Production of Pellet Fertilizer from the Sludge of Thermophilic Aerobic Oxidation System and Its Effects on the Growth of *Chinese cabbage* and Soil Properties

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고온 호기성 산화 시스템의 슬러지로부터 펠렛 비료의 생산과 *Chinese cabbage*의 생육 및 토양 특성에 대한 영향

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Summary

A solid of Thermophilic Aerobic Oxidation(TAO) System was mixed with sawdust or a rice husks. After fermentation was finished, molding machine and a dryer were used, and pellet fertilizer was produced. The fertilizing experiment was carried out as five pieces by Bed soil, TAO solid(TAO-S), TAO pellet fertilizer(TAO-PF), Chemical fertilizer(NPK) and Control(no fertilizer). Growth rate of the *Chinese cabbage* by each treatment was examined. Analysis of microbe and soil characteristic before and after crop experiment were carried out.

When the moisture contents of TAO-PF were 18% and 25%, the occurrence rate of microbes for the storage time was increased to 80% and 100% respectively. However, in the 12% of water content treatment was not increased microbes. The concentration of soil bacteria in TAO-PF and TAO-S for 15 day after treatment was $1.5 \times 10^7 \sim 8.0 \times 10^7$ CFU/mℓ, and the concentration of bacteria for 50 day was increased to 6.3×10^7 and 8.3×10^7 CFU/mℓ. However, *Fungus* decreased. The concentration of *Actinomycetes* was increased in TAO solid, Bed soil and TAO-PF treatment. The TAO-S and TAO-PF treatment were normal to compare to the NPK treatment. In this experiment the height and width of the *Chinese cabbage* were 22.3 cm, 16.8 cm in Bed soil and 28.8 cm, 21.3 cm in TAO solid. The leaf number of TAO-S, TAO-PF and NPK treatment were similar to 39.8, 38.3, 40.3 sheet. As the result, the TAO-PF knew that use was possible with fertilizer.

(**Key words** : Pellet fertilizer, Bacteria, Chemical fertilizer, Crop, Soil characteristic)

INTRODUCTION

Organic manures(including sewage sludge and livestock manures) are a valuable source of plant available nutrients and organic matter, contributing to soil quality and fertility, and recycling to

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agricultural land is often the most economic, practical and environmentally beneficial management option. Manure from animal waste has been widely used as an important material for soil improvement, but as the scale of livestock farm is expanded, the production of animal waste has been increased and the restoration of farmland within a region has become difficult. While environmental problems including underwater pollution are coming up to the surface because of overuse of manure from animal waste. However, fertilizers currently used are not clear in its quality and effects, and also have large volume due to high moisture content and need special equipment to spray. These are limiting factors in the distribution and the use of fertilizers. Molding technology helps to make fertilizer into pellets and is being noticed as a measure for the promotion of wide distribution and use of fertilizers, because it can greatly improve defects of the existing fertilizers such as wide transport, storage, and machine spreading(Hara et al., 2003a, b; Matsumoto., 1999).

The content of molded pellet is compressed down to 50 ~ 80% of original fertilizer, and this reduction of volume is very convenient in transport and very cost-effective in wide distribution of fertilizers. Also, it takes less space in livestock farm for the storage during the low-demand period. In particular, molded fertilizer has enough strength for machine spreading and has relatively good particle size and quality, thus it can be applied to various fertilizer spreader that crop farmers have and possible to spread near residential area because the dust production is inhibited. In addition, it has a variety of use not only for the source of organic fertilizer in farms but also in urban landscape, golf course, afforestation, and home gardening.

The nutrient value of organic waste is considered to be moderate, although the variation in waste quality is large dependent on waste type and processing method(Simith et al., 1998; Ushio et al., 2004). The principal requirement of compost for safe application in soil is its degree of stability or maturity, which implies stable organic matter content, and the absence of phytotoxic compounds and plant or animal pathogens(Bernal et al., 1998; Matsuda et al., 1996; Gomez, 1998). Lee et al.(2004), reported that Thermophilic Aerobic Oxidation(TAO) system is a biological fertilizer system that can treat all kinds of organic waste at high temperature over 55℃ and has excellent effects in the production of liquid fertilizer without any trace of microorganisms, the reduction of slurry volume, and the elimination of foul odor included in pig waste slurry.

We manufactured pellet fertilizer by mixing solid material treated with this effective TAO system and rice husks as bulking agent and then investigated the effect of moisture content on storage, the growth of *Chinese cabbage* by using pellet fertilizer and the change in soil properties.

MATERIAL AND METHODS

1. Production of pellet fertilizer

Solids Content(SC) and Moisture Content(MC) of sludge treated with TAO system were 5% and 95%, respectively; SC and MC of rice husks added with bulking agent were 80% and 20%, respectively. The mixing ratio from each was 50 : 50(weight). Microorganism for fermentation was added to the mixture(SC 30%, MC 70%) and fermented for 3 weeks. Fermented manure(SC 47%, MC 53%) was ventilated for 1 ~ 2 days, and then manufactured into oval or round particle

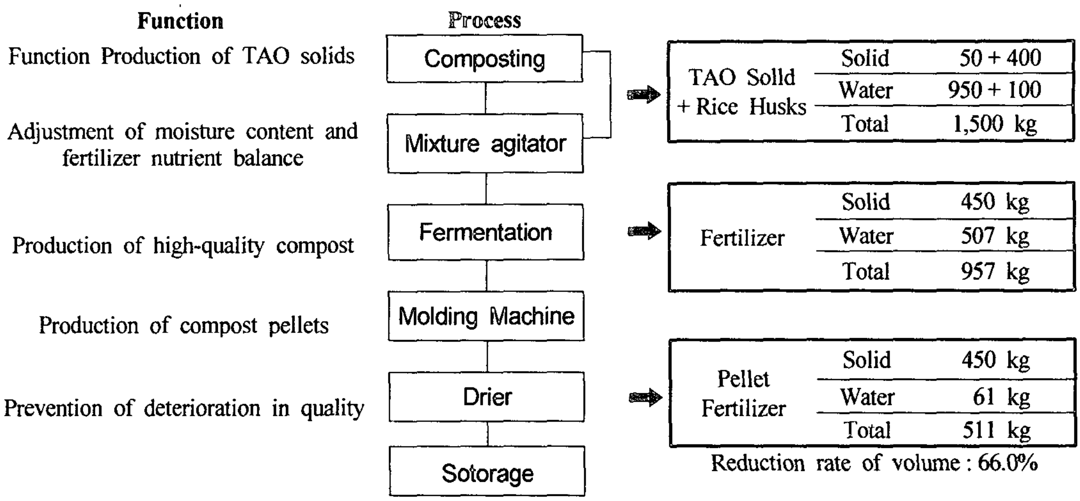

Fig. 1. Flow chart of pellet production.

fertilizer using pellet machine. Pellet fertilizer was air-dried at about 40℃ in the oven for 2 ~ 4 days to control the moisture content as 12, 18, and 25%. Then it was stored air-tight at room temperature(20 ~ 30℃) in the dark and measured at 10 day intervals. Fig. 1 showed the manufacturing process and the function of pellet fertilizer. A chemical characteristics of the TAO-S used in the experiment are listed in Table 1. Contents of nitrogen, phosphorus, potassium, and organic substances of TAO-S were 2.54, 15.35, 0.55, and 26.27%, respectively, which were appropriate for the standard of fertilizer process. TAO-PF was made by mixing TAO-S and rice hull with the ratio of 50 : 50(weight).

Table 1. Chemical characteristics of the TAO-S used in the experiment

pH (1:10)	T-N	P_2O_5	K_2O (%)	O.M	EC (mS/cm)
8.87	2.54	15.35	0.55	26.27	0.42

2. Plant growth

Winter *Chinese cabbage* was used as experimental crops. Soil was clayish and infertile with bad drainage, which became better with a grade of ground. *Chinese cabbage* was grown for 30 days using 105-holes growing seedling tray. Fertilization was performed on the basis of 32-8-20-100-1(N-P-K-Ca-B) kg/10a; 11-8-10-100-1 kg/10a was spread as base manure and then spread 1~3 times as top manure. Treatment groups were divided as Bed soil, TAO solid (TAO-S), TAO pellet fertilizer(TAO-PF), Chemical fertilizer(NPK), and Control, and the test were repeated 3 times.

3. Microbial analysis

In the microbes analysis, a medium used for bacteria analysis was nutrient agar medium(Difco, USA); it was cultured 24 hr for 37℃. Bennett's medium(glucose 10 g, peptone 2 g, yeast extract 1 g, beef extract 1 g, distilled water 1,000 mℓ, Difco, USA) and PDA medium(Potato Dextrose Agar, Difco, USA) were used for *Actinomycetes* and a *Fungi* analysis, it was cultured 5 day for 28℃. The culture was performed by the dilution plate method and counted as colony forming units(CFU) after measuring a colony generated on a medium. Each sample dilution was in three replicate plates. Microbes in soil samples were evenly extracted by mixing 1g of collected soil and 0.85% NaCl with the ratio of 1 : 9 for 30 minutes.

4. Analysis of soils

Soil samples were collected from 0 ~ 10 cm depth at mineral soils in each port. Before analysis, soil samples were ground and passed through a 2 mm sieve. The pH and electrical conductivity(EC) were measured in a 1 : 5(soil : water) aqueous extract. Total nitrogen content in soil was determined by the regular Kjeldahl distillation method. Available phosphorous was determined calorimetrically by molybdate blue method. Exchangeable Ca, Mg and K were extracted from soil with 1N CH_3COONH_4 buffered to a pH of 7.0, and it was determined by Inductively Coupled Plasma Spectrophotometer(ICP, SPECTRO CIROS CCD).

RESULTS AND DISCUSSION

1. Moisture content experiment

The moisture contents of TAO-PF made of TAO-S and rice hulls were 12, 18, and 25% and the result of storage test(rate of mold production) was shown in Fig. 2. For the 12% moisture content, no mold was observed between 10 ~ 50 days; but for the 18% moisture content, 2% of mold was observed after 10 days and 50% after 40 days, showing faster development of mold as time passed. This tendency was more obvious in the 25% moisture content showing 22% of mold after 10 days but increased to 55% after 20 days ınd 88% after 30 days, and completely covered ith mold after 40 days.

Composting is seen as an environmentally ac- able method of waste treatment. The process es the volume of waste and improves the of the waste. It also makes animal waste o handle and transport(Liao *et al.*, 1994a, b; Kashmanian and Rynk, 1995; Georgacakis *et al.*, 1996). Heo and Jeong(2001a, b) reported that liquid fertilization and solid fertilization + liquid fertilization are the most economic methods among various treatments for animal wastes in pork farms, and that the stabilizing quality and application of fertilizer should be easy for the activation in the use of fertilizer. TAO-PF is a fertilizer made from solids, which were produced after animal waste treatment, by mixing with rice hull as a bulking agent in the TAO system in which 30~60% of volume reduction and the production of safe liquid fertilizer without any trace of microbes are possible in the treatment of animal waste. We obtained about 66.0% of reduction in volume in the manufacturing process of TAO-PF through fertilization treatment. Hara et al.(2003a), reported that as for the pellets which were molded under the optimum moisture conditions, a remarkable deterioration in appearance was observed because of the proliferation of the filamentous bacteria. The deterioration of quality by the proliferation of such microorganisms can be prevented by drying the pellets to reduce the moisture to 0.15 kg/kg or less.

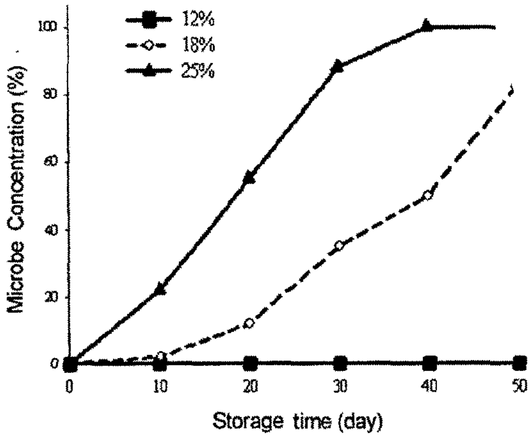

Fig. 2. Comparison of occurrence rate of bacteria by difference of moisture content.

And about 2 hr of drying ventilation is necessary in order to reduce the moisture of the products to 0.15 kg/kg where a long storage is possible. From the above results, it is considered that the distribution to distant places and the storage are possible because there were no changes in quality when stored with 12% of moisture content for long period of time.

2. Change of a soil characteristic and Growth rate of *Chinese cabbage*

Physicochemical properties of soil after 5 days of planting and after harvesting *Chinese cabbage* were shown in Table 2. The pH after 5 days of planting was 6.6 ~ 7.3 showing that the soil was normal, and the EC content was 0.10 ~ 1.10 mS/cm showing that it did not affect the growth of crops even though the difference among treatment groups were great. The N-P-K-Ca-Mg content seemed to directly affect the growth of crops due to the difference following each treatment. In nitrogen content that greatly affects the initial growth, the value of TAO-S was 0.27%, which was twice as much as other treatment groups and about 3 times as much as 0.10% of control group. This tendency was similar in calcium content. In case of phosphorus, the value of TAO-S was 1.04%, which was slightly higher than other treatment groups. The contents of K and Mg were not much different among treatment groups. These differences in N, P, and Ca brought the difference among treatment groups, except the NPK, in the initial growth of *Chinese cabbage*. The excellent initial growth in NPK was due to the fast absorption of nutrients because they are water-soluble, but solid materials such as manure had relatively slow absorption following the degradation of organic substances. Thus, if treated on the basis of chemical fertilizer standard, it is considered that about 30% of fertilizer contents were lacked in the first year. The pH of soil after 50 days of planting was 6.2 ~ 7.6, showing that it was normal in most treatments, but slightly changed to acidic pH of 6.2 in NPK. The EC contents in TAO-S and NPK were 0.31 and 0.19

Table 2. Comparison of soil component for five and 50 days after planting by different type of fertilizer

	Fertilizer	pH	EC	N	P	K	Ca	Mg
			mS/cm	%				
After 5 Day	Control	6.9	0.10	0.09	0.09	0.29	0.38	0.34
	NPK	7.0	0.30	0.12	0.11	0.28	0.43	0.36
	Bed soil	7.3	0.20	0.13	0.11	0.29	0.45	0.34
	TAO-S	7.3	1.10	0.27	1.04	0.27	1.24	0.57
	TAO-PF	6.6	0.20	0.15	0.10	0.34	0.31	0.33
After 50 Day	Control	7.6	0.04	0.108	0.091	0.24	0.40	0.29
	NPK	6.2	0.19	0.125	0.091	0.24	0.33	0.29
	Bed soil	7.3	0.05	0.111	0.089	0.27	0.37	0.28
	TAO-S	6.7	0.07	0.109	0.087	0.32	0.32	0.30
	TAO-PF	7.	0.06	0.137	0.092	0.37	0.35	0.32

C; no fertilizer, NPK; chemical fertilizer, Bed soil; general manure, TAO-S; internal sludge which occurred after treating a pig slurry by TAO system, TAO-PF; TAO solid 50% + Rice husk 50%, respectively.

Table 3. Comparison of growth rate of Chinese cabbage for 50 days after planting by different type of fertilizer

Fertilizer	Survival rate (%)	Height (cm)	Width (cm)	Leaf number sheet	Leaf color
Control	90	20.2	15.5	34.3	2
NPK	96	29.5	21.3	40.3	4
Bed soil	90	22.3	16.8	34.3	3
TAO-S	100	28.8	21.3	39.8	4
TAO-PF	98	25.4	19.8	38.3	3

C; no fertilizer, NPK; chemical fertilizer, Bed soil; general manure, TAO-S; internal sludge which occurred after treating a pig slurry by TAO system, TAO-PF; TAO solid 50% + Rice husk 50%, respectively.

mS/cm, respectively, which were higher than other treatment groups but insignificant to the growth of crops. Contents of N, K, and Mg were 0.11 ~ 0.14%, 0.24 ~ 0.37%, and 0.28 ~ 0.36%, respectively, showing very small difference by treatments.

In Table 3, the growth of *Chinese cabbage* according to different types of fertilizer treatment was compared. NPK and TAO-PF showed the most growth, and TAO-S and Bed soil were the average, and the control group showed the least growth. In case of TAO-PF, height, width and number of leaves were 29.8 cm, 22.2 cm and 41.4 leaves, respectively, showing the most growth; NPK and TAO-S were 29.5 cm, 21.3 cm, and 40.3 leaves and 28.8 cm, 21.3 cm, and 39.8 leaves, respectively, showing the average growth. However, Bed soil and Control were 22.3 cm, 16.8 cm, and 34.3 leaves and 20.2 cm, 15.5 cm, 34.3 leaves, respectively, showing the least growth.

Soil quality is the term currently being used to describe the health of agricultural soils. The researchers proposed a suite of soil attributes (indicators) that could be used to describe soil quality(i.e., physical, chemical, and biological properties). The most desirable attributes are those that are sensitive to short-term changes in soil or crop management practices. Soil physical properties are indicators of the impact of soil and crop management practices(Doran et al., 1994; Gregorich et al., 1994). Evaluation of pH, EC, and total N contents of soil is deemed essential for assessing chemical aspects of soil quality. The chemical aspects are important because they provide a measure of the ability of soil to supply nutrients and to buffer against chemical additives of amendments(Campbell et al, 1991; Churchman and Tate, 1987; Tisdall and Oades, 1982). In growth rate of *Chinese cabbage*, the reason that growth rate of TAO-PF is lower than NPK and TAO solid is because the nutrients of NPK was able to easily absorb crops as a water-soluble. But TAO-PF was slow in its degradation and only about 70% was absorbed during the growth of crops. Particularly when fermentation is incomplete, these phenomena will become greater. Therefore, it is considered that when using particle-type fertilizer, it should be supplemented with particle-type solids + top manure(about 30%) after soil examination and then gradually reduced its amount each year if continuously tested on the same place.

3. Change of soil microbes

Microflora changes after 15 days of planting and after harvesting *Chinese cabbage* were shown in Table 4. It is generally known that there are 0.1 ~ 1.0 billion microorganisms and pathogenic

Table 4. Comparison of soil microbes for 15 and 50 days after planting by different type of fertilizer

Fertilizer	15 day, CFU/mℓ			50 day, CFU/mℓ		
	Bacteria 10^7	Actinomycetes 10^4	Fungi 10^2	Bacteria 10^7	Actinomycetes 10^4	Fungi 10^2
Control	4.0	8.0	ND	3.0	4.0	1.5
NPK	2.5	12.0	ND	2.2	6.2	2.5
Bed soil	3.5	5.0	2.0	4.2	12.0	0.52
TAO-S	8.0	6.0	9.0	8.3	30.0	0.72
TAO-PF	1.5	20.0	22.0	6.3	53.0	4.5

C; no fertilizer, NPK; chemical fertilizer, Bed soil; general manure, TAO-S; internal sludge which occurred after treating a pig slurry by TAO system, TAO-PF; TAO solid 50% + Rice husk 50%, respectively.

bacteria in soil. There are *fungi* that can develop damages in plants and *Actinomyces*, a kind of probiotics, that can inactivate these *fungi*, and bacteria that improve soil aggregates and live by micro-degradation. In Table 4, changes of these soil bacteria were well presented. The range of bacteria by treatment blocks after 15 days of planting was $1.5 \times 10^7 \sim 8.0 \times 10^7$ CFU/mℓ, but decreased from 2.5×10^7 CFU/mℓ and 4.0×10^7 to 2.2×10^7 CFU/mℓ and 3.0×10^7 CFU/mℓ after harvesting in the NPK and the control, respectively. It was similar in case of *Actinomycetes*, and decreased from and 1.2×10^5 CFU/mℓ and 8.0×10^4 to 6.2×10^4 and 4.0×10^4 CFU/mℓ respectively. But in case of *Fungi*, it was not detected in early period but increased to 2.5×10^2 and 1.5×10^2 CFU/mℓ.

The microbial distribution in soil has been explained by the content of clay and organic matter. The close relationship between microbes, organic matter, and clay for the survival of microbes, where organic matter provides the substrate and clay surfaces act as a nutrient supply, has been pointed out(Van et al., 1996). Decomposition is an important determinant of soil fertility and is, therefore, of considerable importance to agriculture. The primary decomposers of organic matter in the soil are fungi and bacteria, of which Fseudomonas and actinomycetes(Lacey, 1973; Chatterjee and Nandi, 1981) are two of the most important groups of soil bacteria. Actinomycetes make up a significant part of the soil microflora. They are major decomposers of complex polymers such as lignocelluloses and chitin, and may inhibit or lyse soil fungi(Goodfellow and Williams, 1983). Soil actinomycetes have varying degrees of inhibitory activity against specific fungi or generally reduce soil fungal populations (Keast and Tonkin, 1983; Friedman et al., 1989; de Boer et al., 1998; Valois et al., 1996; El-Tarabily et al., 2000). At Table 4, the Control and the NPK decreased rapidly if they conducted a rate of *Actinomycetes*:*Fungi*(A/F rate). However, the A/F rate of TAO-S, TAO-PF and the Bed Soil were increased considerably. The greater A/F ratio, that is the more *Actinomyces*, means that the bacteriostatic property of soil is improved and the damage to roots by *fungi* is decreased. The reason is that *Actinomycetes* have the ability to produce antibiotics, chemical substances that inhibit bacterial growth.

CONCLUSIONS

We treated pig slurry using TAO system and then added rice husks as a bulking agent to

these solids produced after the treatment to make TAO-PF. Then effects of TAO-PF on crops and changes of soil characteristics were investigated. The result showed that the proper moisture content of TAO-PF with even nutrients contents was 12% for long-term storage life. In the growth of *Chinese cabbage*, TAO-PF showed better growth than Bed soil sold in the market and Control group with no fertilizer, and similar to that of NPK. Also, it is expected to have substitution effect for chemical fertilizer because it showed better results in changes of soil characteristics than NPK after growing *Chinese cabbage*. However, it is considered that it is supplemented by top manure during the growth period of crops and also its amount should be decreased by year if it is applied to the same place over and over because TAO-PF is slow in degrading organic materials.

적 요

고온호기성발효장치(TAO system)로 발효 처리한 양돈분뇨고형물을 톱밥과 왕겨로 혼합한 뒤 성형건조장치를 이용하여 펠렛 비료를 제조하였다. 제조된 펠렛 비료(TAO-PF)의 비료이용성을 검토하기 위하여 배추를 이용하여 포장시험을 실시하였으며, 수확 후 생육량 및 토양의 생물, 이화학적 변화를 분석하였다. 생육실험은 펠렛 비료(TAO-PF)를 포함하여 시판 상토(Bed soil), 발효고형물(TAO-S), 화학비료(NPK), 무비료(대조구)로 나누어 실험하였다. 제조된 발효펠렛(TAO-PF)의 상온저장성은 미생물의 증식 경향으로 보아 수분 함량이 18%, 25% 처리구보다는 12% 처리구가 적절한 것으로 판단되었다. 배추를 이용한 각 처리구에서의 생육실험 결과, 토양세균의 변화는 TAO-PF 처리구가 NPK, 무비료구 보다 처리기간중 증식하는 경향을 보였으며, 특히 방선균의 증가와 사상균의 감소 현상은 NPK, 무비료 처리구에 비해 TAO-S, TAO-PF 처리구에서 현저하여 발효고형물의 토양시비가 토양생물상 변화에 매우 효과적인 것으로 나타났다. 본 생육실험을 통해 배추의 구고, 구폭, 엽수 등으로 보아 TAO-S, TAO-PF 처리구는 각각 화학비료, 시판상토 처리구를 대체 할 수 있을 것으로 판단된다.

(**핵심단어** : 펠렛비료, 토양미생물, 화학비료, 작물생육, 토양이화학성상)

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