7 Management of composting

SHANG-SHYNG YANG

7.1 Introduction

Proper and regular additions of on-farm organic wastes such as animal manure and crop residues are of utmost importance in maintaining the tilth, fertility, and productivity of agricultural soils; in protecting them from wind and water erosion; and in preventing nutrient losses through runoff and leaching. The restoration and rehabilitation of degraded soils to an acceptable level of productivity can be enhanced by using various off-farm sources of organic wastes such as sewage sludge, municipal solid wastes, crop wastes, and agricultural and industrial processing wastes. However, the quality and acceptability of these materials as soil amendments can be greatly improved through composting, or even by co-composting them with available on-farm wastes.

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints on the economic viability, environmental soundness, and social acceptance of agricultural production systems worldwide. Soil quality has focused on soil productivity, food safety and quality, human and animal health, and environmental quality. It may also play a major role in plant health and in the nutritional quality of the food that is produced.

Composting is a viable means of transforming various organic wastes into products that can be used safely and beneficially as biofertilizers and soil conditioners. It can resolve a number of problems associated with the use of raw and unstable organic wastes as soil amendments such as malodors, human pathogens, and undesirable chemical and physical properties. During the composting process, organic wastes are decomposed, plant nutrients are mineralized into plant-available forms, pathogens are destroyed, and malodors are abated (Parr and Hornick 1992; Yang 1997b). Composting is a microbiological process that depends on the growth and activity of mixed populations of bacteria, actinomycetes, and fungi that are indigenous to the wastes being composted. It can be done by either aerobic or anaerobic methods. However, the aerobic method is generally preferred, since it proceeds more rapidly and provides greater pathogen reduction because higher temperatures are attained.

7.2 Management of composting materials

Many biomass materials show active decomposition accompanied by elevated temperature. However, some of these materials can be used for high-value utilization and are considered unsuitable for composting. For example, grass, straw, and foliage are generally more valuable as feeding materials for livestock. Therefore, other by-products and disposable products are generally considered for composting. These materials range from animal wastes, with a high fertilizer value, to straw and husk, with a minimal fertilizer content (Yang 1994, 1997a). The materials presently used for composting in Taiwan are listed in Table 1. These materials are sometimes processed separately, but more often they are processed as mixed materials to adjust the C:N ratio, bulk density, and moisture content.

Selection of composting materials is important since it directly influences composting quality. There is less possibility of increasing harmful materials in composting of rice straw, but increasing use of livestock manure and industrial and municipal wastes creates concerns for composting. Therefore, selection of good raw materials for composting is crucial in quality control of composting.

Hog manure has low C:N ratio, high bulk density, and bad aeration. Adding straw and corncob to hog manure will improve the C:N ratio and bulk density. Adding nitrogen and phosphate will also improve the composting. The C:N ratios of the composts of chicken manure, hog wastes, soybean oil extract residues with mushroom growth medium wastes decreased from 30 to 15 during composting. Rice hull contained SiO_2 (11.20-14.10%), nitrogen (0.48-0.50%), and potassium (0.31-0.68%); the contents of other elements were low.

Table 1. Materials suitable for composting in Taiwan.

Materials	Characteristic properties
Straw, husk, sawdust, pulp, bark, corncob, bagasse, tea residue, coconut pulp	Porous, low moisture content, not easily fermented without pretreatment
Waste mushroom media	Porous, cellulosic materials
Animal wastes, animal by-products, fishery by-products, sludge, vegetable-market wastes, household wastes, sewage	Sloppy, high moisture content, easily fermented, offensive smell
Green manure	Cellulosic materials
Municipal refuse	Not easily fermented; needs separation of inorganic materials, glasses, plastics

Table 2. Chemical analysis of crop wastes.

Crop waste	C:N	N	P	K	Na	Ca	Mg	SiO	Fe	Mn	Zn	Cu	Ni	Cr	Cd	Pb
	%							mg/kg								
Rice straw (Japonica)	107	0.48	0.07	1.44	0.16	0.36	0.26	8.5	406	418	34	8	20	2	0.52	3
Rice straw (Indica)	85	0.67	0.09	1.41	0.20	0.46	0.39	10.3	455	347	31	5	24	3	0.45	5
Rice hull (Japonica)	116	0.48	0.05	0.31	0.14	0.05	0.03	11.2	186	110	40	7	18	4	0.28	3
Rice hull (Indica)	151	0.50	0.07	0.68	0.20	0.07	0.05	14.1	160	108	43	6	21	6	0.22	2
Corn stalk	61	0.91	0.16	1.34	0.12	0.25	0.29	3.0	183	23	35	6	-	3	0.41	3
Sorghum stalk	74	0.73	0.11	1.61	0.15	0.43	0.37	3.8	268	30	40	10	-	4	0.49	3
Soybean stem	39	1.36	0.16	1.09	0.15	1.41	0.69	3.1	672	45	33	15	-	4	0.43	8
Peanut stem	40	1.33	0.11	0.91	0.10	0.97	0.63	3.4	610	27	17	4	5	4	0.35	4
Peanut hull	-	0.70	0.12	0.46	-	0.48	0.15	1.8	388	45	18	10	26	9	-	-
Bark	-	1.58	0.05	0.60	0.17	1.69	0.21	1.2	2885	47	175	8	26	22	1.16	27
Tobacco leaves	11	3.50	0.14	2.54	0.25	2.49	1.02	4.8	281	63	70	16	-	8	1.74	6
Tobacco factory waste	39	1.12	0.21	0.30	0.26	11.39	0.68	1.8	146	188	156	17	-	4	2.65	9

Source: Hsieh and Hsu 1993

Corn and sorghum stalks contained potassium (1.34-1.61%) and nitrogen (0.73-0.91%). Soybean and peanut stems had high contents of nitrogen, potassium, calcium, and magnesium. Although bark had high contents of nitrogen, calcium, and potassium, it also had high content of phenolic compound. Therefore, composting of bark is necessary.

Tobacco leaves and tobacco factory wastes had high contents of nitrogen, potassium, calcium, magnesium, and nicotine (Hsieh and Hsu 1993) (Table 2). Vegetable wastes had high crude protein and crude fat contents, while bamboo shoot wastes had high cellulose and hemicellulose contents. Food wastes contained high total carbon and total nitrogen contents, while C:N ratio was low. Cow feces contained high crude fiber and ash contents, while total nitrogen, crude protein, phosphate, and potassium contents were low. Hog feces had average total nitrogen, crude protein, phosphate, and potassium contents; while chicken feces had high ash, total nitrogen, crude protein, phosphate, and potassium contents (Yang *et al.* 1991; Tsai and Yang 2004) (Table 3).

Biosolids, municipal solid wastes, yard wastes, and food wastes contain pathogens. In yard wastes, the major source of pathogens is domestic animal feces; in food wastes, eggs, chicken parts, and other contaminated sources can result in significant levels of pathogens. Composting, if carried out properly, is very effective in destroying pathogens. This is primarily the result of temperature-time relationships. However, other factors contribute to the demise of pathogens such as antagonistic organisms and ammonia. Regrowth of salmonellae is not a serious problem as these organisms die very quickly during curing and storage. Knoll (1961) described several experiments on different *Salmonella* strains subjected to composting temperature at the composting plant. After 14 days of reactor time with temperatures of 55°-60°C and a moisture content of 40-60%, the product did not contain pathogens.

Pig manure has a considerable copper content coming from feed materials. Sewage sludge has a relatively high nutrient content and can be used as an organic fertilizer. However, it has a high content of heavy metals and, possibly, harmful organic materials. Human manure waste sludge had high phosphate and lead contents (Um and Lee 2001). Food wastes mainly come from agricultural products and can be used as raw materials for composting. The problem with food wastes was high salt (4.10%) and fat (3.53-8.02%) contents (Tsai and Yang 2004). According to company

Table 3. Compositions of organic raw materials for composting.

Item	Total carbon	Total nitrogen	C:N	Ash	Carbo-hydrate	Cellulose	Lignin	Crude protein	Crude fat	Hemi-cellulose
	%	%		%	%	%	%	%	%	%
Sludge	44.2	7.0	6.3	14.9	11.6	7.5	13.6	43.6		
Rice root	41.1	0.9	45.9	15.5	22.8	31.8	17.1	5.6		
Rice straw	39.1	0.7	60.2	12.8	25.0	37.0	11.2	4.1		
Rice hull	40.1	0.5	74.1	18.6	16.3	41.9	20.6	3.4		
Wheat straw	42.2	0.3	126.0	10.9	21.6	48.2	15.5	2.1		
Paper waste	40.6	0.3	140.0	18.1	6.8	55.2	15.3	1.8		
Sawdust	50.4	0.2	242.0	1.3	10.9	48.2	30.5	1.3		
Lignin reagent	66.5	0.1	923.0	-	-	-	-	-		
Vegetable waste	-	-	-	14.73-26.38	0.56-11.72	8.61-20.38	-	14.05-49.28	2.47-10.49	1.28-5.06
Bamboo shoot waste	-	-	-	4.48-8.30	1.93-3.82	14.73-38.11	-	17.93-21.10	0.84-0.89	9.09-10.66
Food waste	43.12	2.03	9.00							
Food waste in college dormitory	37.39-57.06	1.54-3.25	11.53-28.42	9.53-10.34						
Food waste in national apt.	49.87-56.35	2.15-2.63	21.46-23.26	8.42-10.32						
Cow feces		0.30		7.4-29.7	26.1-41.3			12.9-18.7		
Hog feces		0.60		16.0	44.0			20.0		
Chicken feces		1.60		15.0-	12.7-			28.0-		

Source: Yang *et al*. 1991; Tsai and Yang 2004

Table 4. Nutrient contents of sludge from different sources.

Sludge	T-C	T-N	P_2O_5	K_2O	Cu	Cr	Cd	Pb
	%	%	%	%	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
Sludge from water purifying system	20.13	0.91	0.59	0.52	218	-	-	-
Sewage sludge	26.86	2.05	2.58	0.38	1,015	270	3	-
Human manure waste	32.26	2.72	7.31	0.35	138	43	3	67
Textile sludge	30.83	3.73	1.51	0.29	269	411	1	35
Food sludge	49.98	3.51	1.52	0.54	103	49	8	65
Dairy sludge	43.29	5.86	4.68	0.55	72	28	0.4	9
Paper sludge	30.67	0.48	0.17	0.30	111	42	3	42
Alcohol sludge	38.43	4.28	1.18	0.99	128	24	0.4	67
Beverage sludge	41.75	4.05	2.03	0.56	163	89	17	148
Oil sludge	37.14	1.47	0.70	0.23	43	117	19	191

Source: Um and Lee 2001

type, harmful materials in sludge are different. Sludge from food processing companies has a lead content and that from dairy industries has a low metal content. Sludge from oil industries has chromium and lead contents, and some harmful effects on plant growth were reported (Table 4). Sludge from industrial wastewater treatment process used as raw materials for composting needs safety examination.

Some say that mixing harmful material with sound material can dilute adverse effects. But it is necessary to exclude such contaminant in the selection of raw materials. There are specific inspection standards for the preinspection of required usable materials. These standards include effective constituents of classified harmful materials. In Korea, the standards of composting materials are as follows: organic material, >60%; As, <50 mg kg^{-1}; Hg, <2 mg kg^{-1}; Pb, <150 mg kg^{-1}; Cd, <5 mg kg^{-1}; Cu, <500 mg kg^{-1}; Cr, <300 mg kg^{-1}; Zn, <900 mg kg^{-1}; and Ni, < 300 mg kg^{-1} (Um and Lee 2001).

Co-composting is a waste treatment method where different types of wastes are treated together. As an attractive method of resource recovery and waste disposal, it offers many advantages. Co-composting is expected to cost less than separate treatment systems, mainly due to the low cost per volume treated at large treatment plants. Co-composting of potato starch sludge and piggery manure as a substitute for sawdust was established. Composting by the aerated static pile method for 10-14 days and curing process with stacking the composts in 10-12 bags high can obtain a good product (Yang *et al.* 2001).

Municipal solid wastes contain 74-84% organic matter, 1.4% nitrogen, 0.1% phosphorus, and 0.1% potassium in Jakarta, Indonesia. The addition of nitrogenous compounds to adjust the C:N ratio can often accelerate the process by alleviating the microbial demand for nitrogen. Urea addition accelerated the composting process (47 days for urea addition and 54 days for control) (Prihatini and Kurnia 2001).

7.3 Problems in the use of composts

7.3.1 High price

Average price of commercial compost is about $2 for a 20-kg package in Korea and about $3 in Taiwan. When compared with nitrogen supply only, the price of compost is 20 times higher than that of chemical fertilizer. Although most farmers agree on the positive effects of composts, some low-grade composts are very popular for their low price and some crop damages are attributed to industrial wastes used as raw materials.

7.3.2 Unbalanced nutrient content

Livestock manure composts are the major commercial composts in Korea, while both livestock manure composts and vegetable-market waste composts are the major composts in Taiwan. However, some companies provide sewage sludge as raw materials for composting. These materials are mixed with livestock manure for composting and have a high phosphate content (Table 5). Therefore, compost is applied with a mixture of chemical fertilizers to get appropriate ratios in N, P, and K.

7.3.3 Immature compost

Composting is minimizing the damage from intermediate compounds in the degradation of organic materials. It takes about 6 months in a natural environment and about 80 days in an industrial facility. Some immature composts are being sold in the market. Biological indicators or regulations should be established for maturity determination.

7.3.4 Salt accumulation and environmental pollution

When livestock manure compost is applied as N requirement to crops, phosphate input becomes an excess of 200-954% over standard input. Food waste compost has high concentrations of salt and fat. Excess application of such compost damages crops by salt accumulation in the soil. Generally, such soil shows unbalanced excess accumulation of phosphate, potassium, and nitrate (Um and Lee 2001; Tsai and Yang 2004).

Table 5. Composition of composts.

Item	pH	Moisture content	Organic matter	Total organic carbon	Total nitrogen	C:N	P	K	Ca	Mg
			%					%		
Hog waste compost	6.9	41.1	85.	38.2	2.1	16	1.0	0.4	4.2	0.5
Hog waste and rice hull compost	7.9-8.3	25.6-36.8	71.6-77.6	32.2-34.9	1.4-2.4	15-23	3.8-5.5	1.7-3.1	3.3-4.3	0.9-2.4
Cow waste, chicken waste, sawdust, and bagasse compost	7.5	42.0	65.0	29.3	1.9	15	2.3	1.7	5.5	1.3
Cow waste and rice hull compost	7.1	36.2	63.2	28.4	2.3	12	2.9	5.0	3.0	2.3
Chicken waste compost	7.7	29.6	50.0	22.5	2.2	10	9.2	4.6	14.3	1.8
Chicken waste and rice hull compost	7.1	22.9	55.2	24.8	2.0	12	6.3	4.5	8.6	1.6
Sheep waste compost	9.3	57.2	76.1	34.2	2.7	13	2.1	4.2	5.9	1.2
Manure compost	-	60.0		10.8	0.3	36	0.1	0.04	-	-
Bagasse compost	-	68.0	73.0	33.0	1.08	30	0.2	0.57	-	-
Bagasse and hog waste compost	-	67.0	58.0	26.0	1.22	21	0.25	0.48	-	-
Bark compost	-	-	37.6	2.0	189.3	-	-	-	-	-
Sawdust compost	-	-	42.2	1.9	22.0	-	-	-	-	-
Sludge and rice hull compost	8.1	19.4	53.9	24.3	2.4	10	6.6	0.7	8.9	1.1
Vegetable waste compost	6.9	60.4	63.8	37.1	1.08	34.4	0.76	1.13	3.67	0.27

7.3.5 Greenhouse gases emission

Unsuitable handling or treatment of livestock wastes has caused the emission of harmful gases such as ammonia from livestock production systems. In addition, livestock wastes contribute significantly to the emissions of CO_2, CH_4, and N_2O, which are greenhouse gases. Some efforts have already been made to quantify the emissions from livestock waste stores and treatment systems. One cubic meter of swine dung heap compost emitted 400-970 g of ammonia, 0.6-386 g methane, and 1.9-71.9 g nitrous oxide. During composting for eight days, each cubic meter of compost produced 2 g of CO_2, 239 mg CH_4, and 660 mg NH_3. Each ton of hog wastes, cow wastes, and chicken wastes produced 22.1 g, 16.3 g, and 12.9 g of methane, respectively, during a year of composting. Methane emission rates from the compost of the mixture of hog wastes, chicken wastes, and sawdust ranged from 0.12 mg^{-2} h^{-1} to 707 mg^{-2} h^{-1} depending on the stage of maturity. Nitrous oxide emission rates were between 0.15 mg m^{-2} h^{-1} and 25.0 mg m^{-2} h^{-1}, and those of carbon dioxide ranged from 1,036 mg m^{-2} h^{-1} to 19,558 mg m^{-2} h^{-1} (Osada *et al.* 2000; Tang and Wang 2000; Osada 2001; Chen *et al.* 2003; Lai *et al.* 2003).

7.3.6 Quality control

Compost manufacturing standards are based on the supply of organic materials to the soil. There are no regulations on nutrient content. The commercial organic fertilizer and commercial compost companies are small in scale compared with other manufacturing industries. They thus have difficulties in keeping their high-quality manpower and in maintaining their composting facilities. Special fresh industrial wastes that are supplied by the waste disposal companies have many serious problems. Most commercial organic products and composts give the composition on the package label (Table 6). But there is no such information for organic products or composts in bulk, so it is difficult to get practical information for using them.

7.3.7 Heavy metal content

There are some regulations on heavy metals in composts in order to protect soil environment. Allowable heavy metal concentrations on a dry weight basis are used in Taiwan, Europe, the USA, and Japan, and on a fresh weight basis in Korea (Table 7). Although sewage sludge contains considerable

Table 6. Standards of compost in Taiwan.

Item	Moisture content	Organic matter	Total nitrogen	Total phosphate	Total K_2O	Cu	Zn
	%						
Compost (general)	<35	60	0.6	0.3	0.3	0.01	0.08
Layer waste compost	<35	40	2.0	2.0	1.0	0.01	0.08
Mixed compost	<35	40	0.3	0.3	0.2	0.00	0.08

Table 7. Allowance of heavy metal content in composts.

Country	Cd	Cr	Cu	Hg	Ni	Pb	Zn	As	Co	Mo
	mg/kg									
USA	2-25	1000	450-1000	5-10	50-200	250-1000	900-2500	-	-	10
Japan	5	(1.5)	-	2	-	(3)	-	50	-	-
Austria	4	150	400	4	100	500	1000	-	-	-
Belgium	5	150-200	100-500	5	50-100	600-1000	1000-1500	-	-	-
Colombia	2.6	210	100	0.8	50	150	315	13	26	5
Italy	10	3500(Cr^{+3}) 10(Cr^{+6})	600	10	200	500	2500	-	-	-
Holland	0.7-2	50-200	25-300	0.2-2	10-50	65-200	75-900	5-25	-	-
Canada	3-4	50	60-100	0.15-0.5	60	150-500	500	10-20	25	2-3
Spain	40	750	1750	-	400	1200	4000	-	-	-
Switzerland	3	150	150	3	50	150	500	-	60	20
Korea	5	-	-	2	-	150	-	50	-	-
Taiwan	5	150	150	2	25	150	500	50	-	-

amounts of plant nutrients such as organic matter, N, P, and K, it is not used in agricultural practices because of its high concentration of heavy metals. The Cu contents are generally high in poultry and hog composts – from 9 mg kg^{-1} to 394 mg kg^{-1} and from 6 mg kg^{-1} to 301 mg kg^{-1}, respectively. The Zn contents are between 56 mg kg^{-1} and 1,147 mg kg^{-1} and between 35 mg kg^{-1} and 623 mg kg^{-1}, respectively. The Cr contents are often high in organic manure of animal origin, in hog compost, and in compound organic manure. The contents are 2 mg kg^{-1}-54,324 mg kg^{-1}, 3 mg kg^{-1}-8,486 mg kg^{-1}, and 2 mg kg^{-1}-9,196 mg kg^{-1}, respectively (Table 8). The product of hog compost contains nitrogen, 2.8%; P_2O_5, 1.7%; K_2O, 0.23%; organic matter, 86%; Zn, 349 mg kg^{-1}; and Cu, 140 mg kg^{-1}. Rice straw contains potassium (1.41-1.44%) and nitrogen (0.48-0.67%); the contents of other components are low. The high content of Cr in the manure is conjectured to be related to the admixing of animal skin powder which is the by-product of the leather industry (Lian and Lee 1994).

The sludge of final clarifier has the highest Cu content, the primary clarifier of aerobic treatment comes next, and the anaerobic treatment has the lowest. However, the sludge of anaerobic treatment has the highest Fe and Mn contents (Fu and Chen 1990). The heavy metal contents of sludge depend on the feed supplement.

7.3.8 Organic compounds

The presence of toxic organics in compost depends on the type of feedstock involved. Biosolids can contain organic compounds as a result of the disposal of industrial, commercial, and household wastes. Pesticides can be found in yard wastes and food wastes. Pthalates are found in plastics along with other organic dynes and compounds. Household wastes discharged into the municipal solid waste stream contain oils, solvents, pesticides, and many other toxic organic compounds. Paper products may contain toxic organics as a result of printing inks and ash discharged from incinerators or boilers may contain dioxins.

Compost has been shown to be an effective method of microbial degradation of many toxic organics. Thus, many organisms are capable of decomposing toxic organics and use the C as an energy source. Many of the studies were conducted under laboratory conditions. Therefore, research is needed to develop techniques for cost-effective composting of recalcitrant organic compounds. These may include inoculating specific organisms and providing the environment that sustains them.

Table 8. Heavy metal contents of commercial organic fertilizers.

Organic fertilizer	Cu	Zn	Cd	Cr	Ni	Pb	As
	mg/kg (dry weight basis)						
Oil extract residue	9-161 (24)*	37-372 (73)	0-2.5 (0.27)	0.2-24 (5.7)	1.4-15 (6.3)	0.3-27 (4.5)	0.7-13 (2.6)
Plant residue	1.4-30 (15)	10-127 (53)	0-0.2 (0.03)	2.1-15 (6.7)	4.0-5.7 (4.9)	0.3-5 (3.0)	1 6-100 (36)
Animal residue	1-561 (84)	42-2,827 (424)	0-4.8 (0.68)	2-54,324 (6,252)	0.7-415 (47)	1.4-37 (7.2)	0-66 (9.7)
Chicken compost	9-394 (99)	56-1,147 (286)	0-6.2 (1.4)	1-282 (23)	1.1-30 (12)	0-183 (14)	0-27.3 (9.6)
Hog compost	6-301 (101)	35-623 (232)	0-7.0 (1.9)	3-8,486 (898)	3.5-176 (32)	0.5-60 (17)	1.5-113 (18)
Cow compost	14-225 (82)	51-308 (152)	0-3.7 (1.36)	3.1-314 (39)	4.3-18.6 (11)	1.6-19 (7.4)	0.3-24 (13)
Bark compost	22-52 (34)	77-216 (127)	2-5.6 (3.4)	21-46 (28)	12-31 (23)	13-34 (23)	0.9-65 (25)
Compound compost	2.4-234 (38)	5-814 (163)	0-5.6 (1.2)	2-9,196 (469)	2.4-92 (18)	0-150 (11)	0-57 (13)

*Mean value
Source: Lian and Lee 1994

7.3.9 Distribution and use of composts

The major reasons for non-adoption of rice straw composting include time-consuming interference with various farming activities, difficulty in applying, and burning as a convenient method of disposal. In addition, there are some problems in both quality and handling of standard animal waste composts, namely: content of fertilizer nutrients and fertilizer efficiency are unclear and their seasonal measurement fluctuates notably; maturity of compost is indefinite; special spreader machine and large storage space are necessary, as well as high forwarding charges, because the specific gravity of compost is small and the moisture content is usually high. To solve these problems, the following criteria must be set (Hara 2001):

- Production of high-quality animal waste composts that fit the needs of the cultivating farms by guaranteeing the quality and fertilizer efficiency, and adjustment of the content of plant nutrients of the compost produced for the cultivating plant.
- Production of animal waste composts which can withstand distribution over distances by decreasing the volume and moisture content of produced compost.
- Production of animal waste composts which can be spread easily.
- Creation of manuals of animal waste compost fertilization.
- The handling of animal waste compost, which is produced in granular or pellet form, is better than that of conventional compost.

7.3.10 Shelf life

The major consideration under this item is how to prolong the shelf life of the compost for agricultural applications by the inoculation of biological microbes.

7.4 Inoculation of microbes

Microbes can dissolve insoluble phosphate compounds in soils, fix nitrogen to biomass from the air, mineralize organic compounds to release nutrients, and secrete plant growth-promoting substances. Inoculation of appropriate microbes into composts could improve the quality of composts and shorten the period of maturity. Inoculation of phosphate-solubilizing *Klebsiella pneumoniae* subsp. and nitrogen-fixing *Azospirillum brasilense* into the compost of livestock wastes and mushroom waste media increased the soil phosphate and nitrogen concentrations, and the growth of kale, cabbage, and corn. Inoculation of *Rhizobium japonicum* and *Bradyrhizobium japonicum* for nitrogen fixation supported the growth of food crops and legumes, and increased the yields of soybean, peanut, and alfalfa by 6-21%, 25-69%, and 123-179%, respectively (Kang and Ha 1994; Chien 2001).

The application of microbial inoculants as microbiofertilizers can accelerate the decomposition of organic residues in various processes with a concomitant release of plant nutrients through mineralization; facilitate the uptake of plant nutrients (e.g., mycorrhizal association); increase the nitrogen content of plants through symbiosis (e.g., *Rhizobium*) and other associative N_2-fixing systems (e.g., *Azospirillum*); and improve plant growth and vigor by providing plant growth-promoting substances. The well-nodulated legumes reduce soil erosion and increase soil fertility. The young rubber trees also benefit from the mineralizable nitrogen released during the decomposition of the legume residue. Nitrogen fixation by *Azorhizobium*, *Azospirillum* in association with several plants had been well documented: maize, kallar grass, sorghum, millet, sweet potato, and oil palm. It increased the number, yield, and nitrogen concentration of the crops. Inoculation with VAM (vesicular-arbuscular mycorrhiza) had also been found in rubber, cocoa, *Calopogonium caeruleum*, chili, and groundnut. *Bacillus pumilus* could decompose cellulose and grow at high temperature (Shamsuddin 1994).

In Taiwan, nitrogen-fixing microbes, *Rhizobium*, had been applied in lupins, alfalfa, peanuts, crotelarias, and soybeans to increase crop yields; phosphate-solubilizing bacteria, *Bacillus*, had been used to improve the phosphate availability in the soil; VA-mycorrhizal fungi, *Glomus*, had been inoculated to enhance the nutrition of the host plant (Chang and Young 1992; Tseng *et al.* 1993; Young 1994; Chang *et al*. 2001). For the inoculation of microbes for biofertilizer preparation, it is necessary to investigate the following items: 1) selection of effective and competitive biofertilizers for the crops; 2) inoculant production and application to the field to ensure the benefits of plant-microorganisms symbiosis; 3) study of microbial persistence of biofertilizers in soil environments including stresses on production; 4) agronomic, soil, and economic evaluation of biofertilizers in agricultural production; and 5) study of rhizosphere environment and microbial interaction.

The quality of the municipal solid waste compost could be improved by inoculation with beneficial microorganisms such as antagonists. Inoculation of non-pathogenic *Pseudomonas* spp. to control *Pythium* and *Sclerotium* in tomatoes reduced the damage intensity by the pathogen from 63.0% to 38.9% and from 41.7% to 16.7%, respectively (Iswandi 1994a, b). Antagonistic fungi *Gliocladium frimbiatum* or *Trichoderma hamatum* inoculation into municipal solid waste compost inhibited the *Rhizoctonia*, *Sclerotium, Pythium*, and *Fusarium* diseases in peanuts (Sinaga 1992). Inoculation of non-pathogenic *Pseudomonas* spp. LIES and LD reduced the infection of peanuts by *Sclerotium rolfsii* (Iswandi 1994b).

Inoculation of *Trichoderma* sp. SS_{33} into the compost hastened the decomposition of rice straw-chicken manure mixture, *Azotobacter* sp. H1BFA 4b promoted the biological nitrogen fixation and enriched the nitrogen content, and *Trichoderma-Azotobacter* increased the decomposition rate and nitrogen fixation activity. The biofertilizer prepared with the inoculation increased the soil nitrogen, phosphate, potassium, organic matter, and rice yield (Espiritu and dela Torre 2001).

7.5 Values of composts

Composts are considered substitutes for chemical fertilizers. Compost amendments increased cation exchange capacity, buffering capacity, chelating capacity, soil aggregation, aggregate stability, water-holding capacity, soil porosity, water infiltration, water percolation, nutrient availability, and earthworm population; they decreased soil crusting, bulk density, and plant pathogens. In addition, compost application alleviated acidic and alkaline conditions, and stimulated beneficial microorganisms to produce polysaccharides and/or antibiotics (Parr *et al.* 1994). Among the other values of composts are animal feed, water gain, soil conservation, and soil-carbon sequestration.

The values of four common composts (i.e., cattle manure, crop residues, sewage sludge, and municipal solid wastes) based on their average macronutrient contents are shown in Table 9. The important consideration is good quality composts and residues. Biofertilizers and soil conditioners have far greater values than just their macronutrient contents. These materials have a much greater residual effect on soil tilth and fertility than most chemical fertilizers because of the slow-release character of their nitrogen and phosphorus components. Colacicco (1982) estimated that the cumulative agronomic and economic value of some organic materials applied to agricultural soils could be more than five times greater in the post-application period than the value realized during the year of application. Application of compost improved the development of root systems, increased the diversity of root fungal flora, promoted the growth of plants, reduced the incidence of soil-borne diseases, and depressed the propagation of pathogens (Nitta 1994).

7.6 Effects of composts on crop yields and soil qualities

Application of compost to the soil improved the soil organic matter, P, and Zn contents. The average organic matter, P, and Zn contents of compost application were 2.85%, 8.14 ppm, and 3.53 ppm, respectively; while the values of farmers' practice were 2.18%, 6.14 ppm, and 2.62 ppm, respectively. In addition, rice plant with compost application contained higher N, P, and Zn than that of farmers' practice. More recently, soil quality includes soil productivity, food safety and quality, human and animal health, and environmental quality (Parr and Hornick 1992; Evangelista 2001).

The yields of cabbage in a cattle compost plot with 1.0, 2.0, and 3.0 N application rates were 55-61%, 75-82%, and 84-91% as those with chemical fertilizer application, respectively; while the yields of rice at first crop season were 72-74%, 80-83%, and 88-91% as those with chemical fertilizer application, respectively (Huang and Lin 2001). The relative N efficiencies of compost for cabbage and rice were 0.219-0.329 and 0.254-0.292, respectively. N-value in compost of cattle manure had about 25% of chemical fertilizer. The relative N-value of chicken manure was the highest with 0.37 of chemical fertilizer in rice cultivation, cattle manure (0.34) was the second, and hog manure (0.32) was the lowest. In cabbage cultivation, hog manure (0.37) was the highest, chicken manure (0.29) was the second, and cattle manure (0.25) was the lowest. In peanut production, cattle manure (0.21) was the highest, hog manure (0.19) was the second, and chicken manure (0.11) was the lowest (Table 10). Mineralization rate and amount of N-release varied with soil texture and kind of manure. However, N-value of compost increased gradually year by year in continuous application conditions. Soil Zn contents in all compost plots were higher than those in chemical fertilizer plots. The hog manure compost plot had a higher Cu accumulation (Huang and Lin 2001).

When composts and residues are applied to soils, many of the introduced microorganisms can function as biocontrol agents by controlling or suppressing soil-

Table 9. Values of some organic wastes based on their macronutrient contents.

Organic waste	Nutrients N	P %	K
Cattle manure	4.4	1.1	2.4
Crop residues	1.1	0.2	2.0
Sewage sludge	4.0	2.0	0.4
Municipal solid wastes	0.7	0.2	0.3

Table 10. Relative N efficiency of cattle manure compost.

Year	Crop	Rate of compost-N application (kg N/ha)			
		0	240 (160)*	480(320)	720(480)
1995	autumn cabbage	0	0.2917	0.3021	0.2472
1996	autumn cabbage	0	0.3208	0.3438	0.2847
1997	autumn cabbage	0	0.3542	0.3417	0.2750
1998	autumn cabbage	0	0.3625	0.3229	0.2764
1995	spring paddy rice	0	0.2438	0.1969	0.1958
1996	spring paddy rice	0	0.3375	0.2688	0.2583
1998	spring paddy rice	0	0.2688	0.2781	0.2500
1995	summer paddy rice	0	0.3063	0.3344	0.3021
1996	summer paddy rice	0	0.3688	0.3781	0.3188
1997	summer paddy rice	0	0.3813	0.3156	0.2583

*Value in parenthesis present for paddy soils.

Table 11. Fertilizer N efficiency.

Nitrogen source	Fertilizer efficiency (kg rice kg-1 N applied)
Azolla	3
Fresh rice straw	2
Azolla compost	3
Rice straw compost	7
1/2 Azolla + 1/2 urea	9
1/2 fresh rice straw + 1/2 urea	5
1/2 rice straw compost + 1/2 urea	3
Supergranulated urea	10
Urea	10

borne plant pathogens through their competitive and antagonistic activities (Kloepper *et al.* 1989). The possible mechanisms are the shifts in soil microbiological equilibrium following the addition of microbial inoculants and organic amendments. These include antibiosis, competition, parasitism, detoxification, and inhibition.

7.7 Microbiology of composting

Various microorganisms participate in composting, and the microflora population changes successively at different stages of composting. In the early stages of composting, mesophilic bacteria and fungi are dominant and consume sugar, starch, and protein. As the temperature rises above 40°C, these 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. In other words, sugar and starch are the first to decompose during composting, followed by hemicellulose, and, finally, lignin. During the composting of sewage sludge, the number of mesophilic actinomycetes and fungi was around 10^2 cells g^{-1} of dry compost (Kubota and Nakasaki 1994).

Inoculation or seeding has been reported to be effective in some composting procedures. On the other hand, some negative results have also been reported about inoculation. The rate of composting of sewage sludge is mainly controlled by the degradability of the solid substrate, and not by the kinds of microorganisms inhabiting the compost. The seeding of compost products at the beginning of sewage sludge composting is unlikely to have any appreciable effect on the rate of composting or on the quality of the final product. However, the contribution of thermophilic bacteria and thermophilic actinomycetes to the CO_2 evaluation rate depends heavily on the amount of inoculum added. In the fertilizer N efficiency, *Azolla* and *Azolla* compost score 3 kg rice per kg N applied as compared with 10 for urea and supergranulated urea (Table 11). However, 1/2 *Azolla* + 1/2 the recommended rate for urea increased fertilizer N efficiency to 9, which is comparable to that of urea (dela Cruz 1994).

7.8 Odor control

7.8.1 Ventilation

Many of the materials used for composting are liable to become putrid and stinky. These materials are readily decomposed by microorganisms. Ventilation should provide enough air to avert anaerobic conditions during the temperature build-up stage, but should not remove so much heat that temperatures cannot rise to biologically inhibitive levels. Vacuum has been used as an odor-control measure, so that the exhaust gas can be vented through a scrubber pile. This involves placing a water condenser trap between the composting mass and the scrubber pile. In tests which applied this method, materials composted at the highest temperature gave off the most unpleasant odor, while materials composted at the lowest temperature were judged the least unpleasant. Temperatures which maximized the decomposition rate gave a final product with the least odor.

7.8.2 Biofiltration

Biofiltration involves passing an odorous airflow through a layer of filter material (compost, filamentous peat, etc.), followed by the biodegradation of the captured odor components. The odor components are transferred from the gas to the liquid and solid particles in the filter material. The microbial degradation of the odor components then takes place on these particles. The pressure drop across the biofilters depends not only on the applied air load, but also on the nature and the composition of the filter material.

7.9 Evaluation of compost maturity

Compost maturity is important in assessing both the quality of the end product and its possible uses. Some uses require very mature compost (horticulture, market gardening, plant nurseries, etc.). Others require fresh compost (hot beds in the greenhouse and for mushroom production, etc.). Fresh compost generates heat, while mature compost prevents any adverse effects on plants from the heat of decomposition, a high C:N ratio, or phytotoxic compounds.

Several parameters are available which indicate compost maturity. These include temperature; odor; texture; C:N ratio; pH value; gas production; cation exchange capacity; level of ammonium, nitrate, and immobilized nitrogen; total organic carbon; level of hydrogen sulfide; polysaccharide; adenosine triphosphate; chromatographic tests; colorimetric tests (after extraction of humic components); polymerization of humic substances; hydrolase activity; respiratory activity test; behavior of earthworms; and phytotoxicity tests (germination and growth tests) (Table 12). Although many methods have been proposed, none of these have been pursued far enough to allow full appreciation of their potential value.

7.9.1 Temperature

A temperature rise is necessary not only to accelerate the decomposition of organic constituents, but also to inactivate harmful organisms. Swine manure reached a maximum temperature of 74°C and had an average temperature of 50°-70°C over more than two weeks in a container with a volume of 120 L. In a container of only 12-70 L, the maximum temperature was only 56°-58°C, and temperatures higher than 50°C lasted only two to six days. A temperature higher than 70°C does not favor the growth of fungi in the compost and reduces the rate of decomposition. Therefore, the volume of the different substrates used for composting should be adjusted to give a maximum temperature of around 70°C and temperatures higher than 50°C for more than two weeks. With appropriate aeration, the temperature of swine manure increased on the second day and remained at 50°-70°C for more than two weeks. After 17 days of composting, the volume of the substrate had fallen by 30%. If the compost was not aerated, the maximum temperature was lower than 60°C, and temperatures mainly ranged from 40° to 50°C. Temperatures in the upper layer were higher than those in the middle and bottom layers. Temperature fluctuations in different parts of the substrate were not significantly different in either case.

The maximum temperature of pig farm sludge during composting exceeded 68°C. After 30 days' incubation, the fermented sludge had become good-quality compost (Fu and Chen 1990). The maximum temperature of a mixture of bagasse and swine manure was 63°C, while temperatures remained between 50° and 60°C for more than one week. In the case of a mixture of bagasse and alcoholic slops, the maximum temperature was 60°C, while temperatures remained above 50°C for only two or three days (Huang *et al.* 1994). Straw undergoes rapid decomposition when temperatures reach around 70°C, although not as rapidly as animal wastes. When straw had been chopped and placed in a pile for 55 days, temperatures reached their maximum level on the third day, and remained at 60°-65°C during incubation. Temperatures rose again when the substrate was turned, but over time, the maximum temperature gradually decreased.

When pig farm sludge was composted with rice hull, the temperature increased to 62°C on the second day, eventually rising to a maximum of 68°C. When the same sludge was mixed with composted pig manure and made into compost, the maximum temperature was 74°C on the second day. In both cases, temperatures remained above 55°C for two weeks. The temperature of compost with mushroom growth medium and chicken manure, soybean residues, bone meal, swine manure, urea, or calcium superphosphate is 50°-60°C for three weeks during incubation. Turning the compost will stimulate the decomposition of organic matter and produce heat from the fermentation (Lin 1994).

7.9.2 Odor

Mature composts should smell like forest soil (typical soil odor is caused by actinomycetes). Soil smell is primarily the result of two gases, geosmin and 2-methylisobornol, which are by-products of fungi and actinomycetes. If these two gases are present in

Table 12. Evaluation of the change in composting.

Parameter	Condition for stability	Reference
Fermentation condition		
Temperature	Stable	Stickelberger 1975
pH	Alkali (anaerobic, 55°C, 24 h)	Jann *et al.* 1959
Thermogram	Stable	Owa 1994
Microscopy		
Direct count	Biomass	Jone and Mollison 1948, 1990
Image analysis	Biomass, residue	
Microbes	Decrease, stable (thermophilic)	Citenesi and de Bertoldi 1979
Composition		
COD	COD < 700 mg/g dry compost	Lossin 1971
Soluble COD	Stable	Yang *et al.* 1993
Soluble BOD	Stable	Yang *et al.* 1993
C:N ratio	< 20	Juste 1980
Initial N/Final N	< 0.75	Juste 1980
TOC/TON in aqueous	5-6	Chanyasak *et al.* 1982
Immobilized nitrogen	<1.56% (dry weight basis)	Wang 1978
Ammonia	Absence	Spohn 1978
ATP	Decrease, then stable	Colin 1977
Ash	Increase, then stable	Yang *et al.* 1993
Organic acid	Stable	Owa 1994
Cellulose, hemicellulose	Stable	Inoko *et al.* 1979
Reactive-C	Stable	Zhang *et al.* 1992
Microbial or enzyme activity		
Respiration rate	< 10 mg CO_2/g compost (7 days)	Morel *et al.* 1979
	< 7.5 mg CO_2/g compost (7 days)	Germon *et al.* 1980
	< 2 mg CO_2/g compost/d (very stable) 2 mg-5 mg CO_2/g compost/d (stable) 5 mg-10 mg CO_2/g compost/d (moderately stable) 0 mg-0.5 mg O_2/g VS/h (very stable) 0.5 mg-1.0 mg O_2/g VS/h (stable) 1.0 mg-1.5 mg O_2/g VS/h (moderately stable)	Epstein 1997
Methane emission	Decrease, then stable	Chen *et al.* 2003
Color	Darkish brown, 1<Y<13	Sugahara *et al.* 1982
Odor	Earthy	Chanyasak *et al.* 1982
Geosmin, 2-methylisoborneol	Present	Becker 1995
Headspace gas	Stable	Wang and Tzeng 1986
NO_2^-/NO_3^-	Nitrification start	Finstein and Miller 1985
Reductant	Disappear	Spohn 1978
Organic acid	Disappear	Chanyasak *et al.* 1982
Sugar		
Easy hydrolyze polysaccharides	30 mg-50 mg glucosides/g weight	Morel *et al.* 1979
Reducing sugar/total sugar	< 35%	Inoko *et al.* 1979
Total organic carbon-soluble sugar-fermentation time	I. D. *<2.4 stable, while I. D.< 27 unstable	Morel *et al.* 1979
Humic substances		
Humic carbon/total carbon	>5%	Watanabe and Kurihara 1982
Alkali soluble humic substance	> 110 mg/g total organic substance	Witt 1982
Filter paper method	Dark in center, light in surround, and irregular margin	Hertelendy 1974
UV spectrophotometry	Absorbance of alkali extract is stable	Morel 1982
Gel chromatography	High molecular weight	Kubota and Nakasaki 1994
Near infrared spectroscopy	Correlating to total carbon, total ash, nitrogen, cellulose, hemicellulose, CEC, and lignin contents, and germination index	Harada 1995
Cation exchange capacity	> 60 cmol(+)/kg ash free matter	Harada *et al.* 1971
Hydrolase	Increase very slow and stable	Colin 1977
Bioassay		
Germination test	G. I. **>50	Zucconi *et al.* 1981

*I.D. = 3.166-(0.111 AGE)+(0.059 TOC)+(0.832 pHs), AGE=Day of fermentation, TOC=Total organic carbon, PHs=Hot water soluble sugar

**G.I. = Germination index.

compost, it is possible that they could be used to determine maturity (Becker 1995).

7.9.3 Microcalorimeter analysis

The promotion effect in the decomposition of organic matter was evaluated by analyzing the thermogram. The decomposition of compost was promoted by the addition of microbial materials (Owa 1994).

7.9.4 Biomass production

Three kinds of parameters may be used for determining the maturity of composts: respirometry, analysis of the biodegradable constituents (total organic carbon and polysaccharides), and biochemical activity (ATP and enzyme activity).

1. *Respirometric methods*

Respirometry measures the oxygen uptake or carbon dioxide emission, either in pure compost or in compost mixed with soil. It indicates a marked drop in respiratory activity as the compost matures. Compost is considered relatively mature when the respiration rate is less than 5 mg CO_2-C/g compost C. Rates over this amount reflect different stages of immaturity. Oxygen uptake and composting time have a significant negative correlation. Oxygen uptake less than 1.0 mg O_2/g VS/h is considered relatively mature (Owa 1994; E&A Environmental Consultants 1994). Methane emission from compost below 0.4 mg m^{-2} h^{-1} can be used as the index of maturity (Chen *et al.* 2003).

2. *Degradable organic substances*

A number of physico-chemical parameters are useful indicators because of their high correlation with compost degradability. The correlation between the respiration of a soil and compost mixture, and the dry matter production of ryegrass in a similar mixture, allows us to define two classes of maturity. Compost with a value of less than 2.4, corresponding to a low rate of respiration in the soil and compost mixture, may be considered mature. At the other end of the scale, a value of more than 2.7 shows that the compost is still highly degradable and will stunt vegetable growth, so, therefore, is not mature (Morel *et al.* 1979).

3. *Biochemical parameters*

The concentration of ATP and the hydrolytic enzyme activity (proteolytic, amylolytic, and cellulolytic activities) can be used as indications of compost maturity.

7.9.5 Chemical analysis

During composting, the organic constituents undergo transformations, which lead to biologically more stable components. Apart from the loss of total organic carbon and easily degradable components, an increase in highly polymerized organic products may be found. Total organic carbon, C:N ratio, polysaccharide content, and state of humic substances can all be considered suitable measurements of compost maturity. In addition, cation exchange capacity, water-holding capacity, and ash content may be useful parameters for determining maturity.

1. *Total organic carbon and C:N ratio*

As composting proceeds, the carbon content falls, while the nitrogen content increases, so that the C:N ratio falls. The C:N ratio changes with the ageing of compost, finally reaching values which are characteristic of a stable organic material. The maturity of compost made from urban refuse could be defined in two classes according to the organic matter/nitrogen ratio: semi-mature urban compost (OM:N < 60) and mature urban compost (OM:N < 50). Organic matter content was ≥20 g/100 g dry matter (Owa 1994). As Juste and Pommel (1977) indicated, it is preferable to keep a constant check on changes in the C:N ratio during fermentation rather than measure these occasionally. The C:N ratio and the final C:N/ initial C:N ratio provide good indications of the maturity of compost.

Swine manure has a low C:N ratio, a high bulk density, and poor aeration. The addition of straw and corncob to the swine manure will improve all three factors, while the addition of carbon and phosphate will improve the composting process. The C:N ratio of compost made from chicken manure, swine manure, soybean cake, and mushroom growth waste medium fell from 30 to 15 during composting (Lin *et al.* 1994). Composted swine manure contained 2.8% N, 1.7% P_2O_5, 0.23% K_2O, 86% organic matter, 349 mg kg^{-1} Zn, and 140 mg kg^{-1} Cu (Wang *et al.* 1992). Compost made from husk and bark has a C:N ratio of around 35, and may have certain quality problems. Although bark contains a high level of N, Ca, and K, it also has a high level of phenolic compounds (Table 2). Tobacco leaves and tobacco factory wastes had a high content of nicotine as well as of N, K, Ca, and Mg. Composting to reduce the nicotine content was therefore necessary (Hsieh and Hsu 1993).

The bulk density and water-holding capacity, and the levels of ash, total N, and 1.0 N HCl insoluble nitrogen increased in the course of composting corncob, while the total C and C:N ratio decreased (Chung *et al.* 1993). The bulk density of soil amendments and composts was ≥20 g/100 g dry matter (Owa 1994).

2. *Nitrate content*

In the earlier stages of composting, ammonium is produced by the decomposition of nitrogenous compounds such as protein. As the compost matures, the ammonium is oxidized into nitrate by the action of ammonium-oxidizing bacteria and nitrate-oxidizing bacteria. Consequently, nitrate accumulates in the mature compost. The presence of nitrate can be detected with diphenylamine. A diphenylamine solution dissolved in concentrated sulfuric acid is added to water extracted 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 manure compost but not of swine manure compost and poultry manure compost, which produce only a very small quantity of nitrate even when they are mature.

3. Organic matter content

During composting, the organic matter content decreases, while the ash content increases. The organic matter content remains constant when the compost is mature and stable. Swine manure and cattle manure take three to four weeks to become stable, while stabilization of chicken manure takes two weeks. The decomposition of organic matter during the composting process is characterized by the changes in residual rate (i.e., the percentage of organic matter which remains compared with the original amount). Poultry wastes are more easily decomposed than those of cattle and pig. The decomposition rate of cattle wastes is similar to that of pig wastes.

4. Polysaccharides

When composting begins, the simple polysaccharide content of urban refuse is high (20% of the total organic material). However, this falls to only 4-10% after 240 days. Water-soluble polysaccharides undergo a similar change. Simple polysaccharide components, therefore, are progressively decomposed by microflora during the different stages of thermogenesis and maturation. Water-soluble sugars, consisting mainly of mono- or di-saccharides, disappear much faster than hydrolysable sugars. Genuine polysaccharides, however, take far longer to decompose because of their structure. At the end of the composting period, the quantity of polysaccharides extractable in acid is relatively high. This seems to correspond with newly synthesized stabilized microbial components rather than fractions, which are not yet decomposed.

5. Ash content

The ash content of the substrate is a constant value during composting. Organic matter decomposition leads to a relative increase in the ash content. Therefore, the ash content of the substrate in relation to the total weight of the substrate can be used as a parameter of the maturity of the compost. Compost maturity based on ash content is calculated as follows:

$$Wt = Wo\,(1 - Ao\%/At\%)$$

where Wt = weight of substrate at time t
Wo = weight of substrate at time zero
At = ash content of substrate at time t
Ao = ash content of substrate at time zero
(1 - Ao%/At%) = the degree of maturity

6. Cation exchange capacity (CEC)

The negatively charged CEC of organic matter increases as compost matures. Conventional CEC tests used for soil are not suitable for compost samples. Harada (1995) had developed a suitable and simple method to determine the CEC of compost. The CEC of composted cattle manure increased to 110 cmol(+)/kg over 4-5 weeks, and thereafter remained constant. A highly significant correlation was observed between the CEC and the 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. 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. The CEC of organic amendments and composts was <50 cmol(+)/kg dry matter (Owa 1994).

7. Organic acid generation

Acetic acid, propionic acid, and butyric acid generated with decomposition of organic matter were measured. The concentration of acetic acid in soil solution was increased by the addition of biological soil amendments and composts.

8. pH

Changes in pH have been noted to occur during the composting period and, therefore, have been considered as a possible indicator of biological activity. Generally, the pH drops during the very early stages of composting and then increases to a range of 6.5-7.5. Acid pH values indicate a lack of maturity due to short composting time or occurrence of anaerobic conditions.

9. Organic chemical constituents

Cellulose content yields a good index of the degree of maturity of the compost. Cellulose decreased with duration of composting. Inoko *et al.* (1979) reported that hemicellulose and cellulose (reducing sugars) decreased from about 36% of the total dry weight to about 20% after 60 days. Amino acids and low fatty acids greatly decreased during the composting of refuse and garbage. Zhang *et al.* (1992) suggested that reactive carbon decreased from 33 mg/100 mg sample to about 11 mg/100 mg for 160 days of composting.

7.9.6 Chromatography test

The chromatography test uses humic substances, which are extracted from the compost and isolated using a filter paper. The slightly polymerized components move towards the periphery of the filter paper, while the highly polymerized components stay at the center. Chromatograms are read by the shape and color of three separate zones (Table 13). This technique is essentially qualitative, and gives a quick indication of the state of maturity of the compost. However, the interpretation of chromatograms may sometimes be difficult. It is quite simple to classify compost from the same plant, so the chromatography test is very suitable for compost control when the raw material is known to be homogeneous. Paper chromatograms showed that the time needed for compost to reach maturity was around 10 days in the case of chicken manure, 15 days for swine manure, and 14-21 days for sludge from pig farms (Lin 1994).

Gel chromatography, monitored by UV absorbance at 280 nm of the water extracted from solid samples during composting, can also be used for the evaluation of maturity. Compounds with a relatively high molecular weight correspond to the peak with the least-elution volume. During the composting of sludge, organic compounds in the water extract changed to those with a high molecular weight (Fig. 1). Gel chromatograms, using Sephadex G-15 gel and a compost of mixed urban waste and bark, gave different results. The UV 280 nm absorbance of the relatively high molecular weight compounds, corresponding to the peak with the least-elution volume, increased considerably in one-week-old compost, indicating that the organic compounds in the water extract had shifted to a higher molecular weight. On the other hand, the differences between compost samples after 1 week, 2 months, and 3 months of composting were small (Kubota and Nakasaki 1994).

7.9.7 Humification parameters

Humification ratio was the percentage of total extractable humic-C as related to the total organic-C. Inbar (1979) reported that the total content of humic material extracted from separated cattle manure compost increased from 377 g/kg to 710 g/kg organic matter. Humic material increased rapidly during the first 60 days, and from 60 to 140 days, a very gradual change was noted.

7.9.8 Colorimetric method

Mature composts should be dark-brown to black regardless of the feedstock. Alkaline extraction of the organic material from compost has a brown hue in a range of shades, depending on the age of the compost. The hue is light at the beginning of composting, and tends to darken as the compost matures. These color variations provide the basis for a test to determine maturity, using periodic measurements of the optical density of alkaline extracts from the product. This technique does not require sophisticated equipment, and can easily be used by composting plants. The compost has reached maturity when the optical density of the alkaline extract remains a stable tint.

The 2N KCl extract of composts at different stages was eluted with TSK HW- 55(F). The absorbance at wavelengths of 235 nm, 280 nm, and 490 nm is shown in Fig. 2. The absorbance of raw substrate was very low in all tests, while the absorbance of compost after 17 days' incubation at wavelengths of 235 nm and 280 nm was high. The molecular weight of composted pig manure was around 100,000, while it was only around 10,000 for the control. Molecular weight with the absorption at wavelengths of 235 nm and 280 nm increased as composting continued. There was no significant difference between a supplement of 5% sludge in swine manure, and one of 10%. The odor was the same in both treatments. The color changed from yellowish to darkish brown after 40 days' incubation. The absorbance at wavelength 490 nm represents the humic substances. The absorption of the extract of compost at 490 nm was very weak before 17 days' incubation, while the absorption peak was high after one-month incubation. Therefore, absorption at a wavelength of 490 nm can be used as a parameter for the presence of humic substances and the degree of stability of compost (Sheen and Wang 1994).

7.9.9 Near infrared spectroscopy analysis

A rapid estimate of the quality of cattle waste compost can be obtained by using near infrared spectroscopy analysis. The levels of total C, total N, ash, cellulose, hemicellulose, and lignin of the compost, and its CEC, can be measured by this method. Its biological activity, in terms of inhibition of seed germination, was assayed using *Brassica rapa* seeds, and an attempt was made to estimate this by near infrared spectroscopy.

Table 13. Chromatograms of organic wastes during composting.

Chromatogram	Fresh compost	Mature compost
Center	White to pink	Red to violet
Transition zone	Rings	Irregular outline
Periphery	Brown	Clear with jagged edges

Source: Morel *et al.* 1985

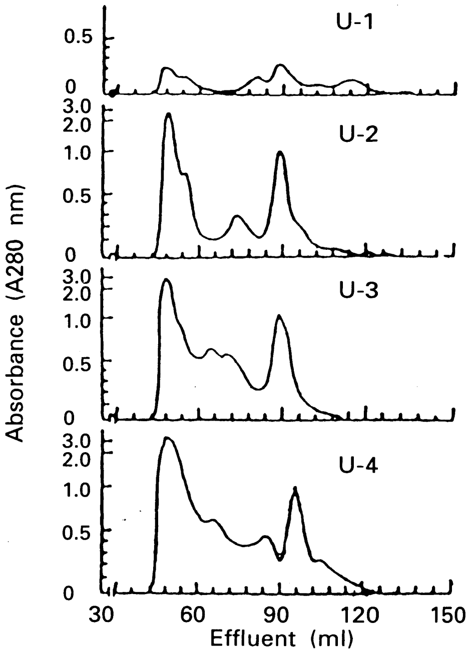

Fig. 1. Change in gel chromatograms for urban waste. U-1: Inlet of composting chamber; raw materials were bark and garbage in 1:5 ratio (volume); U-2: Outlet of the composting chamber after one week in the chamber; U-3: Second stage fermentation after about 2 months under windrow conditions; and U-4: Second stage fermentation at about 3 months (Kubota and Nakasaki 1994).

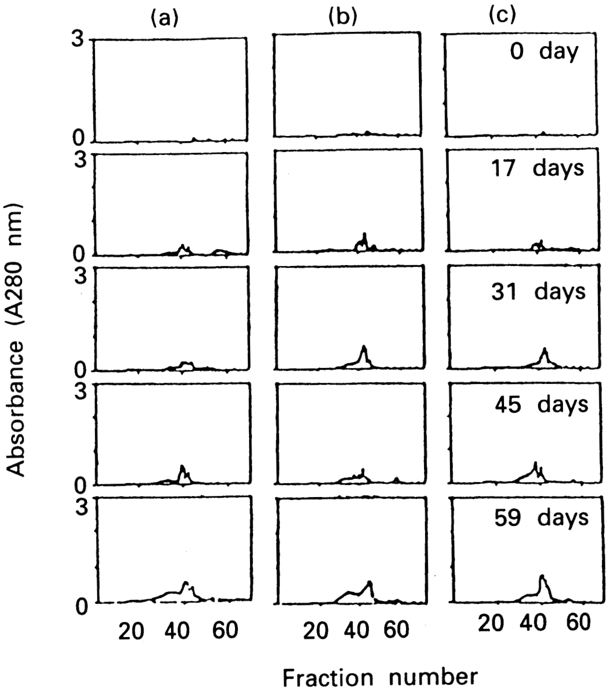

Fig. 2. Absorption spectra of the extract of compost at wavelength 280 nm: a) Pig waste and 10% sewage sludge; b) Pig wastes, 5% sewage sludge and 5% water; c) Pig wastes and 10% water (Sheen and Wang 1994).

Although the accuracy of the estimation was not high, at least severely inhibitory activity could be detected by near infrared spectroscopy (Harada 1995).

7.9.10 Volatile gases

During the composting of swine manure, the concentration of volatile gases is highest in the upper part of the pile and lowest at the bottom of the pile. After 40 days' incubation, the gas concentration remained constant, showing that the compost had stabilized (Sheen and Wang 1994).

7.9.11 Phytotoxicity test

This test shows the presence of phytotoxic properties in composted urban wastes. Two kinds of test plants, maize and bean, are grown in the compost, and their growth compared with that of plants growing in non-enriched peat with a pH raised by the addition of calcium carbonate. E&A Environmental Consultants, Inc. (1990) conducted a study using compost produced from municipal biosolids with eucalyptus or sawdust. Rooted plant cuttings of *Pittosporium tovira* were transplanted into pots containing compost soil mixtures.

7.9.12 Germination test

The analysis of metabolic toxicity may supply a wide range of information on the stabilization process, thus providing a useful instrument for industrial, agricultural, and environmental analyses. Germination tests are a simple and rapid type of bioassay, which can be quickly carried out with simple instrumentation. Cress (*Lepidium sativum* L.) is often selected as the test seed because of its rapid response (24 h). According to one study, maximum sensitivity is at 27°C and after 24 h incubation. This index has proved to be a most sensitive parameter, able to account for both low toxicity (10^{-7}M, or 25 ppb, abscisic acid) which affects root growth, and toxicity which affects germination (Zucconi *et al.* 1985).

Germination of cabbage seed was 50-80% in a composted mushroom growth medium, rising to 80-90% when the medium was composted with a mixture of chicken manure, swine manure, and soybean residues (Lin *et al*. 1994). The germination rate of cabbage grown in composted swine wastes was 88% (Fu and Chen 1990). Germination of radish seed on chicken manure before composting was 4.2%, rising to 91.6% after 10 days of composting, and 95.6% after 32 days of composting. This shows that composted animal wastes or crop residues can be used directly in the field without any damage to growth.

7.9.13 Conductivity

The level of electrical conductivity shows the overall salinity of the substrate. Early in the composting process, the salinity of compost made from wood shavings, and composted urban wastes and grape marc (skins and seeds left after pressing grapes for wine) compost was very high. Levels diminished progressively as composting proceeded. The level of electrical conductivity remained stable at a very low level in sewage sludge and bark compost. Changes in the conductivity do not always follow the same pattern in different piles, but in cases of excessive salinity at the beginning of composting, it defines the point after which the compost may be used. This parameter, which is easy to calculate, seems therefore worth taking into account during the preparation of compost. The electrical conductivity and cation exchange capacity of sewage sludge compost increased and the pH gradually decreased during incubation (Chung *et al*. 1992).

7.10 Conclusions

It can be seen that there are many methods available for assessing compost maturity. Some of these, such as the measurements of biomass activity, require complex laboratory equipment and are not suitable for small compost plants or farms. Others, such as the seed germination tests, are easily carried out with simple equipment and a minimum of scientific training. A major problem in the quality control of composts is the range of variability in the raw materials. Many of the testing methods available are suited to some materials, but not to others. Very few, if any, of the testing techniques described can be applied with equal success to the whole range of materials used in modern commercial compost production.

7.11 References

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