如何適當施用有機肥料以維持土壤生產力和作物品質以防止環境污染在本文均有介紹。

(Japanese Abstract) 摘 要

日本では、畜産業の発展に伴って膨大な量の畜産廃棄物が発生しており、環境汚染問題を生じている。畜産廃棄物は汚染の原因物質と見做されるが、それらはまた貴重な肥料・有機物資源でもある。コンポスト化は、畜産廃棄物の利用を促進する有効な手段である。

コンポスト化技術を改良し、腐熟度を判定する有効な方法を開発するためには、コンポスト化における腐熟過程の解明が重要である。温度変化およびコンポストの組成の変化は腐熟過程を反映しており、腐熟度判定の指標となりうる。また、ジフェニルアミンによる硝酸イオンの検出、CECの測定、および発芽試験が腐熟度判定法として提案された。

家畜排泄物およびコンポストの多量施用は、土壌および作物に悪影響を及ぼすことがある。過剰の排泄物を施用すれば、土壌中に窒素が蓄積され、作物体中の硝酸濃度が高まったり、地下水汚染を生じることがある。土壌の生産力と作物の品質を維持し、環境汚染を防止するために、施用量のガイドラインが提案された。

(Korean Abstract) 초 록

일본에서의 가축생산은 더욱 집약적으로 되어지고 있기 때문에 매년 막대한 량의 가축분 폐기물이 생산되고 있으며, 이로서 일련의 환경오염 문제를 야기시키고 있다. 가축 폐기물은 오염원이 될 수 있지만 한편으로 비료영양분과 유기질의 중요한 공급원도 된다. 퇴비화 과정은 가축폐기물의 이용확대를 촉진하는 효율적인 방법이다.

퇴비화에서 부숙과정의 특징은 퇴비화의 기술을 개량하는데나 부숙 정도를 효율적으로 추정하는 방법으로서 중요한 의미를 갖는다. 온도의 고저와 퇴비의 완숙과정을 설명해 주는 퇴비조성 성분의 변화는 퇴비완숙의 정도를 지칭해 주는 지표가 된다. 덧붙여 설명하면 diphenylamin에 의한 질산염의 검출과 CEC의 결정 및 발아검정은 퇴비의 완숙정도를 추정하는 방법으로도 추천되고 있다.

퇴비의 과도한 시용은 토양과 작물생산에 역효과를 나타낸다. 과도하게 시용한 결과로 농작물중에 질산염이 축적되고 지하수의 오염을 초래하게 된다. 토양 생산성과 작물의 품질을 유지하고 환경오염 방지를 위한 퇴비의 시용 추천량을 권고하였다.

COMPOSTING AND APPLICATION OF ANIMAL WASTES

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ABSTRACT

As livestock production in Japan becomes more intensive, a tremendous quantity of animal wastes is being produced annually, resulting in serious environmental pollution problems. Animal wastes may be pollutants, but they are also an important source of fertilizer nutrients and organic matter. Composting is an effective way of promoting the increased utilization of animal wastes.

Characterization of the maturing process during composting is important in order to improve composting technology and develop an efficient method of estimating 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 CEC, and the germination test, are also recommended as methods of estimating the degree of maturity.

Heavy applications of animal manure and compost may have an adverse effect on soils and crops. When excess manure is applied, the nitrogen accumulates in the soil, resulting in the accumulation of nitrate in crops and pollution of the groundwater. Guidelines for application rates are recommended, to maintain soil productivity and crop quality, and to prevent environmental pollution.

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

At present, however, animal wastes are not being utilized effectively. As the number of animals kept on each farm increases year by year, it becomes more difficult for farmers to recycle all of the animal wastes onto cropland. The management of wastes is becoming a very serious problem, especially for poultry and swine producers who own a limited area of cropland.

In order to accelerate the use of animal wastes in agriculture and to prevent environmental pollution, many difficulties must first 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 applications of raw animal wastes may damage crop plants as a result of excess ammonium, reduction of soil, and the presence of phytotoxic substances. Avoidance of these problems can be achieved to a greater or lesser extent by composting.

In this paper, various studies on the

composting of animal wastes and their application onto cropland are summarized.

COMPOSTING OF ANIMAL WASTES

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).

Raw animal waste is offensive, dirty and sticky, as well as containing readily decomposable organic matter. When large amounts are applied to cropland, the soil may be reduced too much and phytotoxic substances such as phenolic acids and volatile fatty acids may be produced. Furthermore, raw wastes may contain pathogens, parasites, and weed seeds. The objectives of composting are to reduce the offensive odor, to reduce the difficulties in handling, to inactivate the pathogens, parasites, and weed seeds and to stabilize the organic constituents, and thus produce a uniform organic material suitable for land application.

Crop residues such as rice hull and straw, and wood materials such as sawdust and wood chips, are usually admixed as bulking agents in composting to secure fast stabilization. Such admixtures may contain phytotoxic substances (Kusano and Ogawa 1974; Yoshida 1975). A further objective is therefore to decompose phytotoxic substances when such materials are mixed with animal wastes.

Maturing Process of Composting

The characterization of the maturing process during composting is important in order to improve composting methods and develop better ways of estimating the degree of maturity.

Changes in Temperature during Composting

When sufficient air is supplied, the temperature during composting usually rises to more than 60°C. If the air supply is insufficient, however, the temperature does not rise as high as this. Temperature rise is therefore a useful index for assessing whether composting is proceeding well. The temperature profile during the composting of cattle waste is shown in Fig. 1 (Harada and Haga 1983).

The temperature rise is necessary, not

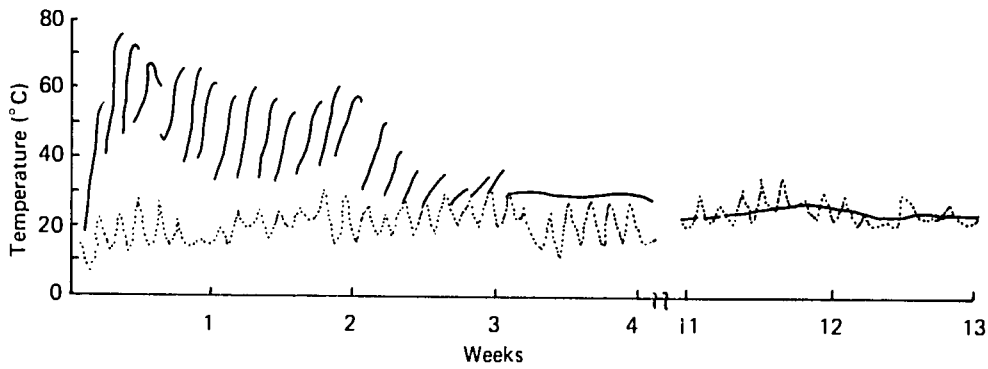

Fig. 1. Changes in temperature during the composting of cattle waste
——— Temperature in pile
····· Air temperature
Source: Harada and Haga 1983

only in order to accelerate the decomposition of organic constituents, but also to inactivate noxious organisms. Pathogens, parasites, fly larvae and weed seeds are all generally killed during composting at temperatures of 60°C or more (Gotaas 1956; Poincelot 1975; Burge *et al.* 1977; Takabayashi *et al.* 1978).

Decomposition of Organic Matter

The organic matter is decomposed and becomes stabilized during composting. Changes in the content of ash, total carbon, total nitrogen and the C/N ratio of cattle wastes are shown in Fig. 2 (Harada and Haga 1983). As organic matter decomposes, there is a relative increase in the ash content. The content of total carbon decreases while total nitrogen increases so that the C/N ratio falls. Marked changes in chemical composition level off after about five weeks, and thereafter constituents change only gradually.

The decomposition of organic matter during composting is characterized by changes in the residual rate (the percentage of organic matter which remains compared to the original amount) (see Fig. 3). The organic matter content can be roughly estimated by the ignition loss (i.e. the amount of material lost when the wastes are burnt).

The decomposition of organic matter over time can be represented by the following equation:

$$Y = A \cdot EXP\ (k \cdot X) + B,$$

where X is the period of composting (days), Y is the residual rate of the organic matter (%), k is the exponential constant, and A and B are constants. Changes in the residual rate of organic matter during composting can be expressed as follows:

$$Y = 49.02EXP\ (-\ 0.0775X) + 52.3$$
(Cattle wastes)

$$Y = 49.54EXP\ (-\ 0.136X) + 52.8$$
(Poultry wastes)

These equations indicate that poultry wastes decompose more easily than cattle wastes.

Changes in Organic Constituents

Changes in the organic constituents during the composting of cattle wastes are shown

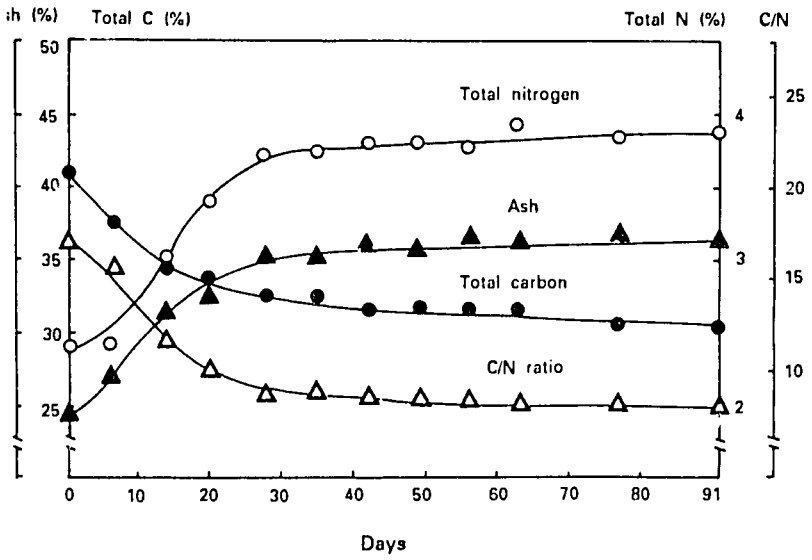

Fig. 2. Changes in the constitution of cattle waste during composting
Source: Harada and Haga 1983

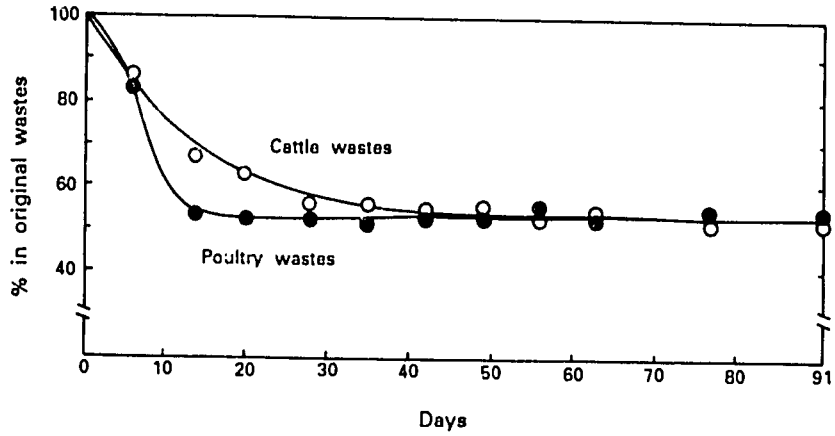

Fig. 3. Changes in residual rates of organic matter during the composting of cattle and poultry wastes
Source: Harada and Haga 1983

in Fig. 4 (Harada *et al.* 1985). The hemicellulose and cellulose content decreased rapidly until after about five weeks, after which little change occurred. The content of lignin increased gradually until composting came to an end.

Various microbes participate in composting, and the microfloral population changes successively during composting. The succession of microflora and the sequence of degradation of composting material are as follows (Poincelot 1975). In the earlier stages of

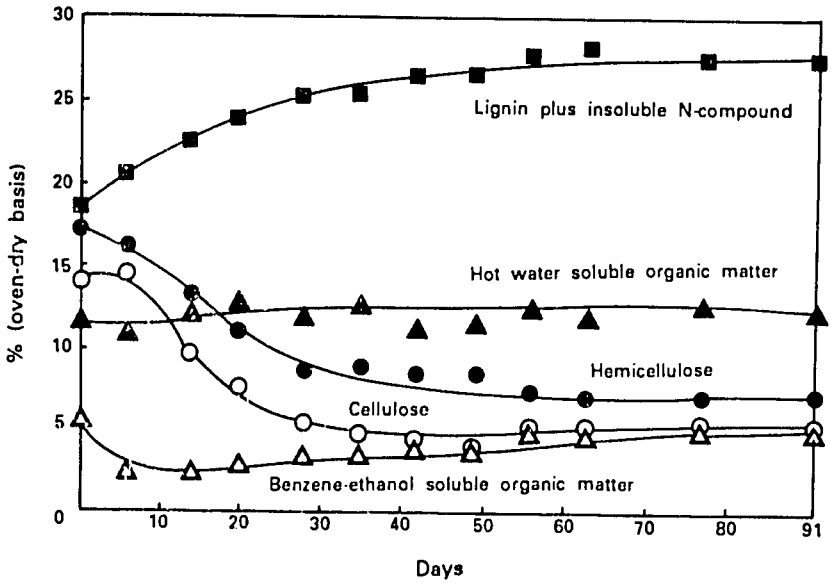

Fig. 4. Changes in organic constitution of cattle wastes during composting
Source: Harada *et al.* 1985

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. At this stage, lipids, hemicellulose, and cellulose are decomposed. Finally, as the temperature falls, mesophilic bacteria and fungi reappear. Consequently, it is the sugar and starch which first decompose during composting, followed by hemicellulose and cellulose, and finally lignin.

Changes in the residual rate of each organic constituent are shown in Fig. 5 (Harada *et al.* 1985). In this study, however, the sequence of degradation described above was not very clear. The degradation of each constituent appears to be proceeding simultaneously in the compost as a whole, since the composted mass is not homogeneous and many reactions occur simultaneously in different micro sites.

Estimation of Maturity

Compost should be well matured before it is applied, since the application of immature compost to soil may cause severe damage to plant growth. Therefore, a method of estimating the degree of maturity of compost is required.

Temperature in the Composting Mass

As described above, the temperature of compost rises with the progress of decomposition, and falls when the organic constituents have become stabilized. Therefore, the temperature in the pile can be used as an index to estimate whether composting has been completed or not. However, temperature changes do not necessarily reflect the extent to which composting has proceeded, since this varies according to circumstances. For instance, the temperature may be relatively low even though the organic constituents have not yet become stabilized, if the composting mass has been dried excessively.

Constituents of Composting Materials

Changes in the constituents also reflect the maturing process. An increase in the content of ash, total nitrogen and lignin, and a

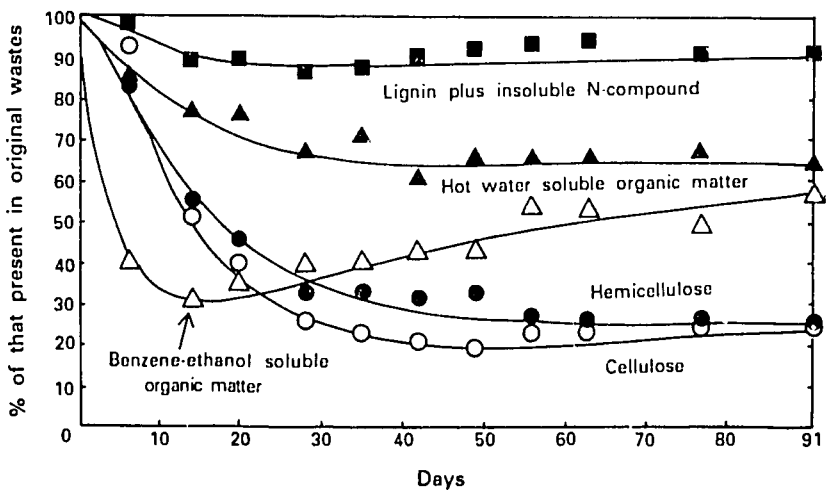

Fig. 5. Changes in residual rates of organic constituents during the composting of cattle wastes
Source: Harada *et al.* 1985

decrease in organic matter, total carbon, hemicellulose, cellulose, and the C/N ratio over time, may serve as indicators for maturation. However, guidelines for maturity should be established separately for each raw material, since the contents of these constituents varies according to the material.

Detection of nitrate by diphenylamine

In the earlier stages of composting, ammonium is produced by the decomposition of nitrogeneous compounds such as protein. The ammonium is oxidized into nitrate by the action of ammonium-oxidizing bacteria and nitrite-oxidizing bacteria during the progress of maturation. Consequently, nitrate accumulates as the compost matures. The presence of nitrate can be detected qualitatively (but not quantitatively) by diphenylamine. Diphenylamine solution dissolved in concentrated sulfulic acid is added to water extract from the compost: if nitrate is contained in the extract, it turns blue. This method can be used to test the maturity of cattle waste compost, but not of poultry waste compost, because very little nitrate is produced even in mature compost made from poultry wastes (Osada *et al.* 1986).

Determination of cation-exchange capacity

The negative charge, i.e. the cation-exchange capacity (CEC), of organic matter increases as the compost matures (Harada and Inoko 1980). 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 content (r = 0.992***) in composted cattle wastes (Harada *et al.* 1984). Therefore, since the CEC reflects changes in the constituents during maturation, it is a useful parameter for estimating the degree of maturity of the compost.

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. Twenty to 50 seeds of winter rape *(Brassica rapa)* are placed on a filter paper in the Petri dish (Ø9cm), 10 ml of water extract from compost is added, and the seeds are then incubated at 20°C under dark conditions. The germination rate is measured after 24 hrs. The germination rate is low when samples of raw material or those from anaerobic portions of the pile are used, and increases as the material matures (Osada *et al.* 1985).

LAND APPLICATION OF ANIMAL MANURE AND COMPOST

Grassland and Forage Crops

Large amounts of animal manure and/or compost tend to be applied to grassland and fields of forage crops, because grass and forage crops generally tolerate high rates of plant nutrients, and respond well to produce high yields. However, when excess manure or compost is applied, nitrogen accumulates in the soil and the concentration of nitrates in crops increases. Using such crops with a very high nitrate content as a feed is hazardous to ruminants. Generally, 0.22% NO_3–N is considered the safety limit (on a dry matter basis) (Wright and Davison 1964). Nitrate easily accumulates in the stalks of corn with heavy applications of manure (Fig. 6). When the annual application rate exceeds 100 mt/ha, the nitrate content in green-cut corn and Italian ryegrass may rise to a dangerous level (Ito *et al.* 1982).

In addition, heavy applications of manure and compost cause an imbalance in the base composition of soils and forage crops. Potassium accumulates in soils under heavy applications, since animal manure contains a high concentration of potassium. Forage crops grown in such potassium-rich soil take up potassium easily, and accumulate it in large quantities in the aboveground parts, particularly in the stalk in the case of corn. The plant uptake of magnesium and calcium is antagonistically lowered with excess potassium in soils so that the ratio of K/(Ca + Mg) in the plants shows a sharp increase (Fig. 7). When the base equivalent ratio, [K/(Ca + Mg)] in forage crops exceeds 2.2, and the magnesium content in forage crops falls below 0.2%, outbreaks of grass tetany in dairy cattle show a marked increase (Kemp and 't Hart 1957).

Therefore, the amount of manure and compost applied to cropland should be within

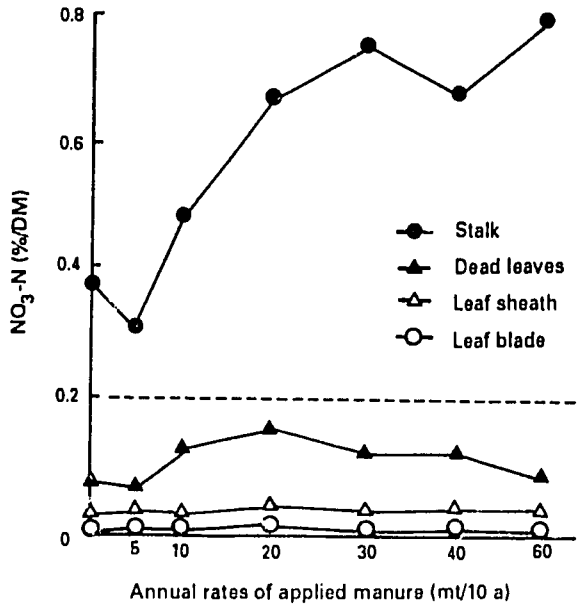

Fig. 6. Nitrate concentrations in green-cut corn as affected by the manure application rates

Source: Ito, Shiozaki and Hashimoto 1982

certain limits. Optimum application rates of animal manure on grassland and forage crops are shown in Table 1 (Kurashima 1983). It is recommended that chemical fertilizers be used together with the animal manure (Table 2). While the full amount of potassium required by crops can be applied in cattle manure, the nitrogen and phosphorus should be supplemented with chemical fertilizer. In the cases of swine and poultry manure which have a high phosphorus content, there is sufficient to meet phosphorus in the manure requirements, while nitrogen and potassium levels should be supplemented by the use of chemical fertilizer.

Paddy Fields

An adequate application of manure and compost onto paddy fields maintains soil fertility and a high, stable rice yield. However, very heavy applications may decrease the rice

Table 1. Recommended application rates of animal manure onto grassland and forage crops

	Target yield (mt/ha)	Manure applications (mt/ha)		
		Cattle	Swine	Dried poultry 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

Source: Kurashima 1983

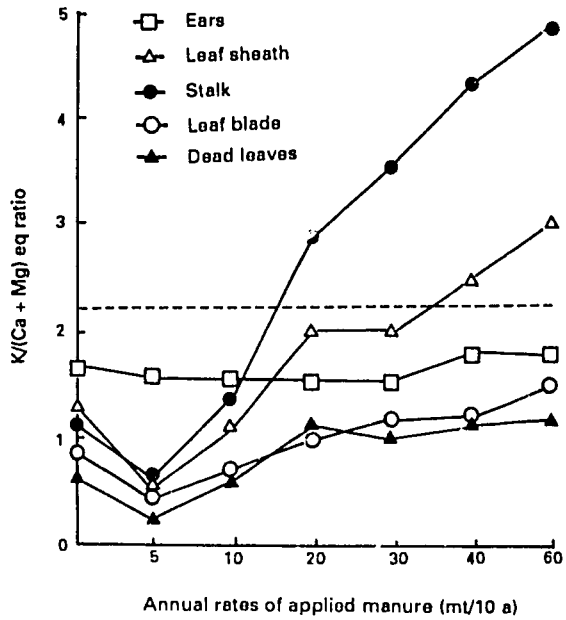

Fig. 7. K/(Ca + Mg) equivalent ratios in green-cut corn as affected by manure application rates
Source: Ito, Shiozaki and Hashimoto 1982

Table 2. Requirements for chemical fertilizers applied together with livestock manure

	Cattle manure			Swine manure			Poultry dried manure		
	N	P_2O_5 (kg/ha)	K_2O	N	P_2O_5 (kg/ha)	K_2O	N	P_2O_5 (kg/ha)	K_2O
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

Source: Kurashima 1983

yield, because of excess nitrogen in the soil. Furthermore, when animal manure containing a large amount of readily decomposable organic matter is applied heavily to paddy fields, soil microorganisms multiply rapidly and reduction of the soil may occur, with a corresponding loss of oxygen. Under such soil conditions phytotoxic substances are produced which may damage the growth of plant roots. Therefore, the application of mature compost to paddy fields is desirable, to avoid excessive reduction.

Optimum application rates of animal manure and compost in wet rice fields are shown in Table 3 (Shiga 1983). The guidelines were based on considerations of the nitrogen content in manure.

However, it must be kept in mind that when animal manure and compost are applied every year over a prolonged period, the release of nitrogen from the soil increases. Changes in the release of nitrogen after successive applications of manure are shown in Fig. 8. When swine manure or poultry ma-

Table 3. Recommended application rates of animal manure and compost in paddy fields

Unit: mt/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	-

Source: Shiga 1983

nure is applied repeatedly, not much nitrogen accumulates in the soil, since such manure decomposes easily. In the case of cattle manure, however, the annual decomposition rate of manure, or the release rate of its nitrogen, can be as low as 30%. The rest of the nitrogen in the manure is carried over into succeeding years, and the release of nitrogen increases year by year. In the case of compost, this trend is even more marked.

Vegetable Fields

In vegetable fields, the application of manure and compost is important in providing a good nutrient supply, since vegetables generally require a much higher level of nutrients. It is also important in maintaining the chemical, physical, and biological properties of soil, so that fields producing vegetables remain highly productive. As the content of organic matter in the soil increases with manure applications, so the CEC of the soil increases. A negative charge in soil implies the ability to retain nutrients in the forms of cations (ammonium, potassium, calcium, magnesium etc.). The effect of manure applications is remarkable, particularly on soils low in humus and

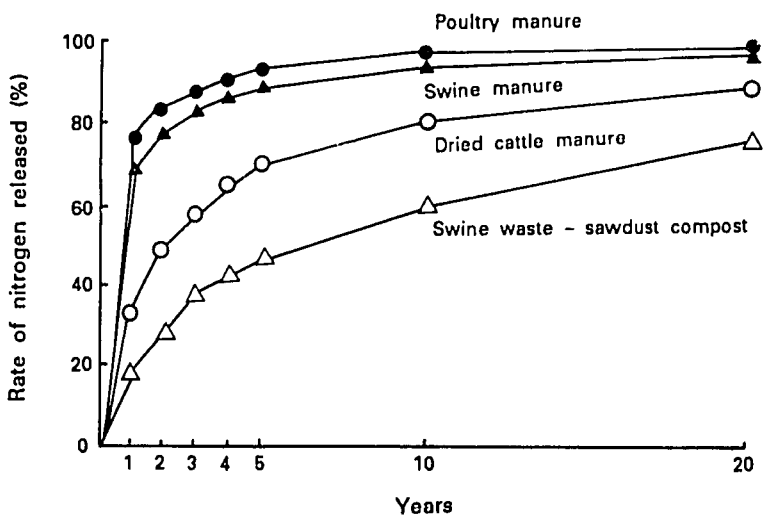

Fig. 8. Increase in the rate of nitrogen released (% of nitrogen released annually of total nitrogen applied in that year) with successive manure applications

Source: Shiga 1983

clay. The air and water permeability of soil also improves after applications of manure. As a result, the ability of plants to take up water and nutrients is enhanced, with improved root growth. Furthermore, the increased activity of soil organisms accelerates the circulation of materials in the soil.

However, as is also the case with other crops, heavy applications of manure may bring about an imbalance in the base compositions in both soil and vegetables. Kinoshita *et al.* (1980) reported that the concentration of calcium in onion bulbs decreased with the application of a compost made from swine wastes and sawdust. In addition, heavy applications of manure may cause environmental pollution. Not all of the nitrogen released from manure is taken up by crops, and the unutilized nitrogen is transformed into nitrate by nitrification. This nitrate readily leaches down into the subsoil and eventually into groundwater, because soil has a poor ability to retain nitrate. As application rates of manure increase, so does the leaching of nitrate. Ogawa *et al.* (1988) reported that nitrate had accumulated in the soil down to a depth of 2 m after the harvest of a cucumber crop which had received applications of dried swine manure at a rate of 100 mt/ha.

The optimum application rates for animal manure and compost in vegetable fields are shown in Table 4. (Yumura 1983). Three groups of guidelines are proposed, according to whether the fertilizer requirements of the vegetables are low, medium, or high.

CONCLUSION

Composting is an effective method for promoting the utilization of animal wastes. In this paper, the maturing process which animal wastes undergo during composting has been characterized, and the conditions described which accelerate the maturing process. The quality, and particularly the maturity, of compost is important if increased utilization is to be made of livestock manure. Although many methods are available for estimating the degree of maturity of compost, a more practical and reliable method is still needed.

The application of animal manure and compost to cropland is beneficial to the improvement of soil productivity. However, the heavy application of manure has an adverse effect on soils and crops. Although optimum application rates for manure and compost have been tentatively recommended, more reliable standards applicable to each particular region, soil, and crop are needed. Further systematic research should be carried out, in order to establish efficient nutrient recycling systems for animal wastes.

Table 4. Recommended application rates for animal manure and compost in vegetable fields

Unit: mt/ha

Fertilizer requirements of vegetables*	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 with low fertilizer requirements: potato, spinach, radish
Vegetables with medium fertilizer requirements: cabbage, lettuce, tomato
Vegetables with high fertilizer requirements: cucumber, green pepper
Source: Yumura 1983

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