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Suzuki, Takeshi ; Ikumi, Yoshio ; Okamoto, Syo-taro ; Watanabe, Ikuo ; Fujitake, Nobuhide ; Otsuka, Hiroo

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Title: Aerobic Composting of Chips from Clear-cut Trees with Various Co-materials

Authors: Takeshi Suzuki*, Yoshio Ikumi[1], Syo-taro Okamoto[1], Ikuo Watanabe[2], Nobuhide Fujitake, Hiroo Otsuka

*Corresponding auther: fax:+81-78-803-5848 e-mail:tsuzuki@ans.kobe-u.ac.jp

Affiliations:

Faculty of Agriculture, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan

1 Graduate School of Science and Technology, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan

2 Kansai Electric Power Co., Inc., 1-7 Seika-cho, Souraku-gun, Kyoto, 619-0237, Japan

Abstract:

Swollen chips made from trees felled during clear-cutting were composted with various organic and inorganic materials in an aerobic composting reactor for five months and then piled for five months. The organic materials included chicken feces, urea, nitrogenous lime (calcium cyanamide, manure), and material rapidly composted from food garbage in 24-hour bacterial fermentation, while the inorganic materials

were coal ash and volcanic ash. In this paper, we first attempt to estimate the quality and degree of maturity of each compost from its chemical properties. Furthermore, we try to calculate the maturity of the fermented wood chip composts from their mixture ratio of the initial materials by multiple linear regression analysis.

We measured changes in the C/N ratio, nitrate nitrogen (NO_3-N) content, Percentage of humic acid in the alkali soluble fraction (PQ), cation exchange capacity, pH, and EC during the composting period. The degrees of maturity of the composts were estimated via a plant growth test using Chinese cabbage. We found that the CN ratio, NO_3-N concentration, and PQ were suitable for estimating the degree of maturity of wood chip composts. For maturity, the CN ratio should be less than 14, the PQ more than 66.2, and the NO_3-N concentration more than 853 mg kg^{-1}.

We devised an equation to estimate the degree of maturity after ten months by a multiple linear regression analysis from the mixing ratio of wood chips and the co-composted materials. From the multiple linear regression analysis, the above three indices of compost maturity could be estimated from the mixing ratio of the initial materials. This equation should enable us to determine the degree of compost maturity after ten months based on the initial mixing ratio.

Key words: wood chip, compost, coal ash, volcanic ash, chicken feces, index of maturity

1. Introduction

Currently, large tracts of forest are clear-cut to make way for construction projects such as hydroelectric power stations, substations, golf courses and so on. Much wood and lumber is discharged as waste from the cleared fields. These woody wastes are subsequently disposed of by burning. However, it would be preferable to dispose of them without combustion to avoid the release of carbon dioxide, one of the critical greenhouse gases. Instead of burning these woody wastes, we should recycle them as future resources. One solution to this problem is to make compost from the waste. However, wood chips are difficult to decompose because of the complex chemical structure of lignocelluloses. Previous efforts have developed methods of producing wood composts from such sources as bark (Kawada 1979) or saw dust and wood shavings (Fujiwara 1988, Zoes et al. 2001, Suzuki and Kumada 1976), as well as methods of estimating their maturity. However, there have been few reports on composting methods for wood chips. Moreover, there are no firmly established methods of determining the mixing ratio of the initial ingredients and estimating the index of maturity of the final wood chip composts.

Indices of compost maturity include temperature, C/N ratio (Golueke 1981), nitrate nitrogen (Finstein 1985), CEC (Harada and Inoko 1980), pH (Jann et al. 1960), the humic acid:fulvic acid ratio (Forster et al 1993), and so on. However, if the primary compost material is changed, these indices usually become inapplicable. The maturity of such composts and the period needed to reach maturity is not known. Moreover, the mixture ratio of chipped wood and co-materials is not known.

Coal ash is the major waste by-product of coal combustion in electricity-generating power stations throughout the world. However, in Japan only half of the coal ash is used efficiently, and the other half is dumped into the sea as waste. Recently, coal fly ash and bottom ash have been used as co-composting materials with paper pulp (Hackett et al. 1999), litter manure, sawdust pine bark (Brodie et al. 1996), and sewage sludge (Wong et al. 1997, Fang et al. 1999). Composting with coal fly ash reduces the availability of heavy metals and lowers the population densities of thermophilic bacteria (Vallini et al. 1999, Fang and Wong 2000). Although there are clear advantages to using coal ash as a resource, there have been no reports of using coal ash with wood chips. Another possibility is volcanic ash, which may have similar effects as coal fly ash because it is similar in form and elemental composition, aside from its pH and calcium content.

In this paper, we attempt to make compost from wood chips mixed with various organic and inorganic materials. We try to find a method for determining the degree of maturity from the chemical properties of these composts. Moreover, we estimate the finished composts' maturities from their mixing ratios by using multiple linear regression analysis.

2.Materials and Methods

2.1 Materials

The cut trees were collected from the area surrounding the Kanaihara hydroelectric power plant in Japan. This forest was a secondary forest and the community was consisted of a few species such as oak (*Quercus serrata* Murray, *Q. acutissima* Carruthers), Japanese cedar (*Cryptomeria japonica* D. Don), and holly (*Ilex pedunculosa* Miq.) etc. These trees were chipped by Tub Grinders TG525 (Vermeer® Manufacturing Company, USA), and the wood chips were crushed and swelled by a swelling machine (Taiyo Kogyo Corporation, Japan), which crushed them with a screw crusher under high pressure. Both the coal fly ash and the coal clinker ash were from the Electric Power Development Company Co., Ltd. at Takasago Thermal Power Plants in Japan, while the urea was purchased from Mitsui Chemicals and the nitrogenous lime (calcium cyanamide, $CaCN_2$) was purchased from Shin-Etsu Chemical Co., Ltd. Composted material from the food garbage of a restaurant was made with a rapid fermentation reactor for 24 hours. Volcanic ash was collected from the around Mt. Sakurajima volcano, Sakurajima Town, Kagoshima Prefecture, Japan, in April 1998, and charcoal was made by combusting driftwood gathered from the pond of Ochiai Dam in Nakatsugawa City, Japan. The chemical properties of these materials are listed in Table 1.

2.2 Fermentation methods

These swollen wood chips were mixed with various materials at the ratios given in Table 2. Each mixed material was introduced into a fermentation reactor (Youdo-kun, Taiyo Kogyo Corporation, Osaka, Japan) and fermented for five months. The columnar reactor dimensions were volume: 6 m^3; diameter: 2.2 m; height: 1.6 m.

This reactor has a blower unit that can recycle air from the top to the bottom of the reactor with a compressor (flow rate: 0.9 m^3 min^{-1}), and fresh air was blown into it from outside every 3 hours. This system enables the reactor to maintain the heat of the compost in the reactor without a turning process. After five months, the composts were removed from the fermentation reactors and packed in 1-m^3 flexible container bags. Then the bags were piled on a concrete floor for six months. The temperature of the composts increased from 60 to 70°C up to 16 weeks and gradually decreased until 5 months. The moisture content was maintained at between 60-70% throughout the composting period.

2.3 Analytical procedures

We measured pH while using a 10:1 distilled water:sample (w:w) ratio. Electrical conductivity (EC) was measured using a 20:1 distilled water:sample (w:w) ratio. Total carbon (T-C) and total nitrogen (T-N) contents were determined using a CHN analyzer (PE2400 series II CHNS analyzer, Perkin Elmer, Inc., Wellesley MA, USA), and ash content was determined from the difference between a dried sample and a combusted sample at 550˚C after 10 h. In addition, we measured the cation exchange capacity (CEC) by the barium acetate method (Harada and Inoko 1980). To determine the percentage of humic acid in the alkali soluble fraction (PQ), we employed a method that involves extracting a sample by boiling it in water with 0.1M NaOH for 30 min (Kumada 1987). The colored materials extracted were precipitated with concentrated H_2SO_4 and filtered. Next, the precipitates were washed with 0.05M H_2SO_4 and dissolved in 0.1M NaOH. The supernatant and precipitates were determined by the volume of 0.02M K_2MnO_4 consumed (Kumada 1987). The precipitation rate (PQ) was calculated by this equation:

$$PQ=a/(a+b)\times 100,$$

where a is volume of 0.02M K_2MnO_4 consumed by total humic acid, and b is volume of 0.02M K_2MnO_4 consumed by total fluvic acid

Nitrate nitrogen (NO_3-N) and ammonium nitrogen (NH_4-N) were extracted by 2M KCl and determined by the steam-distillation method (Mulvaney1996). Total P, K and Ca were measured by inductively coupled plasma emission spectrometry (ICPS-1000III, Shimadzu, Kyoto, Japan) after decomposition by HF and HOCl (Hossner 1996).

To determine of the maturity of compost, a seedling test was conducted using Chinese cabbage (*Brassica campestris*). Fifteen liters of test compost was mixed with

45 L of loamy sand soil, and then chemical manure was added to bring the N, P and K contents to 100 gm^{-3} in the form of $(NH_4)_2SO_4$, CaP_2O_5, and K_2SO_4, respectively. These mixed soils were placed in plastic containers (45x30x7 cm), and nine germinated seeds were planted and grown at 25˚C in a green house. A control test was conducted without compost. After the experiment began, the dry weights of the individual seedlings were recorded. The test was conducted in triplicate.

2.4 Statistical evaluation

We evaluated the analytical values by principal component analysis (PCA) using SPSS for Windows, version 11.5.1 (SPSS Inc.). The data were not transformed, and a correlation matrix between variables was used. Stepwise multiple linear-regression analyses were performed using SPSS for Windows, version 11.5.1 (SPSS Inc.).

3. Results and Discussion

3.1 Properties of compost after ten months

Table 3 shows the chemical properties of the composts after ten months of incubation. Compost made from only swollen chips (1) and compost made with material from food garbage (1F) were higher in carbon content but lower in CEC after ten months of incubation. These were immature composts because nitrogen starvation occurred during seedling experiments when the composts were added to soil (Table 3). The composts made from swollen wood chips and chicken feces (1Cs and 1Cw) were also immature after ten months of incubation, based on the results of the seedling tests. However, other chemical data were almost the same as those for composts that were fully mature. Therefore, these composts need to be fermented for a few months. Other composts seemed to be sufficiently mature, based on chemical data and seedling tests. These mature composts were made with ingredients that contained more than 15% nitrogen; therefore, it is necessary to add more than 15% chicken feces by volume or other nitrogen-rich ingredients to produce fully mature composts.

Larger quantities of chicken feces were added to 1Us2, 1Lw, 3Us and 4Uw, providing these compost samples after ten months of incubation with higher phosphorous and calcium concentrations than other samples. Moreover, the ratio of added chicken feces positively correlated with the contents of P_2O_5 (r=0.561, n=17, p<0.05) and CaO (r=0.698, n=17, p<0.01). These results indicate that the ratio of added chicken feces is suitable for phosphorous and calcium. Samples 1Lw, 2Ls and 3Lw, which contained nitrogenous lime, had higher pH values than other composts. The ratio of nitrogenous lime positively correlated with pH (r=0.493 p<0.05 n=17). The ratio of added coal clinker ash also positively correlated with pH values (r=0.673, n=17, p<0.01). The coal clinker ash is inclined to increase pH values, and Fang et al. (1999) reported that coal ash is good for adjusting the pH value of sewage sludge compost. Coal fly ash, on the other hand, didn't have any significant correlation with pH values in this study, due to the small amounts of added coal fly ash.

The contents of organic carbon co-composted with several inorganic materials (2, 3, 4) were lower than others because of the lower organic contents of ashes. The adding ratio of ash (coal fly ash, coal clinker ash and volcanic ash) was positively correlated with ash contents (r=0.766 n=17, p<0.01) and negatively correlated with organic carbon (r=-0.751, n=17, p<0.01). The quality of compost started in spring was compared with that of compost started in fall. However, there was no clear difference between them. Since the compost reactor used in this study maintained the compost's heat in the reactor, no clear differences were attributed to outside temperature.

Figure 1 shows a PCA ordination diagram of principal component 1 and component 2 of various compost samples from their final chemical properties. Group 1 consisted of wood chip compost with chicken feces and urea. The composts of group 1 (1Cs, 1Cw, 1Uw, 1Us and 1Us2) are assumed to have relatively high CEC, organic matter (high CEC, T-N, T-C), and high K_2O, which could originate from wood. However, 1L (composted from wood chips, chicken feces and nitrogenous lime) was not a member of group 1, due to its high CaO content originating from nitrogenous lime. Group 2 (2Us, 2Uw, 2Ls, 3Uw, 3Lw) consisted of chips composted with ash (coal fly ash, coal clinker ash and volcanic ash). The composts of group 2 are assumed to have relatively high pH, EC, and low organic matter. Group 3 consisted of other composts (1, 1F, 5U1, 5U2 and 1Us3). Both 1 and 1F were immature composts according to chemical data such as the CN ratio, content of NO_3-N, PQ value, and results of the seedling test. Although 5U1, 5U2 and 1Us3 were not immature compost samples, they were considered as different from other composts because of their relatively higher NH_4-N contents. These composts started composting during the high-temperature season (July), so more NH_4-N might originate from these composts than from others.

3.2 Indices of maturity

Table 3 shows chemical properties related to the maturity of composts and the maturity of compost estimated from seedling tests. The change in the CN ratios, the pH values, and the total carbon contents decreased according to composting time. In contrast, the total nitrogen, NO_3-N, PQ, CEC, EC and ash contents increased according to composting time in most composts. Therefore, these values may be used as indices of maturity. In particular, NO_3-N content, CN ratio and PQ are assumed to be good indices of maturity. Figure 2 shows the percentages of nitrogen starvation in samples of different values of chemical properties. The 95% composts whose CN ratios were less than 16 did not cause nitrogen starvation, nor did the 100% composts whose CN ratios were less than 14. The 95% composts with NO_3-N concentrations of more than 600 $mgkg^{-1}$ did not cause nitrogen starvation, nor did the 100% compost whose NO_3-N content was more than 900 mg kg^{-1}. The 95% composts whose PQ values were greater than 70 did not exhibit nitrogen starvation, and the 100% composts whose PQ values were grater than 75 did not cause nitrogen starvation. These results indicate that the CN ratio, NO_3-N content, and PQ are useful for estimating the degree of maturity of wood chip composts.

3.3 Multiple linear regression analysis

To formulate a prediction of maturity and estimate the contribution of co-composted materials to maturity, multiple linear regression analysis was carried out between the rate of the co-composted materials (Table1, n=17) as explanatory variables and the available indices of maturity (PQ, CN ratio, and NO_3-N content) after ten months as dependent variables.

Table 4 shows partial regression coefficients and multiple correlation coefficients. From the multiple correlation coefficients, these regressions were found to be significant at $P<0.05$. The decrease in the C/N ratio is attributed to chicken feces, composted material from food garbage, and the charcoal ratio. Chicken feces and urea both contributed to the increase in NO_3-N concentration; in particular, the urea contribution was about six times larger. Chicken feces also contributed to an increase in PQ, and again, the urea contribution was very high. However, the addition of fly ash caused PQ to decrease after ten months. All of these indices of maturity were affected by nitrogen co-materials such as chicken feces, urea and composted material from food garbage. These equations are useful for predicting the maturity of compost fermented after 10 months from the initial mixing ratio of the co-materials.

4. Conclusion

Swollen chips from clear-cut trees can be composted to maturity within ten months by co-composting with various materials. Chicken feces were effective for this purpose due to their CaO and P_2O_5 contents. Ash was also added to increase the ash content, pH and NO_3-N content. The indices of maturity of chip compost are as follows. The CN ratio was less than 14, while PQ was more than 65 and the NO_3-N concentration was higher than 500 mg kg^{-1}. Multiple linear regression analysis showed that chicken feces and urea are useful co-materials for achieving mature composts. The multiple linear regression analysis indicated that chicken feces, composted material from food garbage, and charcoal reduced the CN ratio, while chicken feces and urea increased NO_3-N content and PQ. The multiple linear regression enabled us to predict the maturity of final wood chip compost from the mixed ratio of the co-materials.

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Figure caption

Fig. 1. Graphic representation of the variables measured for each compost sample after ten months. (a) The variables (arrows) in a PCA ordination diagram, principal components 1 and 2. (b) The samples represented by sample name on the same PCA axes as in (a).

The arrow shows in which direction lies the greatest variance for the represented variable. The length of the arrow indicates the variance of the variable.

Fig. 2. Percentage of nitrogen starvations in all compost samples at different values of (a) NO_3-N concentration; (b) PQ; and (c) CN ratio.

Table 1 Chemical properties of composted material used at compost (dry weight basis)

Material	Water content (g kg^{-1})	pH	EC (dS m^{-1})	T-C (g kg^{-1})	T-N (g kg^{-1})	C/N ratio	Ash content (g kg^{-1})
Swelled Chipped wood	372	6.8	1.3	330	5.2	63.5	129
Chicken feces	159	8.1	10.0	194	20.6	9.4	375
Composted material from food garbage	115	6.5	7.2	449	38.3	12	99
Coal clinker ash	342	9.8	0.1	-	-	-	-
Coal Fly ash	3	11.4	2.2	-	-	-	-
Volcanic ash	4	5.8	0.9	-	-	-	-
Charcoal	275	7.9	0.2	748	2.9	258	27

-: Not determined

Table 2 Initial mixing ratio of co-composted material on a dry weight basis

Compost name	CW	CF	U	NL	CFG	CBA	CFA	VA	CC	Date of fermentated
1	100	0	0	0	0	0	0	0	0	1997/06/02-1998/04/02
1Cs	85.2	14.8	0	0	0	0	0	0	0	1997/06/02-1998/04/02
1Cw	82.6	15.0	0	0	0	0	0	0	0	1998/05/01-1999/03/12
1Us	85.0	14.4	2.9	0	0	0	0	0	0	1997/06/02-1998/04/02
1Uw	58.5	14.5	2.9	0	0	0	0	0	0	1998/05/01-1999/03/12
1Us2	45.5	22.1	2.2	0	0	0	0	0	0	1998/05/11-1999/03/12
1Us3	87.4	10.5	2.1	0	0	0	0	0	0	1999/07/16-2000/05/21
1L	69.3	25.6	0	5.1	0	0	0	0	0	1998/11/18-1999/09/20
1F	85.0	0	0	0	15.0	0	0	0	0	1998/11/18-1999/09/20
2Us	51.7	18.7	1.9	0	0	18.7	0	0	0	1998/05/11-1999/03/12
2Uw	85.0	19.7	2.0	0	0	19.7	0	0	0	1998/05/11-1999/03/12
2S	75.7	15.1	0	3.0	0	30.2	0	0	0	1998/05/11-1999/03/12
3Uw	69.3	20.9	2.1	0	0	0	20.9	0	0	1998/05/01-1999/03/12
3Lw	56.1	17.0	0	3.4	0	0	34.1	0	0	1998/11/18-1999/09/20
4Uw	60.7	21.8	2.3	0	0	0	0	21.8	0	1998/11/18-1999/09/20
5U1	73.7	12.0	2.4	0	0	0	0	0	12.0	1999/07/16-2000/05/21
5U2	79.2	9.5	1.9	0	0	0	0	0	9.5	1999/07/16-2000/05/21

CW: Chipped wood; CF: Chicken feces; U:Urea; NL:Nitrogenous lime; CFG: Composted material from food garbage; CBA: Coal bottom ash; CFA: Coal fly ash; VA: Volcanic ash; CC:Charcoal

Table 3 Chemical properties of composts

Sample name	Incubation period (month)	pH	EC (dS m^{-1})	T-C (g kg^{-1})	T-N (g kg^{-1})	C/N ratio	CEC (cmol$_c$ kg^{-1})	PQ	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	CaO (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_3- N (mg kg^{-1})	Ash content (g kg^{-1})	Maturity*
1	7	6.8	0.2	419	4.2	99.7	35.2	60.0	-	-	-	0	35	130	×
	10	6.3	0.8	371	5.4	68.7	30.7	42.1	0.8	1.6	6	4	23	113	×
1Cs	7	7.7	0.9	318	15.2	20.9	67.4	73.6	-	-	-	40	58	300	×
	10	7.9	2.6	289	15.0	19.3	67.3	58.1	11.9	14.2	51	6	23	257	×
1Cw	5	7.9	1.4	423	14.2	29.8	57.3	52.5	-	-	-	4	43	190	○
	7	6.9	5.5	391	18.6	21.0	72.4	52.7	-	-	-	9	27	283	×
	10	6.6	4.3	323	19.7	16.4	81.8	61.2	20.7	13.7	120	79	44	374	×
1Us	7	7.3	2	360	26.5	13.6	71.1	75.9	-	-	-	1	1821	210	○
	10	7.0	4.9	335	27.9	12.0	81.2	70.7	13.0	15.4	64	1470	84	238	○
1Uw	5	7.9	2.2	414	20.9	19.7	63.4	63.5	-	-	-	66	73	157	○
	7	6.8	4.9	392	19.3	20.3	73.6	59.6	-	-	-	40	20	226	○
	10	6.1	5.7	396	25.1	15.8	78.2	69.4	12.2	7.6	85	3564	72	282	○
1Us-2	3	6.9	1.6	446	12.9	28.2	45.7	48.3	-	-	-	9	438	173	×
	5	7.2	2.2	459	22.2	20.7	63.1	55.2	-	-	-	108	299	147	×
	7	7.7	2.5	419	29.9	85.6	418.7	22.9	-	-	-	219	98	229	○
	10	7.4	2.9	430	31.1	13.8	95.0	25.3	12.3	13.4	112	1343	108	253	○
1Us-3	3	6.4	0.4	447	6.6	44.0	30.6	56.2	-	-	-	0	1576	367	×
	5	6.3	0.8	380	7.8	32.9	38.5	57.5	-	-	-	296	1238	440	×
	7	5.5	3.2	425	15.3	15.0	44.1	71.1	-	-	-	945	1649	514	○
	10	6.1	2.4	258	11.4	21.4	44.0	70.6	3.2	4.8	17	853	997	473	○
1Lw	3	8.2	1.7	278	12.3	22.7	49.4	56.8	-	-	-	605	468	448	○
	5	9.4	3.0	183	13.3	13.7	51.8	54.7	-	-	-	2554	148	610	○
	7	8.4	3.4	218	14.8	14.8	55.3	56.7	-	-	-	1453	53	567	○
	10	7.7	4.0	204	14.3	14.3	53.2	65.1	40.9	11.7	124	1544	30	589	○
1F	5	6.7	0.4	450	11.4	39.3	45.0	48.0	-	-	-	184	177	134	×
	10	6.4	0.65	428	11.9	32.0	62.8	51.6	2.5	1.9	19	0	30	163	×

-: Not determined

Maturity: ×: Dry weight of Chinese cabbages of the seedling test were less than that of control. ○: Dry weight of Chinese cabbages of the seedling test were larger than that of control

Table 3 Continued

Sample name	Incubation period (month)	pH	EC (dS m^{-1})	T-C (g kg^{-1})	T-N (g kg^{-1})	C/N ratio	CEC ($cmol_c$ kg^{-1})	PQ	P_2O_5 (mg kg^{-1})	K_2O (mg kg^{-1})	CaO (mg kg^{-1})	NO_3-N (mg kg^{-1})	NH_4^+- N (mg kg^{-1})	Ash content (g kg)	Maturity*
2Us	5	8.2	2.3	248	18.2	13.6	47.2	63.3	-	-	-	123	173	526	○
	7	8.3	4.5	220	17.7	12.4	45.9	66.2	-	-	-	2714	101	552	○
	10	6.5	5.5	252	19.8	14.4	65.6	67.7	9.6	7.2	60	389	58	589	○
2Uw	3	7.2	1.8	252	15.4	26.3	40.9	58.2	-	-	-	0	164	515	×
	5	7.3	1.3	286	14.3	20.0	34.7	65.2	-	-	-	2	76	437	×
	7	8.1	1.6	228	16.6	13.7	37.2	73.5	-	-	-	81	43	533	○
	10	8.0	1.7	173	17.5	11.6	48.8	70.3	1.6	6.4	73	3329	96	491	○
2Ls	3	7.9	1.0	235	13.0	25.5	28.4	34.4	-	-	-	12	38	536	×
	5	8.6	1.8	211	14.5	14.6	30.7	52.0	-	-	-	14	45	596	×
	7	8.0	2.5	146	11.3	12.9	38.6	64.4	-	-	-	961	75	695	○
	10	10.2	2.0	197	14.5	13.6	43.7	64.1	9.8	3.0	112	1271	64	617	○
3Lw	3	8.3	1.6	168	10.9	16.8	36.5	50.9	-	-	-	10	501	635	×
	5	8.1	2.9	193	10.9	17.5	41.4	51.5	-	-	-	2294	102	592	○
	7	8.0	3.0	208	12.8	16.0	43.3	54.6	-	-	-	1328	79	602	○
	10	7.3	3.0	166	9.7	17.2	41.1	49.3	22.6	9.0	75	1393	36	664	○
3Uw	3	7.7	1.6	196	9.3	21.0	42.4	56.6	-	-	-	747	501	591	×
	5	7.1	2.5	187	8.9	21.0	42.3	58.3	-	-	-	1073	102	585	○
	7	7.9	1.7	201	11.0	18.2	50.3	62.1	-	-	-	484	79	609	○
	10	7.0	2.5	179	10.0	18.0	50.1	59.9	29.6	12.2	64	591	28	620	○
4Uw	5	7.2	3.1	253	15.8	16.0	36.7	60.7	-	-	-	143	209	490	×
	10	6.6	6.8	202	14.4	12.4	41.6	72.2	17.4	9.5	101	3141	19	622	○
5U1	3	7.3	1.0	374	11.3	39.4	32.2	55.9	-	-	-	0	1559	219	×
	5	5.7	2.2	340	16.6	22.9	40.0	64.5	-	-	-	1334	2455	292	○
	7	5.7	4.5	301	22.8	18.6	37.3	67.9	-	-	-	255	1986	311	○
	10	5.5	5.8	393	22.1	17.8	56.7	59.8	9.8	6.9	27	400	1983	277	○
5U2	3	7.0	0.7	313	10.2	36.5	38.3	59.9	-	-	-	0	1533	346	×
	5	5.9	1.9	266	15.4	22.1	37.2	64.6	-	-	-	1126	2383	377	○
	7	5.9	3.1	239	20.1	15.0	42.9	70.3	-	-	-	1260	2181	420	○
	10	6.4	4.4	310	22.0	14.1	43.3	71.9	9.4	7.8	30	432	1943	398	○

-: not determined

Maturity: ×: Dry weight of Chinese cabbages of the seedling test were less than that of control. ○: Dry weight of Chinese cabbages of the seedling test were larger than that of control

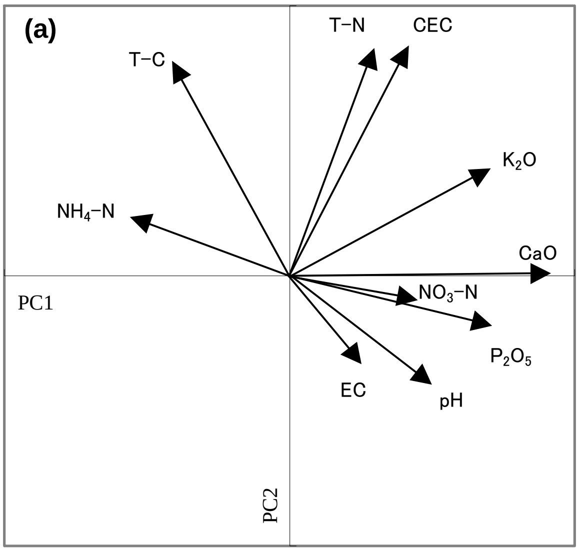
Table 4 Multiple-regression analysis of relationship of co-materials mix ratio to indices of final compost maturity

Dependent variables	Independent variables[a]	Regression coefficients	Multiple correlation coefficients [b]
CN ratio	CT	49.53	
	CF	-1.851	-0.726**
	Charcoal	-1.211	-0.767**
	CMF	-1.169	-0.809**
NO_3-N	CT	-29.64	
	CF	6.542	0.488*
	Charcoal	36.94	0.607*
PQ	CT	50.48	
	Urea	3.693	0.686***
	CF	0.637	0.784***
	CFA	-0.408	-0.884***

[a]CT: Constant term; CF: Chicken feces; CMF: Composted material from food garbage; CFA: Coal fly ash

[b]Significance from F value at *P<0.05 **P<0.01 ***P<0.001

Figure 1


(a)
T−N
CEC
T−C
K2O
NH4−N
CaO
NO3−N
PC1
P2O5
EC
pH
PC2

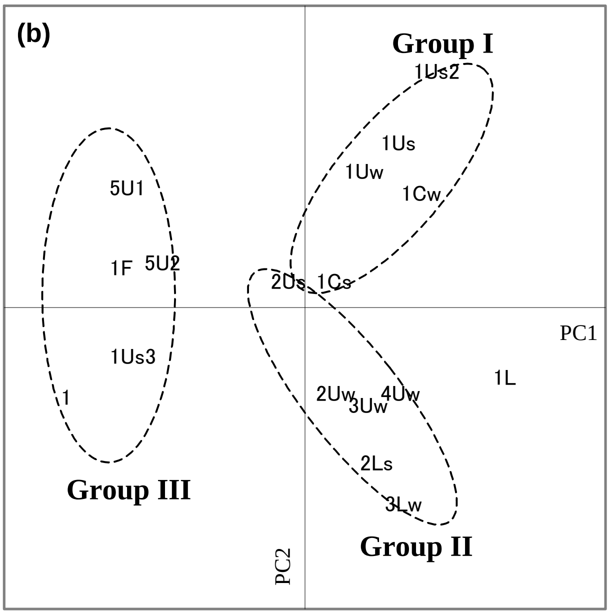
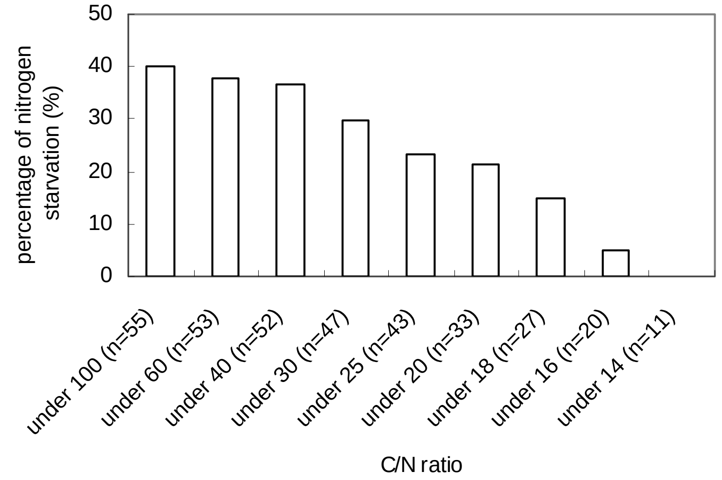
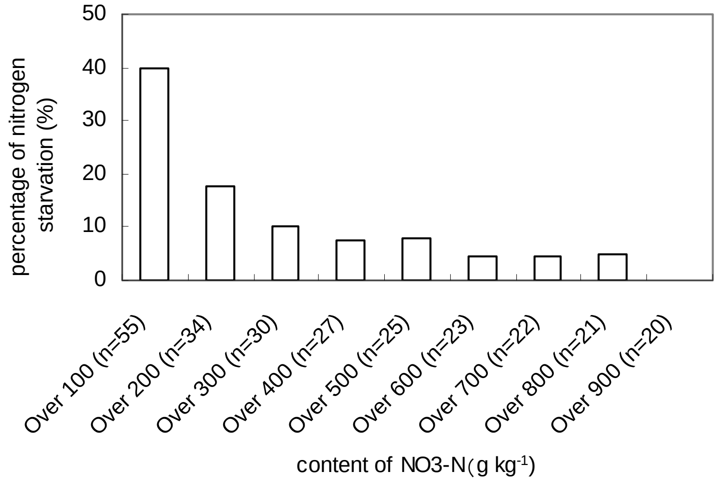
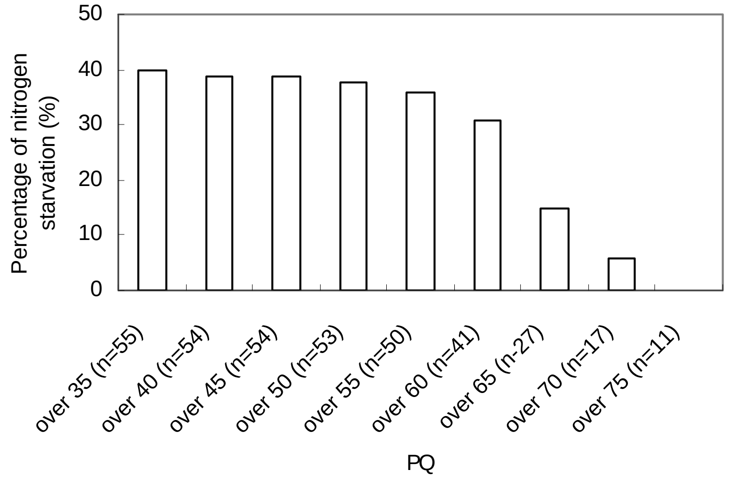

(b)
Group I
1Us2
1Us
1Uw
1Cw
5U1
1F
5U2
2Us
1Cs
PC1
1Us3
1L
1
2Uw
3Uw
4Uw
2Ls
3Lw
Group III
Group II
PC2

Figure 2


50
40
30
20
10
0
percentage of nitrogen starvation (%)
under 100 (n=55)
under 60 (n=53)
under 40 (n=52)
under 30 (n=47)
under 25 (n=43)
under 20 (n=33)
under 18 (n=27)
under 16 (n=20)
under 14 (n=11)
C/N ratio


50
40
30
20
10
0
percentage of nitrogen starvation (%)
Over 100 (n=55)
Over 200 (n=34)
Over 300 (n=30)
Over 400 (n=27)
Over 500 (n=25)
Over 600 (n=23)
Over 700 (n=22)
Over 800 (n=21)
Over 900 (n=20)
content of NO3-N（g kg-1)


50
40
30
20
10
0
Percentage of nitrogen starvation (%)
over 35 (n=55)
over 40 (n=54)
over 45 (n=54)
over 50 (n=53)
over 55 (n=50)
over 60 (n=41)
over 65 (n-27)
over 70 (n=17)
over 75 (n=11)
PQ