(9) PRODUCTION OF HIGH QUALITY COMPOST USING SUITABLE ADDITIVES

添加材を用いた高品質コンポストの製造

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ABSTRACT; It is necessary to make high quality compost in order to expand the utilization of biosolid produced in sewage treatment plants. The high quality compost should not only possesses characteristics of ordinary compost, but also has superior ability to improve soil properties and contains more plant nutrients. Additives, which were possessed of two functions, were used in this research. One is called bulking material function that contributes to adjusting moisture content and improving the permeability of air during the active composting. The other is called soil amendment function that contributes to improving soil properties and to balancing plant nutrients. Cedar chips, zeolite, charcoal and rice bran were used in this study. The results indicate that cedar chips are the suitable bulking material because it possesses large water adsorption capacity and low bulk density. Zeolite not only has high ability of NH_3 adsorption but also possesses large value of cation exchange capacity (CEC). Charcoal functions as soil amendment. Rice bran contains a fairly high amount of plant nutrients. The compost in which cedar chips, zeolite, charcoal and rice bran are added contains high ability of improving soil property and fairly amounts of plant nutrients. Using these materials as the additives, the high quality compost was produced.
KEYWORDS; Compost; Dewatered sewage sludge; Additive; Plant nutrients.

1. Introduction

A serious and complex problem in urban and rural areas today is disposal of huge amounts of dewatered sewage sludge cake produced from wastewater treatment plants[1]. Reclamation in shore and land filling have been widely practiced and difficulties are now arising in finding proper disposal sites. Incineration is costly due to the consumption of fuel and it also requires disposal of ash. Ocean dumping will be prohibited in 1997 because of causing environmental problems. It has become necessary, therefore, to consider the land application of dewatered sewage sludge cake. It is one method to convert this sludge into stable organic matter through the composting process[1,3]. Composting can turn dewatered sewage sludge cake into a product that is esthetically acceptable, essentially free of pathogens, easy to handle and less in readily decomposable organic matter. Furthermore, compost can be used to improve soil structure and provide nutrients for plant growth.

Much research on composting has been done and many kinds of bulking materials, such as rice husks,

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sawdust and straw, were commonly used[1-13,15]. To improve nutrients in compost, zeolite and charcoal were used[3]. However, the utilization of compost is still low at present. It is because that general compost has less plant nutrient than chemical fertilizer and is inconvenient to be transported and used[1]. In order to expand the utilization of compost, production of high quality compost is necessary. High quality compost must not only have the properties which the ordinary compost possess but also be nontoxic and contain additional plant nutrient compounds as well as having a superior texture and consistency for conditioning the soil[3].

In this research, four kinds of additives (cedar chips, zeolite, charcoal and rice bran) were used. These additives had two functions. One was called bulking material function that contributes to adjusting moisture content and improving the permeability of air during the active composting. The other was called soil amendment function that contributes to balancing plant nutrients and increasing the ability to improve soil properties for compost. The objective of this research is to investigate the effects of these additives on producing high quality compost.

2. Materials and Methods

2.1 Composting materials

(1) Dewatered sewage sludge cake

The dewatered sewage sludge cake tested in this experiment was sampled from Hiezu Wastewater Treatment Plant. It was dewatered by a movable dewatering machine placed on a truck (produced by Kurita Water Industries Ltd.) using ferric chloride and amphoteric polymer as coagulants. The characteristics of this dewatered sludge cake is shown in Table 1. The moisture content of it was approximately 80%. Volatile matter (VM), total carbon (T-C), nitrogen (T-N) and phosphorus (P_2O_5) were 76%, 40%, 7.5% and 4.31% on a dry weight basis, respectively. The content of total potassium (K_2O) was low, it had only 0.44% on basis of dry weight. The concentrations of Hg, Cd and As in this sludge cake were lower than the legal limited, it is possible to make this sludge into high quality compost for agricultural use.

Table 1. Characteristics of sludge cake

Item	Value	Legal limited
Moisture content (%)	80.5	
Volatile matter (%)	76.0	
T-C (%)	40.0	
T-N (%)	7.5	
P_2O_5(%)	4.31	
K_2O (%)	0.44	
Cu ($mg \cdot kg^{-1}$)	206.60	
Zn ($mg \cdot kg^{-1}$)	559.80	
As ($mg \cdot kg^{-1}$)	3.39	50
Cd ($mg \cdot kg^{-1}$)	4.39	5
Hg ($mg \cdot kg^{-1}$)	0.20	2
pH	5.6	

(2) Additives and seed microorganisms

In this research, four kinds of materials, such as cedar chips, zeolite, charcoal and rice bran, were used as additives. The characteristics of cedar chips (produced by Sanin Maruwa Forestry Company), zeolite (produced by Izumo Chemical Company), charcoal (produced by Hiezu village) and rice bran (Hujimoto Grain Mill) are shown in Table 2. Cedar chips have large water adsorption capacity and low bulk density. Zeolite has high cation exchange capacity (CEC). Charcoal and rice bran have high concentrations of N, P and K. Seed microorganisms used for inoculation was a compost product from former laboratory composting process.

Table 2. Characteristics of additives

Additive	Cedar ships	Charcoal	Zeolite	Rice bran
Size of particle (mm)	1～3	2～4	0.5～1.0	Powder
Moisture content (%)	13.1	7.4	4.4	13.5
Water adsorption capacity ($g \cdot g^{-1}$)	2.53	1.30	0.63	3.18
Specific surface area ($m^2 \cdot g^{-1}$)	2.5	36	140	---
Diameter of pore (μ m)	40～50	30～40	0.2～0.5	---
Bulk density ($g \cdot cm^{-3}$)	0.16	0.13	0.96	0.24
T-N (%)	0.5	1.3	0.1	2.2
P_2O_5 (%)	0.02	0.14	0.02	5.37
K_2O (%)	0.07	0.69	0.31	2.10
CEC ($cmol(+) \cdot kg^{-1}$)	29.3	6.7	70.5	---

2.2 Composting apparatuses

Pilot and laboratory scale apparatuses were used in this research. The flowchart of these apparatuses is shown in Fig. 1. In the pilot scale apparatus, a turning machine was installed. The volume of reactor was 2 m^3 (1.4 m in diameter, 1.5 m in depth). Air was introduced into the bottom of the reactor by a blower through air flow meter with 20 kPa(G) of air pressure. Temperature was determined using glass thermometer by hand. The laboratory scale apparatus was a plastic cylindrical container surrounded by styrofoam insulation. Effective volume of the reactor was 20 liters. Air was supplied by an air compressor (Hitachi 0.2OP5S) and air pressure was reduced to 20 kPa(G) by regulator. Aeration rate was controlled by an air flow meter (KOFLOC, RK1650). A perforated plastic plate was placed at the bottom of the reactor in order to support composting materials and distribute air. Temperature was determined using a thermocouple that was inserted into composting materials in the reactor, monitored by a computer (NEC, PCKD55K) and recorded by a recorder (Chino, RH720RNN).

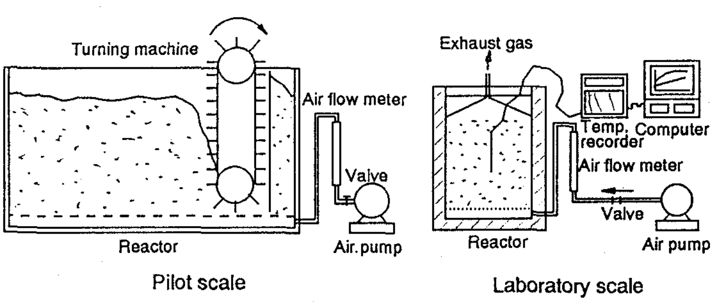

Fig.1. Schematic diagram of experimental apparatus

2.3 Composting procedure

(1) Pilot scale experiment

The pilot scale experiment was completely mixed type at one period (two days). In order to keep temperature of mixture at high level, new composting materials were added into the reactor every other day before the temperature of mixture decreased to lower than 45°C. Before adding new composting materials, nearly 200 kg of compost was taken out from the reactor and about 250 kg of new composting materials, according to the designated mixing ratio of bulking material (Table 3), were added into the reactor in order to keep the total weight of mixture in the reactor stable (approximately 1000 kg). When the new composting materials were put into the reactor, they were mixed with compost which was left in the reactor by the turning machine (new composting materials / compost was approximately 1 / 3). Air was continuously supplied by the blower with the aeration rate of 100 $l \cdot m^{-3} \cdot min^{-1}$(air pressure was 20 kPa(G)), and the following active composting was conducted. In order to find the suitable bulking material, three materials, cedar chips, charcoal and zeolite, was tested in the experiment. The mixing ratios of each additive were from 10% to 30% on wet weight basis (Table 3). Temperature and working condition of turning machine in the composting procedure were recorded.

Table 3. Changes in working condition of turning machine using different additives in different mixing ratios

Mixing ratio of additive (%)*	Working condition of turning machine**		
	Zeolite	Charcoal	Cedar chips
10	×	×	×
20	×	×	○
30	×	○	○

* Additive / sludge cake (w.w. / w.w.)

** ○ Turning machine worked smoothly

× Turning machine did not work

(2) Laboratory scale experiment

The laboratory scale experiment was conducted in three series. In three series, different additive 1 with the mixing ratio of 20% and additive 2 with the mixing ratio of 0 to 40% were composed in different combination. Although rice bran contains high concentration of plant nutrients, the mixing ratio of it was 10%. It was because that rice bran contains high concentration of biodegradable organic matter and the composting process will be prolong while using a large amounts of it. In order to investigate the effects of additive 2 on soil amendment function , five experiment runs, in which same weight of sludge cake (6.0 kg), seed compost (2.0 kg), rice bran (0.6 kg) and different mixing ratios of additive 2 (0 to 40%) were used, were conducted in each series. The different combinations of additives in each series and different mixing ratios of additive 2 in each experiment run were shown in Table 4. Before the experiment, the dewatered sewage sludge cake was crushed thoroughly by hand, and homogeneously mixed with the additives and seed according to the designated mixing ratio. Then it was transported into the reactor. The air flow rate was kept at 100 $l \cdot m^{-3} \cdot min^{-1}$ (air pressure was 20 kPa(G)), and active composting reaction was begun. Once the active composting started, the temperature of the mixture rose with heat generated by biological oxidation, CO_2 and NH_3 were produced. The temperature of mixture was continuously monitored and recorded. Concentration of CO_2 and NH_3 in the exhaust gas were measured. The active composting was terminated when the temperature of mixture fell to the room temperature.

2.4 Analytical methods

Determination of concentration of CO_2 and NH_3 in the exhaust gas was carried out by gas chromatography (Shimadze, GC14A) and glass tube detector (GASTEC Company). Moisture content was determined by the weight difference before and after drying the samples at 105°C for 12 hours[14]. Volatile matter (VM) was determined by the changes in dried sample weight before and after incinerating the dried sample for 1 hour at 600°C. Total carbon (T-C) and nitrogen (T-N) were determined by C-N analyzer (Sumigraph N-C80, Sumitomo Chemical CO.,Ltd). Contents of P and K were determined by inductively coupled plasma emission spectroscopy (Multispectrometer, ICPS2000, Shimadzu Corporation) after the

Table 4. Combinations and mixing ratios of additives and contents of plant nutrients in compost

Series	Combination condition: Mixing ratios of additives				Contents of plant nutrients in compost					
	Additive 1		Additive 2		N		P_2O_5		K_2O	
	(kg)	(%)	(kg)	(%)	Weight (g)	Content (%)	Weight (g)	Content (%)	Weight (g)	Content (%)
	Cedar chips		Zeolite							
A	1.2	20	0.0	0	81.7	3.31	88.1	3.57	22.6	0.92
A	1.2	20	0.6	10	86.0	2.82	88.1	2.89	24.5	0.80
A	1.2	20	1.2	20	89.3	2.47	88.3	2.44	26.4	0.73
A	1.2	20	1.8	30	91.7	2.18	88.4	2.10	28.3	0.64
A	1.2	20	2.4	40	93.7	2.11	88.5	1.99	30.1	0.63
	Cedar chips		Charcoal							
B	1.2	20	0.0	0	79.8	3.48	87.8	3.83	22.6	0.99
B	1.2	20	0.6	10	85.3	3.00	88.7	3.13	26.2	0.92
B	1.2	20	1.2	20	91.1	2.69	89.5	2.64	29.8	0.89
B	1.2	20	1.8	30	97.2	2.46	90.3	2.29	33.4	0.85
B	1.2	20	2.4	40	102.2	2.27	91.0	2.02	37.0	0.82
	Charcoal		Zeolite							
C	1.2	20	0.0	0	85.7	3.69	89.0	3.84	26.5	1.14
C	1.2	20	0.6	10	89.1	3.08	89.1	3.08	28.5	0.99
C	1.2	20	1.2	20	91.8	2.65	89.2	2.58	30.2	0.87
C	1.2	20	1.8	30	94.0	2.33	89.2	2.21	32.0	0.79
C	1.2	20	2.4	40	97.5	2.12	89.3	1.94	34.0	0.74

Note: 1. Wet weight of sludge cake, seed compost and rice bran were 6.0, 2.0 and 0.6 kg, respectively;
2. Weight of additives were on wet basis;
3. Weight of N, P_2O_5 and K_2O were on dry basis.

were wet digested with concentrated HNO_3 + $HClO_4$[14]. Electrical conductivity (EC) and pH were measured by electrical conductivity meter (CM40S, TOA electronics Ltd.) and pH meter (Horiba, M8, with glass electrode) in the 1:10 water extract. Cation exchange capacity (CEC), ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) were analyzed according to the standard methods for soil analyses and determination[14].

3. Results and Discussion

3.1 Suitable bulking material

Addition of bulking material is favorable for the active composting to proceed smoothly and efficiency, because the moisture content can be adjusted and the air permeability of mixture can be improved. The structure of the bulking material affects the efficiency of contact between oxygen and sludge. Therefore, the choice of bulking material is a important factor for the active composting. In this research, the effects of of additive on the stickiness of compost and the working condition of turning machine were investigated by using the pilot scale apparatus. In order to find the suitable bulking material, cedar chips, charcoal and zeolite were tested. The operational conditions and results were shown in Table 3. When the mixing ratio of each additive was at 10%, the temperature of mixture did not rise to higher than 55°C, and the turning machine did not work smoothly. It was because that the dewatered sewage sludge cake had high moisture content, and it became very sticky during the active composting process. This sludge cake stuck on the paddles of the turning machine, and the dumpling occurred when the turning machine worked. This resulted in bad air permeability for mixture and over load condition for turning machine. When the mixing ratio of each additive was increased to 20%, the moisture content of the mixture reduced to approximately 65%. The temperature of mixture reached at approximately 60°C and the turning machine worked smoothly using cedar chips. However, using zeolite and charcoal, it was also difficult to keep the composting process and turning machine going will. When zeolite and charcoal were used with the mixing ratio of 30%, the moisture content reduced to approximately 60%. The temperature increased to approximately 60°C and the turning machine worked smoothly using charcoal. However, the conditions of active composting process and turning machine were also not improved yet using zeolite. This means that cedar chips is the best bulking material and zeolite can not be used as bulking material. Charcoal is worse than cedar chips and better than zeolite. This is because cedar chips have large water adsorption capacity and low bulk density (Table 2). It can extract much water from the sludge cake and expand more volume of mixture than charcoal and zeolite.

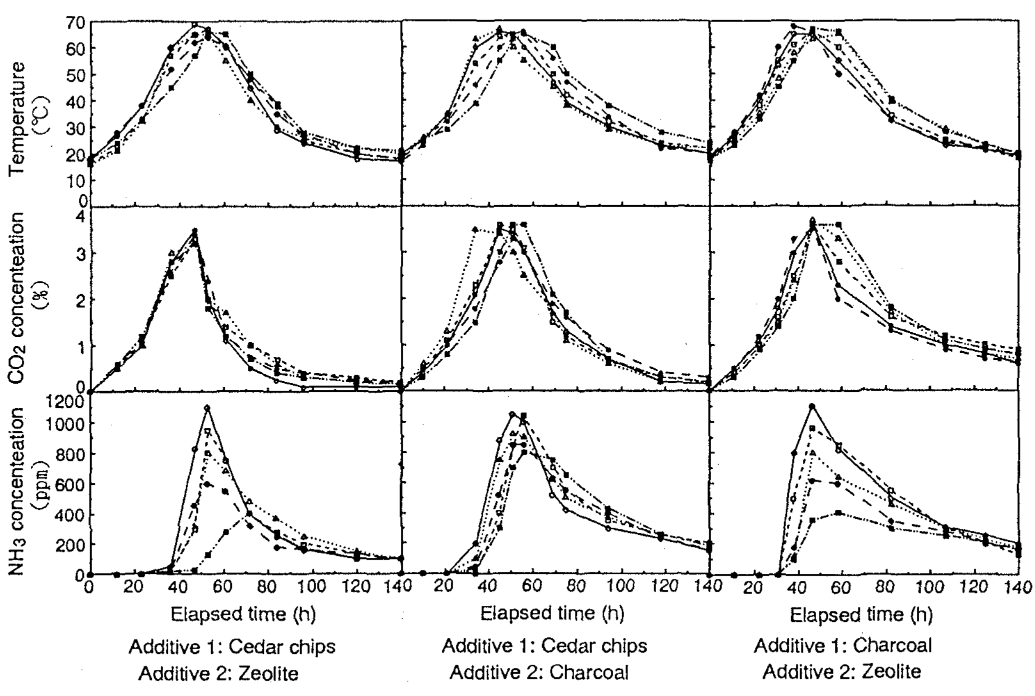

Fig.2. Time courses of temperature, CO_2 and NH_3 concentrations in exhaust gas
Sludge cake: 6kg; seed compost: 2kg; additive 1: 1.2kg; rice bran: 0.6 kg;
additive 2: 0.0kg —•—, 0.6kg ··◦··, 1.2kg ···▴···, 1.8kg –▾–, and 2.4kg –■–.

3.2 Changes in temperature, evolution of CO_2 and NH_3, and nitrogen

This test was conducted using laboratory scale apparatus. Different combinations and mixing ratios of additives were shown in Table 4. In order to investigate degree of active composting and compositions of fertilizer at the same operational condition, cedar chips or charcoal was used as additive 1 for the main function of bulking material with the same mixing ratio of 20% (w.w./w.w.), although for charcoal, this mixing ratio was not suitable for turning machine. Zeolite and charcoal were used as additive 2 for the main function of soil amendment. Rice bran was used for the acceleration of decomposition of sludge and for the increase of plant nutrients. The mixing ratio of rice bran was 10%. Active composting is aerobic biological decomposition process of organic matter in which heat is produced, and CO_2 and NH_3 are generated. Time courses of temperature, CO_2 and NH_3 concentrations in exhaust gas are shown in Fig. 2. In each experiment condition, the temperature began to rise after initiation of active composting, peaked at temperature higher than 60°C, then fell to room temperature after about 6 days. With the changes in quality and quantity of additives, the highest temperature and the periods of maintaining high temperature were nearly unchanged.

As the same as the temperature, the concentrations of CO_2 in exhaust gas were nearly same in each experiment run. This is because the aerobic condition was maintained in each experiment run. The extents of biological reaction were almost the same.

During the active composting process, NH_3 is generated by degradation of proteins and digestion of organic nitrogen compounds, and total nitrogen in the compost was reduced. High concentration of NH_3 in the exhaust gas not only will produce unpleasant odors to pollute the environment but will also decrease the fertilizer efficiency of the compost. With increasing the weight of additive 2, the concentration of NH_3 in exhaust gas were changed (Fig. 2). Changes in the highest concentration of NH_3 in exhaust gas with changes in weight of additive 2 in each experiment series were shown in Fig. 3. It can be seen that the highest concentration of NH_3 decreased when the weight of additive 2 increasing in each series, especially using zeolite. When additive 2 was not added, the concentrations of NH_3 in exhaust gas were approximately 1100 ppm in each series. Using charcoal and zeolite at the weight of 2.4 kg (40%), the concentrations of NH_3 in exhaust

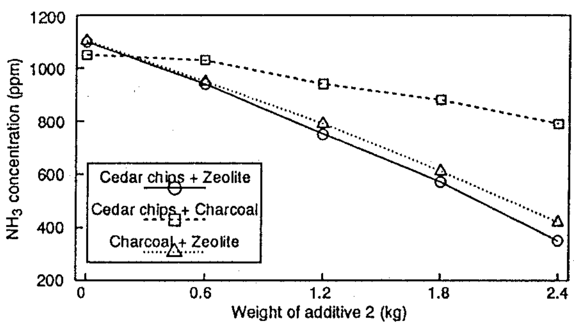

Fig.3. Relationship between weight of additive 2 and the highest NH_3 concentration in exhaust gas

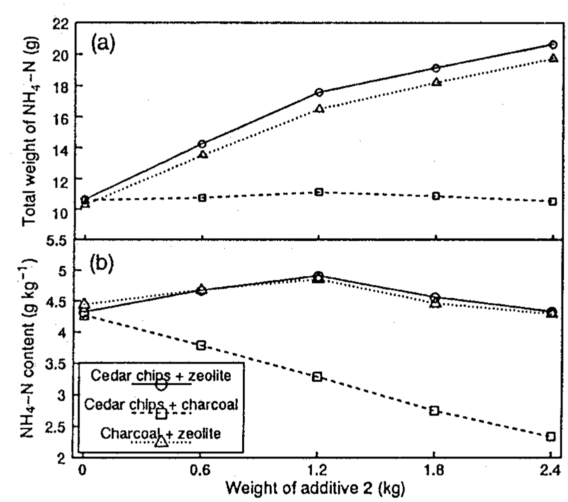

Fig.4. Relationship between weight of additive 2 and total weight of NH_4-N, NH_4-N content in the compost

gas were reduced to approximately 800 and 400 ppm, respectively. In the composting process, NH_3 is generated. It also cause the pH of compost rising. When additive 2 was not added, the pH of compost was approximately 8.0 in each series. When charcoal was used as additive 2, the pH of compost dropped little with increasing the weight of it. While zeolite was used as additive 2, the pH of compost dropped from 8.0 to 7.5 with increasing the weight of it from 0.0 to 2.4 kg. It means that zeolite has high ability of NH_3 adsorption. It is because zeolite has larger specific surface area and smaller diameter of pore than others (Table 2). Using zeolite as additive 2 for the main function of soil amendment, the NH_4-N content in the compost can be increased. Relationship between weight of additive 2 and total weight of NH_4-N, NH_4-N contents in compost were shown Fig. 4. From Fig. 4a, it can be seen that with increasing the weight of zeolite, the total weight of NH_4-N in the compost was increased from 10.6 g to 20.6 g (approximately 2 times). The more the weight of zeolite added, the higher the total weight of NH_4-N in the compost possessed, but it was costly. While increasing the weight of charcoal, the total weight of NH_4-N in the compost was almost unchanged. This result was also because that zeolite possess larger specific surface area and lower diameter of pore than charcoal. This means that zeolite was better soil amendment than charcoal. The changes of NH_4-N contents in the compost are shown in Fig. 4b. Increasing the weight of zeolite, the NH_4-N contents in the compost were increased at first, reached 5 $g \cdot kg^{-1}$, and then decreased. With increasing the weight of charcoal, the NH_4-N contents in the compost were always decreased. The decrease of NH_4-N contents was because of increasing of total weight of compost by increasing additive 2.

Total NO_3-N in each compost were almost the same, approximately 170 mg in average. The values of NO_3-N contents in every compost were ranged from 35 $mg \cdot kg^{-1}$ to 70 $mg \cdot kg^{-1}$ with the change of weight of additive 2. Nitrification in each composting process were nearly the same.

3.3 Changes in CEC, pH and EC

CEC is one of the important chemical properties of soil. The changes in CEC of compost using various additives at different mixing ratio are shown in Fig. 5. When additive 2 was not used, the CEC of compost using cedar chips was higher than that using charcoal. This is because cedar chips possess higher CEC than charcoal (Table 2). The more the zeolite added, the higher the value of CEC contained, but it was costly. While increasing the weight of charcoal, the CEC of compost decreased because increasing total weight of compost . This is because zeolite possesses higher CEC than charcoal (Table 2). It also means cedar chips and zeolite are suitable additives. The changes of pH value of each compost were 7.5 - 8.0. It was higher than dewatered sewage sludge cake due to the release of NH_3 in the active composting process. The sum of soluble ions in the water extracts, as indicated by EC measurement, decreased due to the part of sludge cake weight decreasing in the samples with increasing the weight of soil amendment. The values of EC were ranged from 4.8 to 2.0 dS m^{-1} in each compost.

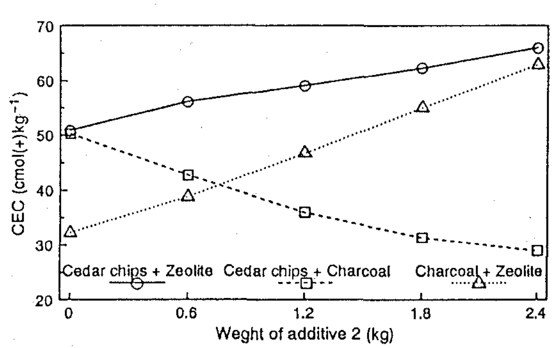

Fig.5. Relationship between weight of additive 2 and cation exchange capacity (CEC) of the compost

3.4 Changes in composition of plant nutrients

Table 4 indicates the changes in nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O) of these plant nutrients in compost. Increasing the weight of zeolite from 0.0 to 2.4 kg (0 to 40%), the total weight of N in compost increased from 81.7 to 93.7 g for series A and 85.7 to 97.5 g for series C. This is because that zeolite has high ability to adsorb NH_3. While increasing the weight of charcoal from 0.0 to 2.4 kg (0 to 40%) in series B, the total weight of N in the compost also increased from 79.8 to 102.2 g. It is because that charcoal possesses relatively high content of N at a value of 1.3% (Table 2). The total weight of P_2O_5 in each compost nearly unchanged. The K_2O content of compost is higher using rice bran than general compost because rice bran contains high concentration of K_2O. Increasing the weight of soil amendment from 0.0 to 2.4 kg (0 to 40%), the total weight of K_2O in the compost increased from 22.6 to 30.1 g for series A, 22.6 to 37.0 g for series B and 26.5 to 34.0 g for series C. Especially increasing charcoal (in series B), the weight of K_2O content had large increased. This is because charcoal contains more K_2O in itself than zeolite contains (Table 2). The percentage of N, P_2O_5 and K_2O in the compost decreased with increasing the soil amendment in each series because of the total weight of compost increased with increasing the soil amendment. The more the weight of soil amendment added, the higher the value of N and K_2O in compost possessed, but it was costly. The optimum mixing ratio of each soil amendment was depended on the former results and the price of it.

4. Conclusions

In this research, additives, such as cedar chips, zeolite, charcoal and rice bran, were tested in order to produce high quality compost. The functions of additives were investigated. From this research, the results can be summarized as follows:

(1) Cedar chips are the suitable bulking material that can improve the permeability of air to sludge cake for active composting and keep the turning machine working well.

(2) Zeolite has high ability of NH_3 adsorption and high value of CEC, It is the suitable soil amendment. Charcoal and rice bran contain a fairly amounts of plant nutrients. They are also the high-class additives.

The high quality compost that has high ability to improve soil properties and contains more plant nutrients can be produced by using cedar chips, zeolite, charcoal and rice bran as the additives.

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