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Composting of Livestock Waste and Development of Operating Parameters
I. Development of Optimum Process Parameters in Cow Manure Composting

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축산 폐기물의 퇴비화 및 운용지표 개발
I. 우분의 퇴비화에 있어서 최적 공정운용지표의 개발

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초 록

우분의 효율적인 퇴비화를 위한 최적 공정운용지표를 결정하기 위하여 실험실규모의 퇴비화 반응기를 설치하였다. 우분에 톱밥을 소량 혼합하여 초기의 C/N비를 24, pH를 6.9로 조절하였다. 송기량을 200 *ml*/min kg. VS, 500 ml/min kg. VS, 1000 ml/min kg. VS, 1500 ml/min kg. VS로 정하여 퇴비화를 실시하고 온도 상승곡선과 최종 C/N비, 분해율로 퇴비화의 효율을 판단한 결과 1000 ml/min kg. VS에서 가장 양호한 퇴비화가 진행되었다. 한편 수분함량을 40%, 50%, 60%, 70%로 달리하여 퇴비화를 실시한 결과 수분함량이 50%일 때 가장 퇴비화의 효율이 좋았으며 20일 후의 분해율은 43%였다. 또한 초기의 pH는 모두 중성내지 약 알카리성으로 상승하였으며 퇴비화의 효율에 있어서는 별다른 차이가 없었다. 즉 온도 상승곡선과 C/N비의 저하, 분해율에 있어서 비슷한 결과를 나타내었다.

상기 실험으로 결정된 최적 운용조건하에서 퇴비화를 실시하여 미생물수를 계수하였다. 세균의 수는 퇴비화의 시간에 따라 증가하여 실험종료일인 20일째는 건조 퇴비화 물질 1g당 1.5×10^9세포 였으며 방선균은 1.1×10^8개체, 곰팡이는 3.0×10^8 개체였다. 방선균과 곰팡이의 숫자는 다른 연구 결과에서 나타난 수치보다 대체로 높았다. 또한 지표세균군을 계수하였는 바 대장균군은 초기에 건조 퇴비화 물질 1g당 3.1×10^3, 분원성 대장균군은 7.5×10^2 세포, 분원성 연쇄상구균은 5.6×10^5 세포 존재하였다. 이러한 개체군수는 퇴비화의 시간이 지남에 따라 감소하여 대장균과 분원성 대장균은 16일째에, 분원성 연쇄상균은

20일째에 발견되지 않았다. 이러한 지표세균군들의 생존기간은 타 연구결과에 비해 대체로 더 길었다. 우분의 퇴비화에서 분리동정된 세균속은 *Bacillus* 속이 89.3%로 가장 많았으며 *Bacillus* 속 중에서는 B. *circulans* complex가 가장 많이 출현하였고 *B. stearothermophilus, B. sphericus, B.*의 순이었다.

ABSTRACT

In order to determine the optimum operational paramsters in cow manure composting, 4 laboratory scale composters were established. The cow manure was mixed with certain amount of saw dust to adjust the initial C/N ratio to 24, initial pH to 6.9 and composting was performed with varying operational conditions. It was found that the optimum aeration rate was 1000 ml/min kg. VS, the optimum moisture content 50% and no significant difference was found with different initial pH condition. Microorganisms were counted under the optimum conditions determined in this study. At the end of the experimental period, the number of bacteria, actinomycetes and fungi was 1.5×109 cells, 1.1×108 cells and 3.0×108 cells/g dry compost, respectively. At day 0, the number of coliforms, fecal coliforms and fecal streptococci was 3.1×103 cells, 7.5×102 cells and 5. 6×103 cells/g dry composting material, respectively. Their population was decreased with time lapse, However, their survival time was longer than those reported by other researchers. Microorganisms were identified at the end of the experiment. Genus *Bacillus* was the most dominant comprising 89.3% of the total population. Among the Genus *Bacillus*, B. circulans compoex was the most abundant, followed by *B. Stearothermophilus, B. Sphericus, B. licheniformis* and *B, brevis.*

Key words—Composting, Cow manure, Composting microorganisms, Coliform survival, *Bacillus*

INTRODUCTION

Cow manure, which is generated in considerable amount at countryside in Korea, has been traditionally used for soil conditioner with little treatment. Usually cow manure was piled in the field for several months and then applied for crops. As the increased use of chemical fertilizers and with the lack of labor force in agriculture due to the agricultural population decrement, cow manure was seldom applied and thus agricultural waste problems occurred. Actually there are many cases of surface and ground water contaminations in the vicinity of liverstock feedlots. (Korea Environmental Protection Agency, 1992)

Compost from cow manure is an excellent soil conditioner improving physicochemical properties in soil. It also contains considerable amount of nutrients for plant growth. Thus, long term application of compost to soil greatly helps healthy crop growth so that farmers can decrease the frequent use of pesticides on crops.

Most of studies show that the compost exercises a positive influence on crops due, inter alia, to its ability to supply nutrients to the plants (Terman et al., 1973; De Haan, 1981).

Although the cow manure is a good composting material, unmatured compost could give damages on crops (Jimnez and Garcia, 1989). Thus, it is necessary to develop an optimum process parameters in cow manure compositing for fast stabilization. In recent years many research have been performed to optimize composting process (Finstein and Miller, 1985). Some of these research results could be appicable to the optimization of cow manure composting process. However, the physical and chemical properties of organic wastes are somewhat different so that process optimization for cow manure which is produced in Korea is necessary.

The purpose of this study was to develop process parameters for optimization of cow manure composting. The effect of aeration volume, C/N ratio, pH and moisture content on temperature and decomposition rate was investigated. Also, some microbiological study was performed to help interpret the significance of process parameters.

MATERIALS AND METHOD

Composting Reactor

Fig. 1 shows the schematic diagram of experimental unit. The composting

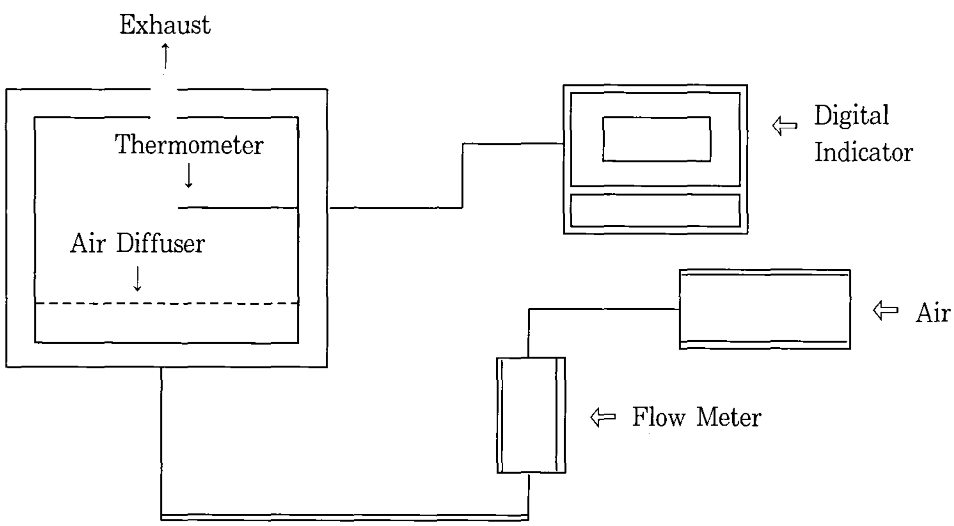

Fig. 1. Schematic Diagram of Composting Reactor

reactor was consisted of 4 acryl cylinders with diameter 20 cm and height 25 cm. Each reactor was insulated by wrapping up it with 3 cm thick styrofoam. Under each cylinder 2 air diffusers were installed. The amount of air was controlled by flow meter. An electrical thermometer was inserted in the middle of each reactor for temperature measurment. Mixing of the composting material was done by shaking vigorously with hands each reactor once a day.

Analysis

Moisture content was measured by calculating weight loss of sample after storing in a drying oven at 105℃ for 2 hours (Korea Environmental Protection Agency, 1991). For pH measurement, one gram of sample was taken, 1:5 dilution was made with distilled water and then pH was measured after 5 minutes mixing with a spatula (Korea Agricultural Development Agency, 1988).

For the determination of volatile matter, 1g of sample was taken. After 2 hours' incubation in a muffle furnace at 600℃, then the ignition loss was calculated (Korea Agricultural Development Agency, 1988). Total organic carbon and total Kheldahl nitrogen were measured by the method shown by "Analytical Method in Soil Chemistry" published by the Institute of Agricultural Technology (Korea Agricultural Development Agency , 1988).

Decomposition percentage was determined by dry weight difference between initial composting material and final compost product.

For the enumeration of bacteria, fungi and actinomycetes, standard methods for the examination of water and waste water (17th ed., APHA, AWWA, WPCF, 1989) was followed (Total count: 9215C; coliform: 9221B; fecal streptococci: 9230C: actinomycetes: 9280B; Fungi: 9610C). Bergy's manual of Systematic Bacteriology (Eds Crieg and Holt, 1984) and Biochemical Tests for Identification of Medical Bacteria (Mac Faddin, 1980) were referred for the identification of bacteria.

RESULTS

Phase Ⅰ: Effect of aeration rate on cow manure composting

The raw cow manure and saw dust was mixed in 9: 1 by wet weight basis. The moisture was adjusted to 50%. Initial C/N ratio was 24. To adjust pH around 7, certain amount of $Ca(OH)_2$ was added. Thus, the adjusted initial pH was 6.9. The air was supplied by air diffusers. Table 1 show the experimental conditions in phase Ⅰ.

Fig. 2 shows the temperature change with different aeration rate. In most cases temperature showed peak at day 6.

Table 1. Experimental Conditions in Phase I

Condition Reactor	Aeration Rate	Moisture Content(%)	C / N ratio	Initial pH
1	200 ml/mim kg VS	50	24	6.9
2	500 ml/min kg VS	50	24	6.9
3	1000 ml/min kg VS	50	24	6.9
4	1500 ml/min kg VS	50	24	6.9

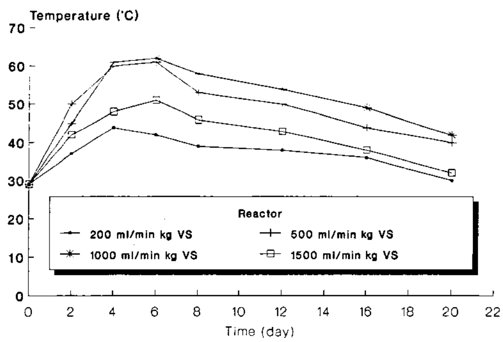

Fig. 2 Change of Temperature with Different Aeration Rate.

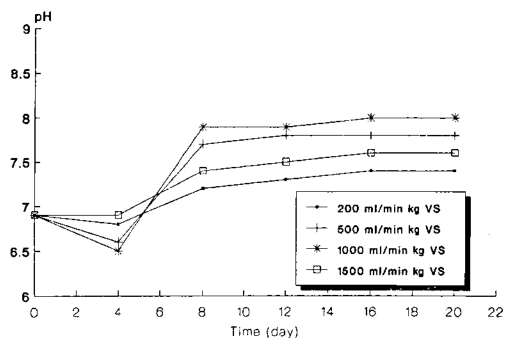

Fig. 3 Change of pH with Different Moisture Content.

The highest temperature was obtained with the aeration rate of 1000 ml/min kg VS throughout the entire phase. The second was that of 500 ml/min kg VS, followed by that of 1500 ml/min kg VS and that of 200 ml/min kg VS in decreasing order.

Fig. 3 shows pH change with different aeration rate. In all cases pH decreased at day 4 and then increased again. At day 20, the highest pH value was resulted with the aeration rate of 1000 ml/min kg VS. The reactor supplied with 500 ml/min kg VS showed the second highest pH value.

Change of C/N ratio with different aeration rate was shown in table 2. At day 20, the reactor with the aeration rate of 1000 ml/min kg VS reached at 13, which was the lowest C/N ratio among 4 reactors. The reactor with the aeration rate of 200 ml/min kg VS reached at 17, which was the highest C/N ratio.

Table 3 shows the decomposition percentage of the composting material with different aeration rate. The reactor with 1000 ml/min kg VS showed the best

Table 2. Change of C/N ratio with Different Aeration Rate

Aeration rate	Initial C/N ratio(day 0)	Final C/N ratio(day 20)	Difference
200 ml/min kg VS	24	17	-7
500 ml/min kg VS	24	14	-10
1000 ml/min kg VS	24	13	-11
1500 ml/min kg VS	24	16	-8

Table 3. Decomposition percentage with Different Aeration Rate

aeration rate	Decomposed(%)	Remained(%)
200 ml/min kg VS	26	74
500 ml/min kg VS	39	61
1000 ml/min kg VS	42	58
1500 ml/min kg VS	30	70

decomposition percentage followed by the reactor with 1500 ml/min kg VS and 200 ml/min kg VS.

Phase Ⅱ: The effect of moisture content on cow manure composting

In the experiment phase Ⅱ, moisture content of the composting material was changed with the other process parameters fixed. The experimental condition of phase Ⅱ is shown in Table 4.

Fig. 4 shows change of temperature with different moisture content. The reactor with 50% of moisture content

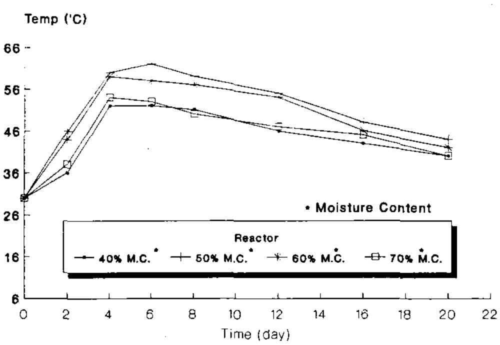

Fig. 4. Change of Temperature with Different Moisture Content.

Table 4. Experimental Conditions in Phase Ⅱ

Reactor	Moisture content(%)	C/N ratio	Aeration rate	Initial pH
1	40	25	1000 ml/min kg VS	6.8
2	50	25	1000 ml/min kg VS	6.8
3	60	25	1000 ml/min kg VS	6.8
4	70	25	1000 ml/min kg VS	6.8

showed the highest temperature throughout the entire phase followed by the reactor with 60% of moisture content, that with 70% and that with 40% in decreasing order.

Fig. 5 shows the change of pH with different moisture content. For all cases, the pH dropped at day 4 and then increased to the end. At day 20, the reactor with 50% of moisture content reached at pH 8.2, which was the highest value among 4 reactors.

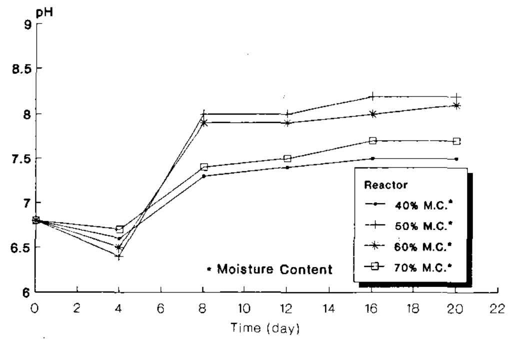

Fig. 5. Change of pH with Different Moisture Content.

The reactor with 60% of moisture content showed the second highest pH value, followed by that with 70% of moisture content and that with 40% moisture content.

Table 5 shows the change of C/N ratio with different moisture content. At day 20, the reactor with 50% of moisture content showed the lowest final C/N ratio, followed by that with 60% of moisture content and that with 40% of moisture content in decreasing order.

Decomposition percentage with different moisture content is shown in Table 6. The reactor with 50% of moisture content showed the highest decompo-sition, followed by that with 60% of moisture content, that with 70%

Table 5. Change of C/N ratio with Different Moisture Content

Moisture content (%)	Initial C/N ratio (day 0)	Final C/N ratio (day 20)	Difference
40	25	19	6
50	25	14	11
60	25	16	9
70	25	18	7

Table 6. Decomposition Percentage with Different Moisture Content

Moisture Content	Decomposed (%)	Remained (%)
40%	30	70
50%	43	57
60%	41	59
70%	32	68

Table 7. Experimental condition of Phase Ⅲ

Initial pH	Aeration rate	Initial C/N ratio	Initial temp.	Moisture content(%)
5.6	1000 ml/min kg VS	26	30℃	50
7.1	1000 ml/min kg VS	26	30℃	50
8.7	1000 ml/min kg VS	26	30℃	50

of moisture content and that with 40% of moisture content in decreasing order.

Phase Ⅲ: Experiment with acidic and alkaline pH conditions

In this phase of experiment, the effect of acidic and alkaline pH on cow manure composting was examined. The experimental condition of Phase Ⅲ is shown in Table 7.

Fig. 6 shows the temperature change during the experimental phase Ⅲ. Generally 3 reactors showed similar temperature change profile although the reactor started with initial pH 7.1 showed slightly higher one.

Fig. 6 shows the pH change during the composting period with different initial pH condition. In the case of the reactor with initial pH 5.6, pH increased steadily throughout the experimental period and reached at pH 7.5 at day 20.

In the case of that with initial pH 7.1, pH slightly decreased at day 4 and then increased steadily to the end reaching at pH 7.8 at day 20. The reactor started with initial pH 8.7 showed a slight pH increment throughout the experimental period.

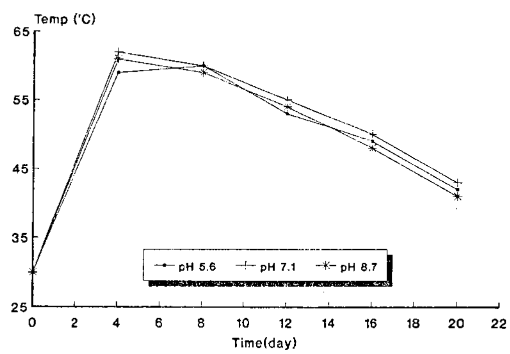

Fig. 6. Change of Temperature with Different Initial pH.

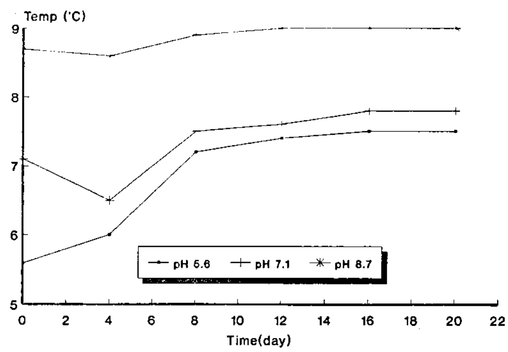

Fig. 7. Change of pH with Different Initial pH Condition.

Table 8. Change of C/N ratio with Different Initial pH condition

Initial pH	Initial C/N ratio (day 0)	Final C/N ratio (day 20)	Difference
5.6	26	15	11
7.1	26	14	12
8.7	26	16	10

Table 9. Decomposition Percentage with Different Initial pH Condition

Initial pH	Decomposed (%)	Remained (%)
5.6	39	61
7.1	41	59
8.7	38	62

The change of C/N ratio with different initial pH condition is shown in Table 8. The final C/N ratio was similar for 3 reactors with different initial pH condition, although the reactor started with initial pH 7.1 showed slightly lower C/N ratio than the other two reactors.

Table 9 shows the decomposition percentage with different initial pH condition. There were very little differences in decomposition percentage among 3 reactors.

Phase Ⅳ: Microoganisms present in cow manure composting

In this phase, microoganisms in the cow manure composting reactor were counted. Samples were taken from the reactor started with initial pH 7.1 in Phase Ⅳ. Table 10 shows the number of microoganisms found in cow manure composting. The bacterial population was present with the greatest abundance. The number of actinomycetes and fungi was present in similar abundance. Their numbers were lower in one or two order of magnitude than bacterial count. Coliforms was 3.1×10^3 and they disappeared at day 16. Fecal coliforms were present in smaller numbers than

Table 10. Number Microoganisms found in Cow Manure Composting

Microoganism	day 0	day 8	day 16	day 20
Bacteria	1.2×10^5	1.0×10^8	7.2×10^8	1.5×10^9
Actinomycetes	1.5×10^4	3.4×10^6	5.3×10^7	1.1×10^8
Fungi	2.0×10^5	1.4×10^6	1.0×10^7	3.0×10^8
Coliforms	3.1×10^3	1.2×10^1	0	0
Fecal Coliforms	7.5×10^2	0.9×10^1	0	0
Fecal Streptococci	5.6×10^5	3.5×10^3	3.2×10^1	0

Table 11. Bacteria Isolated from Cow Manure Composting

Species	Number($\times 10^8$)
Bacillus circulans complex	38
B. stearothermophilus	31
B. coagulans	24
B. sphaericus	12
B. licheniformis	10
B. subtilis	7
B. brevis	5
Unidentified *Bacillus*	7
Non-sporeformers	16

coliforms and also disappeared at day 16. The initial number of fecal streptococci was 5.6×10^5, then decreased thereafter and they disappeared at day 20.

Bacteria isolated from cow manure composting is shown in Table 11. Bacteria isolated were predominantly Bacillus, consisting 89.3% of the total bacterial count. Among Genus *Bacillus*, *Bacillus circulans* complex was the most abundant followed by *B. stearothermophilus*, *B. coagulans*, *B. sphericus*, *B. licheniformis*, and *B. brevis*.

DISCUSSION

Aeration

In this study, the optimum aeration rate was 1000 ml/min kg VS. This result was in accordance with the value obtained with agricultural waste composting (Seong-Ho Lee, 1990). With the aeration rate of 200 ml/min kg VS, oxygen supply seems to be insufficient. The aeration rate of 1500 ml/min kg VS seems to cool down the composting material by over-aeration.

Air supply in the composting has several functions. It makes microoganisms to perform aerobic metabolism, control temperature, and remove moisture, CO_2 and other gases. If excess amount of air is supplied, the composting process could be slow down due to temperature drop by cooling and moisture loss (MacGregor et al, 1981). The aeration rate of 200 ml/min kg VS seems to cause oxygen deficiency in the compost pile. De Bertoldi et al. (1982) reported that more than 18% of oxygen concentration should be included in the air supply to achieve an effective composting.

Although the percentage of oxygen was not determinated in this study, the aeration rate of 200 ml/min kg VS appears to give insufficient concentration of oxygen which could achieve effective composting.

Moisture content

In this study, the optimum moisture content was 50% with the aeration rate of 1000 ml/min kg VS. This result is also in good accordance with other research result. Quite a few researchers reported that optimum moisture content is between 50% and 60% and the decomposition rate is decreased when the moisture content is below 40% or above 60% (Golueke, 1972; Poincelot, 1971). However, the optimum moisture content also appears to depend upon the structure of the reactor and the property of composting material. For example, in sludge composting usually the moisture content of 50-60% can not achieve effective composting since the material is compacted, so the air can not easily penetrate into it and thus the microbial activity is inhibited (Choe et al., 1991).

pH

In general, the optimum pH range for composting is wide, which is usually 5.5-8.0 (Chung, 1992). There exist optimum pH range for microbial growth. In this study, pH didn't affect greatly on the efficiency of composting. Actually there was no significant difference in decomposition percentage whether the initial pH is acidic, or alkaline. In most case, if composting is started with acidic pH, it tends to be increased to neutral or alkaline pH. Sometimes, CaO, $CaCO_3$ or $Ca(OH)_2$ is added to control pH. However, pH control is generally considered to have little effect on the composting efficiency (Finstein and Morris, 1975; Chung, 1984). Therefore, pH control for effective composting seems not to be a necessary operational factor.

In some cases, pH is decreased at starting period in composting. In this study, pH was dropped at the beginning stage. It seems that organic acids could be formed during the initial stage of decomposition (Bae, 1991).

Change of C/N Ratio

The C/N ratio of the final compost

Table 12. Initial and Final C/N Ratios

Researchers	Initial C/N	Final C/N	Final C/N / Initial C/N	Composting days
Parra (1962)	31.0	19.0	0.61	63
Kehren (1967)	27.0	14.0	0.52	40
Chanyasak & Kubota (1981)	20.7	14.9	0.72	not indicated
Chanyasak et al (1982)	21.5	16.1	0.75	120
Lavasseur & Saul (1982)	33.0	18.0	0.55	70
This study (Phase Ⅲ)	26.0	14.0	0.54	20

product can be an indicator of compost maturity. Many researchers had experiments with various composting materials. Their initial C/N ratio were between 20.7-33.0 and final C/N ratio were between 14-19 (Table 12).

Although C/N ratio criteria can not be considered as an absolute indicator of the degree of compost maturity, the C/N ratio of final compost product should be approximately less than 18. This is consistant other research results performed in Korea (Kang et al, 1987). Actually their results were somewhat lower than 18, reaching at 11 to 15.

Since the final C/N ratio is affected by the initial C/N ratio to some extent, the ratio of final C/N to initial C/N could be used as an indicator of compost maturity. However, this ratio is dependant upon the value of initial C/N ratio. Usually when started with higher Initial C/N ratio, it tent to be higher. Therefore, this ratio should be considered as a supplementary indicator, not as an absolute indicator.

Microorganism

In this study, heterotrophic count for total bacteria started with 1.2×10^5 and reached at 1.5×10^9 at the end. The number of actinomycetes and fungi was less than bacteria in one order of magnitude.

This number is in the typical range in composting. Usually typical number of bacteria in composting is between 10^7 and 10^9, and the number of acti-

Table 13. Response of Some Bacteria to High Temperature (Finstein and Morris, 1975)

Microoganism		Response
Salmonella typhosa	:	No growth beyond 46℃, death within 30 min at 55-60℃
Salmonella spp.	:	Death within 1 hr at 56℃ death within 15~20 min at 60℃
Shigella spp.	:	death within 1 hr at 55℃
Esherichia coli	:	Most die within 1 hr at 55℃ and within 5 min at 71℃
Brucella abortus or *suis*	:	death within 3 min at 61℃
Micrococcus pyogenes var. aureus	:	Death within 10 min at 50℃
Streptococcus pyogenes	:	Death within 10 min at 54℃
Mycobacterium tuberculosis var. hominis	:	Death within 15~20 min at 66℃ or momentary heating at 67℃
Mycobacterium diptheriae	:	Death within 45 min at 55℃

nomycetes and fungi is less than bacteria in two order of magnitude. In the case of cow manure composting, it seems that the population of actinomycetes and fungi contribute significantly in the decomposition process.

Coliforms and fecal coliforms were not present at day 16. This means that they disappeared between day 8 and day 16. Fecal streptococci disappeared between day 16 and day 20. The death of bacteria depends upon the temperature. Most coliforms, fecal coliforms and pathogenic bacteria are killed within one hour at 55 ~60℃ (Table 13).

Therefore, many states in USA require for all mechanical composting to keep temperature above 55℃ for 3 days. In this study, coliforms and fecal coliforms survived longer than the specified times in Table 13. It seems that it takes longer to kill those indicator microorganisms in a compost pile and so thus with pathogenic bacteria.

Bacteria isolated from cow manure composting was predominantly *Bacillus* and among Genus *Bacillus*, *Bacillus circulans* complex was the most abundant followed by *B. stearother-mophilus*, *B. coagulans*, *B. sphericus*, *B. licheniformis and B. breris*. This is also in good accordance with other research results (Strom, 1985).

SUMMARY AND CONCLUSION

Experimental scale composters were established to determine the optimum process parameter for efficient cow manure composting. When composting was performed with different aeration rates ranging from 200 ml/min kg VS to 1500 ml/min kg VS, the optimum aeration rate was found to be 1000 ml/min kg VS judging by the temperature profile and decomposition percentage. Experiment with varied moisture content showed that the optimum moisture content for cow manure composting was 50%.

Composting with initial pH 5.6 and with 8.7 showed that there was no significant difference in composting efficiency. In both cases, it gradually increased to netral and alkaline pH with the similar final C/N ratio and decomposition percentage.

Microorganisms were counted in a composting reactor with an optimum condition determined from the above experiment. The number of bacteria increased with the composting period and reached at 1.5×10^9/g dry compost.

The number of actinomycetes and fungi was 1.1×10^8/g and 3.0×10^8/g dry matter at the end, respectively. These numbers were somewhat higher than the other results. The number of coliforms, fecal coliforms and fecal streptococci in the initial composting material was 3.1×10^3/g, 7.5×10^2/g and 5.6×10^5/g dry matter, respectively. Their populations decreased with the time lapse. Coliforms and fecal coliforms were not present at day 20. Generally, their survival times were longer that the other study results. Bacteria isolated from cow manure composting were predominantly *Bacillus.* Among Genus *Bacillus, B. circulans* complex was the most abundant followed by *B. stearothermophilus, B. sphericus, B. licheniformis and B. brevis.*

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