การทำปุ๋ยหมักจากมูลสุกรโดยใช้ระบบอัดอากาศ

นางสาว ชนกพร หนูหอม

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

สาขาวิศวกรรมสิ่งแวดล้อม

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COMPOSTING OF PIG MANURE USING FORCED-AERATION SYSTEM

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เนื่องจากมูลสุกรทำให้เกิดกลิ่นเหม็นและเป็นแหล่งกำเนิดของเชื้อโรค ทำให้เกิดผลกระทบต่อสิ่งแวดล้อม เนื่องจากมูลสุกรมีสารอาหารและแร่ธาตุที่มีประโยชน์และโทษ เช่น โลหะหนักตกค้างในดิน, การสะสมตัวของสสารและแร่ธาตุในน้ำผิวดิน ทำให้เกิดการเจริญเติบโตของพืชน้ำอย่างรวดเร็ว (Eutrophication) ซึ่งเกิดผลกระทบต่อสิ่งมีชีวิตอื่น และการปนเปื้อนของน้ำใต้ดิน ในขณะเดียวกันมูลสุกรซึ่งมีสารอาหารและแร่ธาตุเหล่านี้ สามารถนำกลับมาใช้ประโยชน์ต่อการเกษตรได้ โดยการทำปุ๋ยหมัก อย่างไรก็ตามการนำกลับมาใช้ใหม่นี้ ควรเป็นวิธีที่ประหยัดและปลอดภัยต่อสิ่งแวดล้อม

การศึกษาวิจัยนี้เป็นการทำปุ๋ยหมักจากมูลสุกร โดยแบ่งเป็น 2 ชุดการทดลอง ชุดแรก 6 กอง และชุดที่สอง 3 กองการทดลองในชุดแรกกำหนดให้ค่าสัดส่วนเริ่มต้นของคาร์บอนต่อไนโตรเจน (C/N ratio) 20:1, 30:1 และ 40:1 อย่างละ 2 กอง (กองแรกมีการอัดอากาศ 0.6 m^3/d/kg ของของแข็งระเหยทั้งหมด 24 ชั่วโมงต่อวัน และอีกกองหนึ่งไม่มีการอัดอากาศใช้ เป็นกองสำหรับอ้างอิง) ส่วนชุดที่สองกำหนดให้มีค่าสัดส่วนเริ่มต้นของคาร์บอนต่อไนโตรเจน 20:1 ในแต่ละกองเท่ากันแต่มีการอัดอากาศในเวลาที่แตกต่างกัน กล่าวคือ 6 ชั่วโมง, 12 ชั่วโมง และ 18 ชั่วโมงต่อวันตามลำดับ ในการทดลองนี้กองปุ๋ยแต่ละกองเตรียมจากส่วนผสมของมูลสุกรสดและฟางหญ้าบดละเอียด และมีการพลิกกลับกองวันละครั้ง มีการวิเคราะห์ทางเคมีและฟิสิกส์ตลอดการทดลอง รวมทั้งการวิเคราะห์หาแบคทีเรียโคลิฟอร์มทั้งหมด (Total Coliform bacteria) ซึ่งเป็นตัวบ่งชี้ความสะอาดและปลอดภัยของปุ๋ยหมักที่ได้

จากการศึกษาวิจัยครั้งนี้พบว่ากองปุ๋ยที่มีการอัดอากาศ 24 ชั่วโมงต่อวัน และสัดส่วนเริ่มต้นของคาร์บอนต่อไนโตรเจน 20:1 เป็นปุ๋ยที่สะอาดปลอดภัย มีสารอาหารที่สำคัญต่อพืช คือ ไนโตรเจน, ฟอสฟอรัส และ โปแตสเซียม (N:P:K) และใช้ระยะเวลาในการหมักสั้นที่สุดคือ 28 วัน ส่วนกองปุ๋ยอื่นปราศจากเชื้อโรคและปลอดภัยโดยใช้ระยะเวลาหมัก 35 วัน ทั้งนี้ขึ้นอยู่กับความแตกต่างของสัดส่วนคาร์บอนต่อไนโตรเจน และเวลาในการอัดอากาศที่แตกต่างกัน การทดลองนี้พบว่า กองปุ๋ยที่มีสัดส่วนเริ่มต้นของคาร์บอนต่อไนโตรเจน 20:1 และอัดอากาศ 0.6m^3/d/kg ของของแข็งระเหยทั้งหมด 24 ชั่วโมงต่อวัน เป็นสภาวะที่เหมาะสมที่สุดในการทำปุ๋ยหมักจากมูลสุกรในครั้งนี้ ปุ๋ยหมักทั้งหมดนี้ไม่เพียงแต่ใช้ประโยชน์ในการปรับปรุงดินเท่านั้น แต่ยังสามารถเป็นปุ๋ยซึ่งมีสารอาหารที่สำคัญต่อพืชด้วย

สาขาวิชาวิศวกรรมสิ่งแวดล้อม ลายมือชื่อนักศึกษา

ปีการศึกษา 2544 ลายมือชื่ออาจารย์ที่ปรึกษา

CHANOKPRON NOOHOM: COMPOSTING OF PIG MANURE USING FORCED-AERATION SYSTEM.
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Pig manure causes obscene odor and is a pathogenic source. Inappropriate disposal of manure may pose environmental problems such as the accumulation of heavy metals in soil, pollution of surface water (eutrophication) due to run-off of nutrients and pollution of ground water due to microbial contamination and nutrients leaching. At the same time, pig manure contains useful nutrients which can be recycled into agricultural land. However such a recycling must be done in an environmentally sound, economically feasible and socially acceptable manner. Composting has been considered such a method which can produce hygienically safe and agriculturally useful humus like material (compost).

In this study, composting of pig manure was undertaken with two sets of experiments. First set includes six static piles (open at the top) with initial C/N ratio of 20:1, 30:1 and 40:1 in every two piles (one with artificial air supply rate of 0.6 m^3/d/kg of volatile solids, 24 hours a day and another without any artificial air supply, i.e., control). Second set includes three open piles with the C/N ratio of 20:1 and artificial air supply rate of 0.6m^3/d/kg of volatile solids for varying periods, such as 6 hours, 12 hours and 18 hours a day. Each composting pile was prepared by mixing the fresh pig manure with chopped hay in a pre-assigned ratio and turned manually, everyday. The chemical and physical parameters were observed throughout the composting period. Total coliform bacteria was used as the hygiene indicator.

The compost pile with forced-aeration for 24 hours a day and initial C/N ratio of 20:1 yielded safe compost product with appropriate N:P:K value in a shortest period (i.e., 28 days). Other compost piles yielded safe compost products on or after the composting period of 35 days, depending on their initial C/N ratios and air supply conditions. This suggested that compost piles with C/N ratio of 20:1 and artificial air supply rate 0.6 m^3/d/kg of volatile solids for 24 hours a day is the best condition for preparing compost from pig manure and hay. All of the compost products prepared can be used not only to improve the soil quality but also to give necessary fertilizer value to certain extent.

สาขาวิชาวิศวกรรมสิ่งแวดล้อม	ลายมือชื่อนักศึกษา
ปีการศึกษา 2544	ลายมือชื่ออาจารย์ที่ปรึกษา

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List of Abbreviations

C	=	Carbon
C/N	=	Carbon to nitrogen ratio
CO_2	=	Carbon dioxide
g	=	gram
μg/mL	=	microgram per milliliter
H_2O	=	Water
K	=	Potassium
kg/m^3	=	kilogram per cubic meter
m^3/day/kg	=	cubic meter per day per kilogram
L	=	Liter
L/min	=	Liter per minute
mg	=	miligram
mm	=	millimeter
N	=	Nitrogen
NH_4^+	=	Ammonia
NO_3^-	=	Nitrate
O_2	=	Oxygen
P	=	Phosphorus
p	=	Significant level
SO_4^{2-}	=	Sulphate ion
SUT	=	Suranaree University of Technology
TKN	=	Total kjeldahl nitrogen
TC	=	Total carbon
TS	=	Total solids
TVS	=	Total volatile solids
VS	=	Volatile solids
VSS	=	Volatile suspended solids

CHAPTER I

INTRODUCTION

1.1 General

Production of livestock, such as, cattle, pigs, chicken etc. in Thailand is a large farm activity in the present days. Environmental pollution problems arising from such farms are due to the generation of wastes in the forms of manure, urine and other related wastewater runoff. Manure causes obscene odor and is also a pathogenic source that supports the growth of a variety of pathogenic species, such as, different kinds of flies.

There were 271 pig farms in Nakhon Ratchasima, a north-eastern city of Thailand, in 1999. The total number of pigs in these farms are 230,368 (Nakhon Ratchasima City Livestock Authority, 1999). The manure (wet waste[1]) produced by these pigs is around 529 metric tons. A pig farm is also in operation at the Suranaree University of Technology (SUT) which has about 800 pigs in 1999.

According to Teekakul and Klinsukol (1993), there are 4 main methods for handling the pollution caused by pigs in an environmentally sound manner as explained below:

(a) Transformation of solid wastes into fertilizers by drying is the easiest way to deal with solid wastes. The process takes up about 3-5 days before the fertilizer is usable. This process is popular because the pig manure can be kept for a longer period of time and the moisture content is also decreased during the process. In this way the problems due to germs and odor is decreased. However, there are some disadvantages of this process, such as, the loss of nitrogen. Moreover, if the treatment process is not properly controlled, the accumulated pig manure can become a pathogenic source.

(b) Treatment of waste water before it is let out into public water source.

(c) Mixed farming such as operating a pig farm above the fish pond.

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[1] Wet waste produced by each pig is estimated as 5.1 % of total live weight per day considering the average weight of a pig is 45 kg (source: Polprasert, 1996).

(d) Modernization of farm operation method.

Preparation of compost could be a better method to deal with the problem of pollution. Moreover composting is a recognized waste recycling method and compost can be used to in the agricultural farms as the plants nutrients (N, P, K) source which can replace chemical fertilizer to a certain extent.

This study considers composting of pig manure collected from the pig farm of the Suranaree University of Technology (SUT) after mixing it with hay.

1.2 Objectives

The main objectives of this study were:

(1) to investigate the appropriate C/N ratio that is optimum for producing compost from pig manure, and

(2) to examine the aeration period that is optimum for the production of compost from pig manure.

1.3 Scope and Limitations of the Study

In this research, open compost piles (open at the top) of fresh pig manure mixed with hay have been studied. The conditions and considered parameters for investigation include

(1) initial C/N ratio of 20:1, 30:1 and 40:1 in every two compost piles (one with artificial air supply rate of 0.6 m^3/d/kg of VS, 24 hours a day and another with no artificial air supply, i.e., control),

(2) three compost piles (open at the top) with initial C/N ratio of 20:1 and air supply rate of 0.6 m^3/d/kg of VS for the aeration period of 6, 12 and 18 hours a day), and

(3) examination of chemical, physical characteristics such as moisture content, temperature, acid-base values (pH), ash, nitrogen content (N), phosphorus content (P), potassium (K), and biological characteristic, i.e., total coliform bacteria throughout the composting period.

CHAPTER II

LITERATURE REVIEW

2.1 Objectives, Benefits and Limitations of Composting

Composting has proved to be an effective means of, not only producing a fertilizer for crop growing, but also recycling the wastes for further beneficial use. Its main purposes and advantages are as follows.

(i) Waste stabilization. The biological reactions occurring during composting will convert the putrefaction forms of organic wastes into stable, mainly inorganic forms which would cause little further pollution effects if discharged on to land or into a water course.

(ii) Pathogen inactivation. The waste heat produced biologically during composting can reach a temperature of about 60^{o}C, which is sufficient to inactivate most pathogenic bacteria, viruses and helminthic ova, provided that this temperature is maintained for at least 1 day. Therefore the composted products can be safely disposed of on land, or used as fertilizers and soil conditioners.

(iii) Nutrient and land reclamation. The nutrients (N, P, K) present in the wastes are usually in complex organic forms, difficult to be taken up by the crops. After composting, these nutrients would be in inorganic forms such as NO_3^- and PO_4^- suitable for crop uptake. The application of composted products as fertilizer to land reduces loss of nutrients through leaching because the inorganic nutrients are mainly in the insoluble forms which are less likely to leach than the soluble forms of the uncomposted wastes. In addition, the soil tilth is improved, thereby permitting better root growth and consequent ready accessibility to the nutrients (Goleuke, 1982). The application of compost to unproductive soils would eventually improve the soil quality and the otherwise useless lands can be reclaimed.

(iv) Sludge drying. Human excreta, animal manure and sludge contain about 80-95 percent water, which makes the costs of sludge collection, transportation, and disposal

expensive. Sludge through composting is an alternative in which the waste heat produced biologically will evaporate the water contained in the sludge.

2.2 Process Microbiology

The composition of organic wastes for composting is so varying from the highly heterogeneous materials present in municipal refuse and sludge to virtually the homogeneous wastes from food processing plants. Thus, the destruction of organics coupled with the production of humic acid to produce a stabilized end product involves a complexity of biochemical reactions. Consequently, the microorganisms responsible for such reaction also vary, depending upon the temperature change during the course of composting. Figure 2-1 shows the typical temperature phases developed in composting process. They are described below in brief.

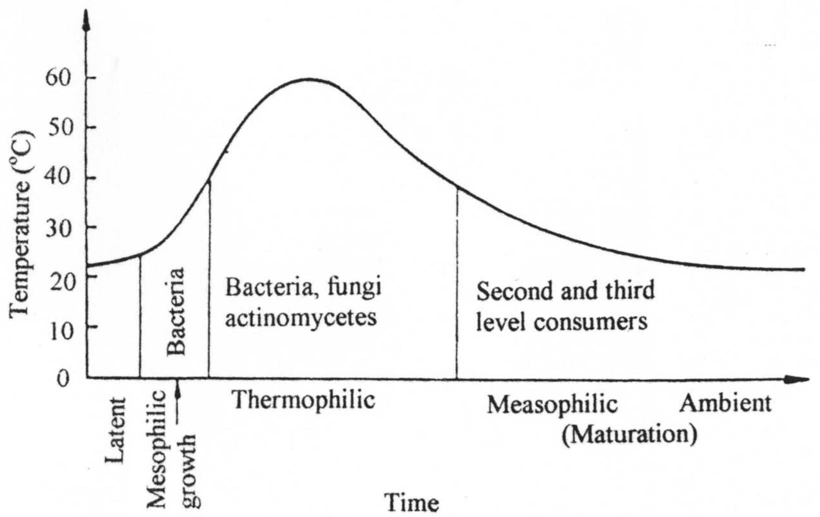

Figure 2-1. Patterns of temperature and microbial growth in compost pile (Polprasert, 1996).

(i) Latent phase. It is corresponding to the time necessary for the microorganisms to acclimate and colonize in the new environment of the compost heap.

(ii) Growth phase. During this period, numbers of microorganisms are increasing exponentially. Due to the biologically produced heat, the rise of temperature to mesophilic level is observed.

(iii) Thermophilic phase. The temperature rises to the highest level. This phase waste stabilization and pathogen destruction are most effective.

(iv) Maturation phase. The temperature decreases to mesophilic and, subsequently to ambient level. This phase is for the final transformation of waste to humus.

Although three major groups of organism, which carry out biological transformation in the composting process, are bacteria, actinomycetes, and fungi, other involved may include invertebrates, such as nematodes, earthworms, mites, and various other organism. These organisms establishes a food chain, consisting of three-level consumeres as illustrated in Figure 2-2.

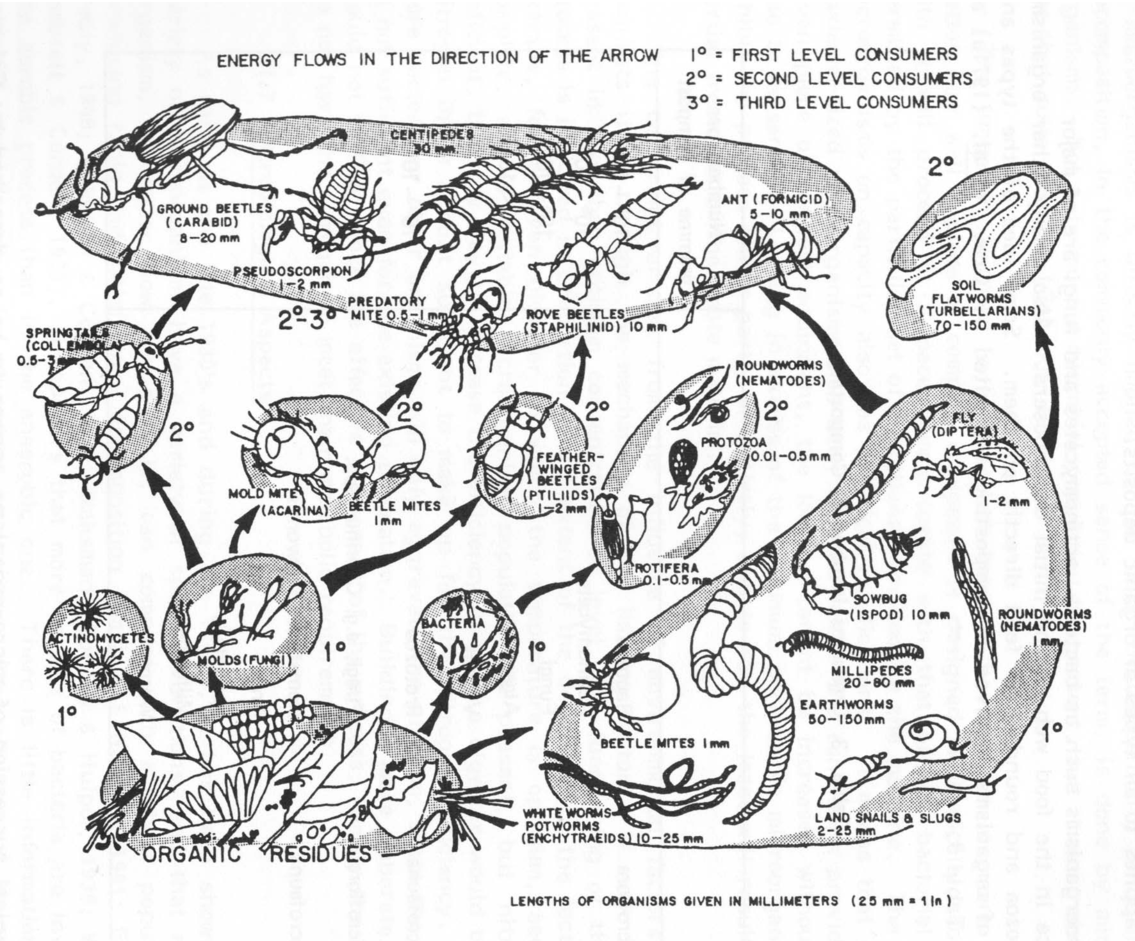

Figure 2-2. Food web of compost pile (Polprasert, 1996).

The organic matter is initially decomposed by the first-level consumers, such as bacteria, fungi (molds), and actinomycetes. Biological waste stabilization is undertaken mainly through the bacterial reactions in both mesophilic and thermophilic phases. In the final stages, as the temperature declines, members of the actinomycetes become the dominant group, which causes the heap surface to be white or gray in color. After these stages, the first-level consumers become the food of second-level consumers, such as mites, beetles, nematodes, protozoan, and rotifers. The third-level consumers, such as centipedes, rove beetles, and ants, prey on the second-level consumers.

2.3 Environmental Requirements

To maintain the effectiveness of a composting process, environmental conditions in the composting pile must be adjusted to favor microbial growth; otherwise, process failure would occur, due to chemical and physical conditions being unbalanced to promote the growth. Factors needed to be properly controlled in the composting operation are as follows.

(i) Nutrient balance. Although several elements play role in microbial growth, the most important nutrient parameter for composting is the carbon-nitrogen (C/N) ratio. Optimum composting is reportedly operated with the C/N ratios in the range of 25:1 to 35:1 by weight, (Haug, 1995). C/N ratios of some selected wastes are summarized in Table 2-1.

(ii) Particle size and bulking materials. The particle size of composting materials, in general, should be as small as possible in order to allow much exposure of their surface to the oxygen and to be easily decomposed by the microorganisms. Therefore, they should be shredded into small pieces, prior to being brought to composting. Usually, nightsoil, sludge, and animal manure contain fine solid particles suitable for microbial decomposition. Meanwhile, other materials, such as organic amendments and/or bulking materials added to raise the C/N ratio; provide structural support within the composting pile, thereby creating void spaces for the existence of O_2 to be used in aerobic composting. In addition, they increase the quantity of degradable organic carbon and reduce bulk weight. Such additives are sawdust, rice straw, peat, hay, domestic refuse.

Table 2-1. C/N ratios of selected wastes.

Type of waste	**Nitrogen (Percent of dry weight)**	**C/N ratio**
Night soil	5.5-6.5	6-10
Urine	15-18	0.8
Cow manure	1.7	18
Poultry manure	6.3	15
Pig manure	3.8	-
Raw sewage sludge	4-7	11
Digested sewage sludge	2-4	-
Activated sludge	5	6
Grass clippings	3-6	12-15
Non-legume vegetable wastes	2.5-4	11-12
Mixed grass	2.4	19
Wheat straw	0.3-0.5	128-150
Oats straw	1.1	48
Sawdust	0.1	200-500

Source : Polprasert (1996).

Nevertheless, bulking materials can be either organic or inorganic and of sufficient size, which, when added to sludge, will provide structural support and maintain air space within the compost mixture.

(iii) Moisture content. An optimum moisture content of the compost mixture is important for the microbial decomposition of the organic wastes. Because water is essential for soluble nutrient transport within cell protoplasm, a moisture content below 20 % can severely inhibit the biological process. A too-high moisture content will cause leaching of nutrients and pathogen from the composting pile, which would contaminate nearby receiving water bodies unless preventive measures are provided. In aerobic composting, too much water will also block the passage of air, causing the compost pile to become anaerobic and consequently, resulting in a retardation of the process to completion.

A moisture content between 50 to 70 percent is most suitable for composting and should be maintained during the periods of active bacterial reactions, i.e., mesophilic and thermophilic growth (Polprasert, 1996). According to JICA (1982), the suitable moisture content for composting of the solid waste should be in between 50 and 60 percent. Leemaharoungruang (1988) reported moisture content of 45 to 57 percent is suitable for the degradation of solid waste. Below 40 % of moisture content, the pile will begin to dehydrate, causing the biological process of degradation to slow down considerably. This will give a physically stable but biologically unstable compost. Above 60 % of moisture content, the high moisture levels will interfere with aeration by clogging the pores, and anaerobic conditions are created (Lardinois and Van De Klundert, 1993).

Htay (1995) studied the composting of sewage sludge and nightsoil sludge by windrow composting. For the composting of nightsoil sludge with rice straw, moisture content rapidly dropped during the thermophilic phase due to the biodegradation resulting from temperature, which speeded up evaporation rate in the compost piles. For the composting of sewage sludge with rice straw and composting of sewage sludge with nightsoil sludge and municipal solid waste, the moisture content slightly decreased during the first three week and then decreased rapidly. Thus, loss in moisture content and organic matter during composition depend on the magnitude of temperature and air in direct proportion. Lindratsirikul (1988) studied composting of water hyacinth with cesspool slurry using force-aeration with initial moisture content of 65 %. The moisture content was found declining with time in the same trend with this study and the composting process was completed in about 35-50 days. The moisture content at the end of composting was in the range of 45-50.

As night soil, sludge, and animal manure usually have moisture contents higher than the optimum value of 60 %, the addition of organic amendments and bulking materials will help reduce the moisture content to a certain degree. On the other hand, most municipal refuse has moisture contents lower than 60 % and, therefore, water have to be added during the composting period. For the batch operation, the moisture content of the composting mixture can be controlled by adding water to the composting pile once or twice daily. The moisture content should be controlled at the optimum range until the thermophilic period is completed, which can be observed by a temperature decrease and the appearance of the second-and third-level consumers. Where there is reasonable aeration by diffusion and the climate is temperate, little extra moisture is necessary on occasional turning of the pile. In hot climates, however, rewetting is certainly required (Rabbini et al, 1983).

(iv) Temperature. The biologically produced heat within a composting mass is important for two main reasons : (1) to maximize the decomposition of organic matter and (2) to inactivate the pathogens. From an ecological point of view, the composting process is “self destruction” i.e., as the temperature is increased beyond the thermophilic range (greater than 60-65^{o}C), the rate of decomposition in the composting pile is significantly reduced. On the other hand, most pathogenic microorganisms are inactivated effectively at temperatures above 50^{o}C. So the key concern is to control temperature in the compost pile in such a way to optimize both the breakdown of the organic matter and pathogen inactivation. The temperature control can be done by the adjustment of aeration and moisture control, and the utilization of screened compost as insulation cover of the composting pile (Polprasert, 1996).

According to Daiz et al (1993), the initial rise in temperature is gradual (lag phase). Immediately thereafter, if conditions are appropriate, the temperature rises almost exponentially with time until it begins "to plateau" at about 150 or 160^{o}F. Depending upon the system used and the nature of the waste, the period of high temperature persists for 1 to 3 weeks and then begins to decline gradually until ambient temperature is reached. If conditions are less than satisfactory, the high-temperature plateau may last much longer than 3 weeks, although the levels may be lower.

The rise in temperature is due to two factors, namely, heat generated by the microbial population and the insulation against heat loss provided by the composting mass. The latter implies that at less than a critical mass, heat will be lost as rapidly as it it generated and the material will remain at ambient temperature. Under climatic conditions comparable to those encountered in coastal California (Mediterranean climate), the critical volume seems to be on the order of 1 cubic yard. The critical volume is greater in colder climates (Daiz et al, 1993). The heat generated by the microbes results from their respirational activities. Microbes are not completely efficient in converting and utilizing the chemical energy bound in the substrate. Thus, temperature rise becomes an indicator of microbial activity, because the more active the microbial population, the greater is the amount of heat released. The exponential character of the rise in temperature is due to the breakdown of the easily decomposable components of the waste (e.g., sugars, starch, and simple proteins). It is during the period that the microbial populations increase exponentially in population size (Daiz et al, 1993).

Heat liberated from the decomposition of organics increases the temperature of solids and liquid in the composting mixture. As drying occurs heat will be used to evaporated the water. Because the compost is at a higher temperature than the surroundings, heat loss will occur from exposed surfaces of the compost. This loss will be mitigated to some extent by the insulating effect of the compost, which limits conduction of heat from the pile or windrow interior. Loss also will occur as windrowa are turned for aeration. In the aerated pile system, energy will be expended continually to heat air mechanically drawn into the pile. Under equilibrium, conditions, compost temperature will rise to a point where energy inputs are balanced by output. However, maximum obtainable temperatures are limited to about 75 to 80^{o}C because rates of biological activity, and hence heat evolution, begin to decrease above about 55^{o}C . (Golueke, 1977)

If the temperature does not rise, or if it drops suddenly, the pile may be too wet, too dry, or the C/N ratio is too high. If the moisture content is too high, as stated earlier, the material will stink. If it is too low, the material will have a dry appearance (Daiz et al, 1993). If the temperature is too high, additional air supply is required to remove heat from the system and prevent excessively high temperature in the system (Rabbani et al, 1983).

Srivichai (1988) reported that the suitable temperature for composting is in between 40-70^{o}C. If the temperature is more than 70^{o}C bacteria will die or stop growing. According to Gotass (1956), suitable temperature for composting is in between 50-60^{o}C only. The temperature inside the pile (about 12 to 15 in. from the surface) should rise to 110 to 120^{o}F within 24 to 48 hr after starting the process. It should reach to 130^{o}F and higher within 3 or 4 days. Thereafter, the temperature remain at 130^{o}F or higher until all of the readily decomposable material is stabilized. Then, the temperature drops. When it drops to around 110^{o}F, the material is ready for use (Rabini et al, 1983). At a temperature between 64-67^{o}C for 2 to 3 weeks, pathogens effectively killed (Tiquia et al, 1998).

(v) Aeration. Aerobic composting needs proper aeration to provide sufficient oxygen for the aerobic microoganisms to stabilize the organic materials. Oxygen is, not only necessary for aerobic metabolism and respiration of microorganisms, but also for

oxidizing the various organic and inorganic molecules present in the biomass. However, too much aeration is wasteful and can cause a loss of heat from the composting piles; meanwhile, too little aeration would lead to the anaerobic conditions inside the composting piles, which are accompanied by the production of obnoxious odors. Both situations may result in a slow rate of composting and, accordingly, a longer composting period required.

Pos (1991) reported about the use of air in composting process. Good results for composting of crop residues and animal manure were obtained when air was supplied at a rate of 0.07 m^3/s per ton of total digester capacity (assuming an open channel digester with 10-day retention time) for 3-7 minutes in every hour. Such an aeration practice is to supply the minimum amount of air (programmed on an hourly basis) to satisfy the basic oxygen requirements of the microbial population, and to use a temperature sensor to activate the air blower when the temperature exceeds the pre-set optimum level. Another method of expressing air supply is on the basis of volume per unit area of diffusion bed. For the compost heap not exceeding 1.5 m deep, this amounts to 0.57 m^3/s per square meter of the effective diffusion bed area. It is also emphasized that periodical mechanical mixing should not be used as the sole means of aeration because the optimum level of oxygen must be maintained constantly to enhance biological oxidative transformations. Discontinuous aeration, such as that provided by periodical mixing and turning, is not sufficient for proper aeration. Therefore, a more positive and continuous supply of oxygen should be provided

(vi) Mixing and turning. As biological activity tends to clump and colonize in many locations within the biomass, materials in the process of being composted should be mixed or turned on a regular schedule, or as required, in order to redistribute the organisms. Normally, daily mixing is satisfactory. Other benefits obtained from the mixing function include (1) pulverization of conglomerate lumps, (2) improved structure for air movement, and (3) a disruption of potential channels for leaching.

(vii) pH. Aerobic composting normally proceeds at a pH around neutral and rarely encounters extreme pH drop or rise. A slight pH drop may occur during the first few days of anaerobic composting, due to the production of volatile fatty acids. After this period, the pH becomes neutral again as these acids have been converted to methane and CO_2 by anaerobic reactions.

In practice, if required, pH is adjusted at the time of blending the raw materials. When chemical supplements are used to regulate the C/N ratio, some buffering may be required to adjust the pH, limestone or equivalent granular material is frequently used to correct for acidity.

2.4 Process Operations

Most composting operations consist of the following basic steps : (1) preparation of compost mixture; i.e., mixing manure with an amendment and/or a bulking agent; (2) aeration of the compost pile either by air supply, by mechanical turning, or by both and (3) further curing and storage. The Types of composting systems are the Chinese composting pile, Forced-air aeration composting, Windrow composting, and in-vessel system. They are briefly explained below

(i) *Chinese composting pile*. As shown in Figure 2-3, the compost feed (a mixture of numan or animal manure and vegetable matter) is piled up into a heap of approximately 2 m × 2 m × 0.5 m (length × width × height). The compost heap is pierced by perforated bamboo poles to facilitate natural aeration and provide a kind of structural support, and no turning of the compost pile is required. To control excessive heat loss the compost pile is covered with rice straw or a plaster of mud.

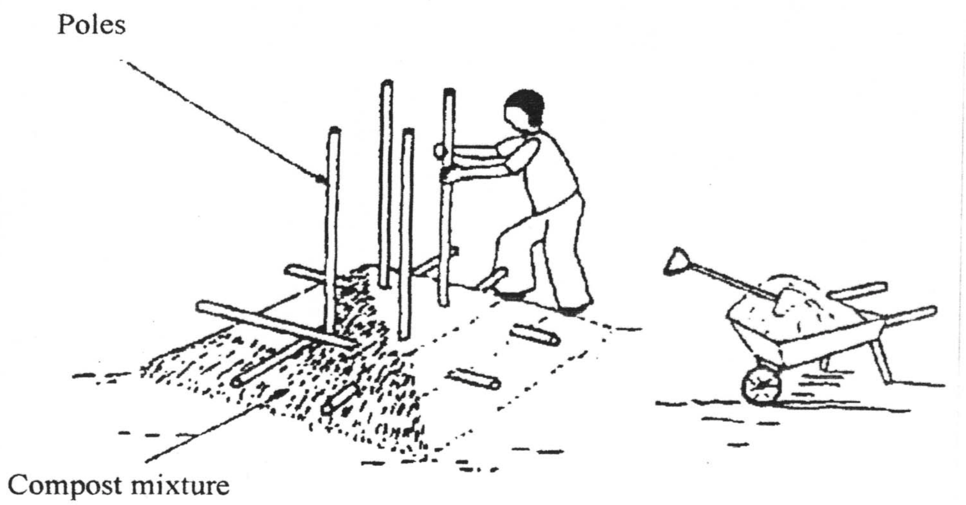

Figure 2-3. Chinese composting pile (IRC, 1982).

The poles can be removed after 1 or 2 days, when the mud had hardened or the compost pile is structurally stable, but they can remain there for a longer period. An experiment conducted at the Asian Institute of Technology (AIT), Bangkok, Thailand, found the time required for compost stabilization to be about 60 days (Polprasert et al, 1980), and the composted product became suitable for use as soil conditioner.

(ii) Windrow composting. This system involves periodic turning of the compost piles, manually about once a week, or mechanically once (or more) daily. The purpose of pile turning is to provide aeration and mix the compost materials, hence there is a faster decomposition rate than that of the Chinese composting pile (Polprasert, 1996). The approximate size of each pile is 13 m × 3 m × 1.5 m (length × width × height), but other sizes, subject to convenience, have also been employed. Figure 2-4 illustrates such a composting pile.

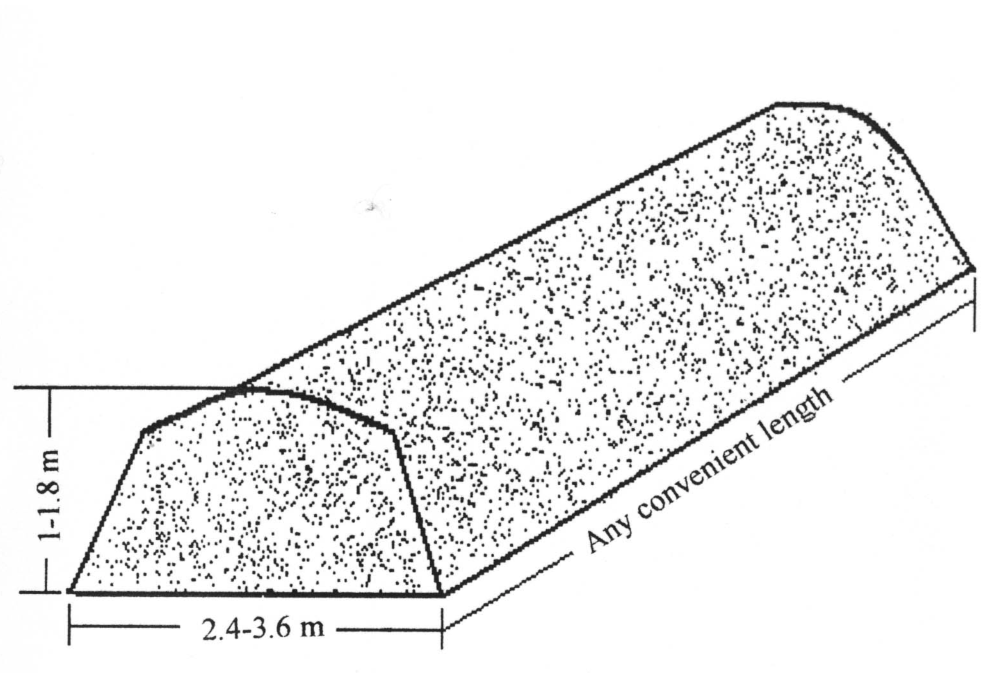

Figure 2-4. Windrow composting pile (Gotass, 1956).

(iii) Forced aeration composting. It consists of a grid of aeration or exhaust piping, over which a composting mixture is placed. A typical static pile system is illustrated in Figure 2-5. Pile heights are about 2-2.5 m. A layer of screened compost is often placed on top of the pile for insulation. The material is composted for 21-28 days and is typically cured for another 30 days or longer (Metcalf and Eddy, 1991).

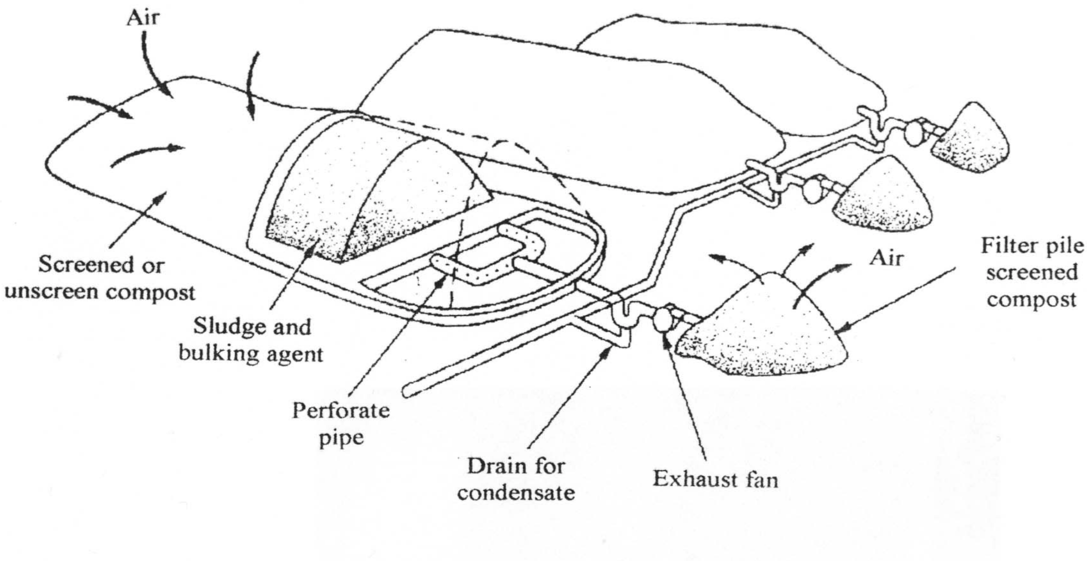

Figure 2-5. Forced-aeration composting pile (Metcalf and Eddy, 1991).

(iv) In-vessel composting systems. In-vessel composting is accomplished inside an enclosed container of vessel.

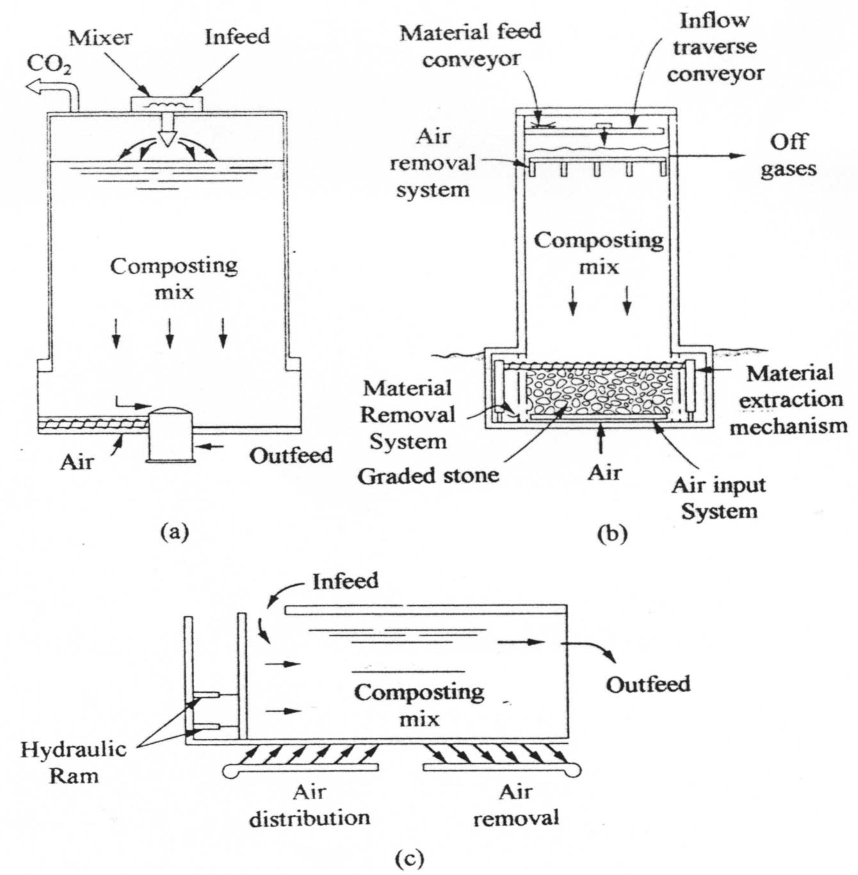

Figure 2-6. Example of in-vessel composting reactor (a) cylinder tower, (b) rectangular, and (c) tunnel (Metcalf and Eddy, 1991).

Mechanical systems are designed to minimize odors and process time by controlling environmental conditions, such as air flow and temperature. The use of in-vessel composting system has increased rapidly in recent years, due to a number of advantages – process and odor control, faster throughput, lower labor costs, and smaller area requirements. Examples of in-vessel composting systems are shown in Figure 2-6 (Metcalf and Eddy, 1991).

There are may criteria to judge the maturity or completion of a composting process. In general, a composted product should contain a low organic content that will not undergo further fermentation when discharged on land, and the pathogens should be inactivated. Haug (1993) proposed some of the approaches to measure the degree of compost stabilization as follows :

(a) temperature decline at the end of batch composting;

(b) decrease in organic content of the compost as measured by the volatile solid (VS) content, percentage of carbon or ash content, and C/N ratio;

(c) lack of attraction of insects or development of insect larvae in the final product; and

(d) absence of obnoxious odor.

Further guidelines regarding the characteristics of an "Ideal Compost" as mentioned by Pos (1991) are:

(a) The color should be dark brown to black, with little or no identifiable particles of the original raw materials.

(b) The organic content should be at least 50 % on an oven dried basis (ODB)

(c) The bulk moisture content should not exceed 20 %.

(d) The compost should possess a moisture holding capacity of 150-200 %.

(e) The ash content should range between 10 and 20 % (ODB).

(f) The total nitrogen content should range between 2.0 – 3.5 %.

(g) The compost may exhibit a slightly soil odor.

CHAPTER III

RESEARCH METHODOLOGY

Pig-manure brought from the SUT farm was mixed with hay chopped up-to 1 to 1.5 inch size in pre-assigned ratios to give the approximate initial C/N ratios of 20:1, 30:1 and 40:1. Some physical parameters related in the preparation of the different compost piles are given in Table 3-1 where moisture content, pH and temperature are the initial values.

3.1 Experimental Set-up

Two types of composting piles one with varying C/N ratio and next one with varying aeration period as shown in Tables 3-1 were prepared. The experimental site for the same was Suranaree Military Camp, Nakhon-Ratchasima.

Nine aluminum composting boxes, each with size 1.2 m × 2.0 m × 0.3 m (length × width × height) were built up and they were filled with the materials for composting. Six of the nine compost piles (boxes) were fitted with an aeration system at the at the bottom of the piles to maintain a constant flow of air through them. The aeration system consisted of an air blower fitted with an automatic control timer and connected to a perforated polyvinyl chloride (PVC) pipe network. Each PVC pipe of one inch inner diameter had several holes in two rows, where each hole had 8 mm diameter and they were 15 cm apart from each other. The pipes were wrapped with a plastic net to protect from blocking of the aeration system inside the compost piles (Figure 3-1).

Table 3-1. Physical parameters.

Compost Pile Type (pig manure + hay)	No. of Pile	Forced-aeration Rate (m^3/d/kg VS)	Moisture Content (%) (initial)	pH (initial)	Temperature (^{O}C) (initial)
Initial C:N ratio 20:1 (control): pile 1	One	no forced-aeration	65.7	7.4	35
Initial C:N ratio 20:1 (forced-aerated): pile 2	One	0.6 (24h/d)	66.3	7.4	36
Initial C:N ratio 30:1 (control): pile 3	One	no forced-aeration	65.6	7.8	33
Initial C:N ratio 30:1 (forced-aerated): pile 4	One	0.6 (24h/d)	64.4	7.7	34
Initial C:N ratio 40:1 (control): pile 5	One	no forced-aeration	63.0	7.6	35
Initial C:N ratio 40:1 (forced-aerated): pile 6	One	0.6 (24h/d)	65.3	7.7	36
Initial C:N ratio 20:1 (forced-aerated): pile 7	One	0.6 (6h/d)	64.4	7.6	35
Initial C:N ratio 20:1 (forced air): pile 8	One	0.6 (12h/d)	66.6	7.5	34
Initial C:N ratio 20:1 (forced-aerated): pile 9	One	0.6 (18h/d)	65.1	7.7	36

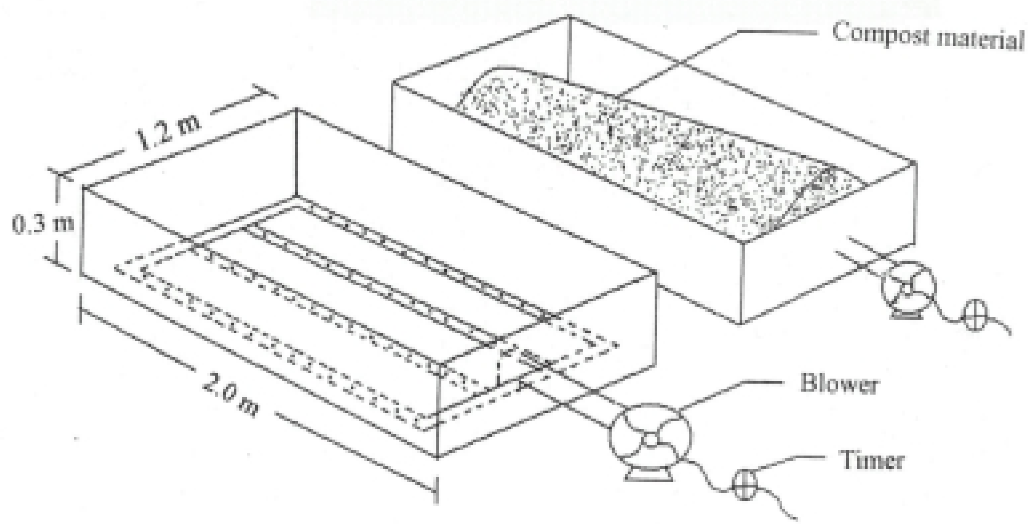

Figure 3-1. Compost pile.

3.2 Sampling and Analysis of Composts

Ten samples, one from each of two points in each side (the top and four lateral sides) of every compost pile were collected to make a composite sample size of about 500 g (each individual sample about 50 gram). Each of the mixed sample, was then placed in aluminum tray for weighing and oven drying at 80^{o}C for at least 36 hours and moisture content was determined. The dried material was then ground and sieved through a one-mm mesh. About 30 gram sample of the sieved material was again dried at 80^{o}C for one hour. Thereafter, a part (about 15 gram) of this sample was separated and stored in a desiccator for analyzing nitrogen by macro Kjehldahl method, and phosphorus and potassium by spectrophotometer while the remaining amount was again oven dried at 105^{o}C for one hour and total solids was measured. Thereafter this was further oven dried at 550^{o}C for one hour and volatile solids was measured. At the same time, percentage of total organic carbon (TOC) was also calculated using the following equation (Gotass, 1956; Goleuke, 1977).

$$\% \text{ TOC} = (100 - \% \text{ Ash residue})/1.8$$

Sampling (to make a composite sample) from each compost pile was done once in every 4 days for the first 12 days and thereafter, once a week till the end. Sampling, for analyzing the pH by pH meter and total coliform bacteria by membrane-filter technique, was done directly from each compost pile once a week. The chart for analysis is shown in Figure 3-2.

Ambient temperature around the compost piles was measured by thermometer two times a day (9 AM and 3 PM) during the entire composting period. Similarly, temperature inside each compost pile (at the depth of 15 cm, 30 cm and 45 cm from the top) was also measured by thermometer twice a day (around 9 AM and 3 PM) throughout the composting period. Each pile was turned on throughout the entire composting period after the measurement of temperature was done at 9 AM every day. By turning a pile could limit excessive rise in temperature due to the supply of air. The end of the composting period was determined by noting some physical and chemical characteristics of the compost, such as, temperature inside the compost pile (equal to ambient temperature), C/N ratio (less than 20), low volatile solid content, color of the compost (such as, brownish black), smell (e.g., soil) and nearly 100 % die-off or non-detection of the total coliform bacteria. Statistical analysis for all the physico-chemical and bacteriological parameters was done by ANOVA method (Jay, 1995).

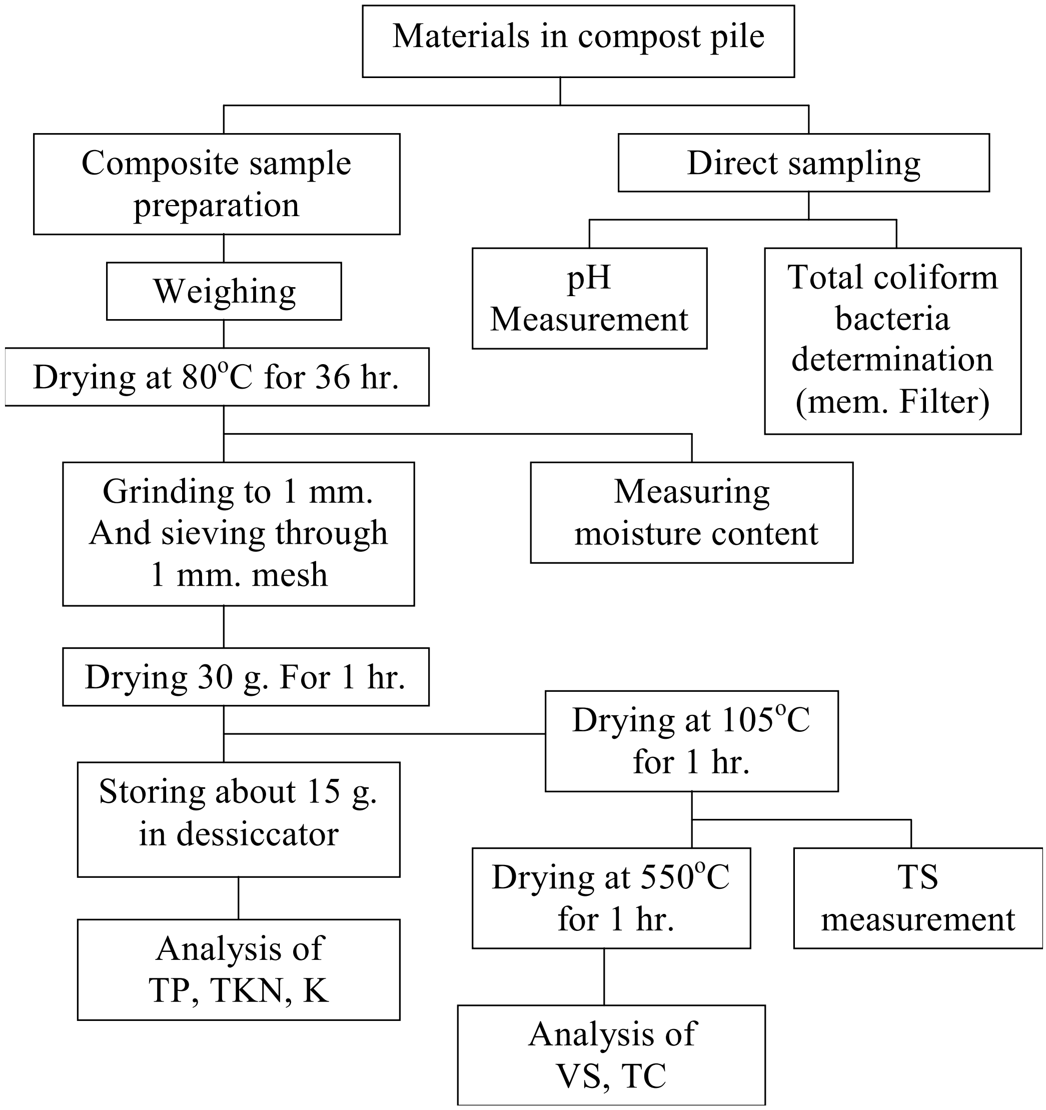

Figure 3-2. Flow chart for laboratory analysis.

CHAPTER IV

RESULTS AND DISSCUSSION

Characteristic of pig-manure and hay analyzed before the preparation of the materials for composting is shown in Table 4-1. From the Table, it is noteworthy that hay has larger carbon, smaller nitrogen and phosphorus contents than the pig-manure has.

Table 4-1. Characteristics of the pig-manure and hay (dry weight basis).

Raw Material	% Carbon (C)	% Nitrogen (N)	% Phosphorus (P)	C/N ratio
Pig manure	39.3	2.54	0.4	15.47
Hay	44.56	0.89	0.2	50.06

Table 4-2 represents the amount of pig-manure and hay used in preparing the compost piles with different C/N ratio. Detail calculation for the preparation of materials for composting with appropriate C/N ratio are given in Appendix A1-1. In the following sub-sections, results of the composting of both sets of the experiments are presented and discussed as well.

Table 4-2. Amount of raw material required in preparing compost piles (dry weight basis).

Compost piles	Raw Materials	Volume (L)	Ratio by volume	Weight (Kg)	Ratio by weight
1, 2, 7, 8 and 9	Pig-manure : Hay	270.00 : 450.00	1 : 1.70	108 : 45	2.4 : 1
3 and 4	Pig-manure : Hay	78.46 : 641.54	1 : 8.18	31.38 : 64.15	1 : 2
5 and 6	Pig-manure : Hay	25.69 : 694.31	1 : 27.0	10.27 : 69.43	1 : 6.8

4.1 Physical and Chemical Properties

4.1.1 Moisture Content

As a prerequisite for successful composting, moisture content was maintained in the range of 30-53 %. The variation of moisture content for first set of experiment is shown in Figure 4-1 (experimental data are shown in Appendix B Tables B1-1 to B1-6). The initial moisture contents for compost piles (control) 1, 3 and 5 were 65.7 %, 65.59 % and 62.96 %, respectively and for compost piles (forced aerated) 2, 4 and 6 were 66.31 %, 64.36 % and 65.25 %, respectively. As shown in Figure 4-1, the moisture content rapidly dropped during the thermophilic phase (i.e., temperature more than 40°C) due to the biodegradation result in high temperature, the microorganism need water and air for breakdown of protein, fat and complex carbohydrates. This speeded up evaporation rate in the compost piles (Htay, 1995). After thermophilic phase, the moisture content decreased gradually and smoothly till the end. After thermophilic phase, decrease of moisture content in forced aerated compost piles (2, 4 and 6) is larger than that for control piles (1, 3 and 5). Because in the forced-aerated piles, microorganisms present can use air everywhere for microbial activity, and evaporation rate is also high although some water is produced by the microbes.

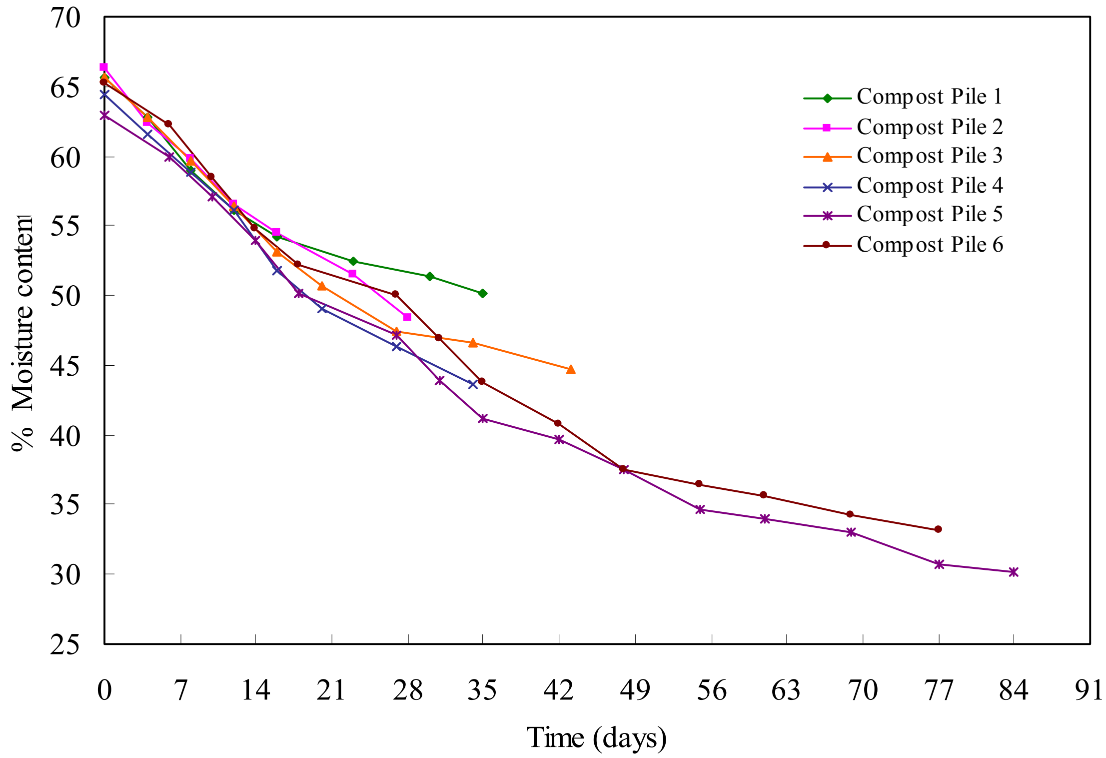

Figure 4-1. Time variation curves of moisture content (experiment set 1).

In the second set of experiment as shown in Figure 4-2 (experimental data shown in Appendix B Tables B1-7 to B1-9). the initial moisture content for compost piles 7, 8 and 9 were 64.35 %, 66.59 % and 65.08 %, respectively. Decrease in moisture content in compost piles 7, 8 and 9 is in the same trend. After two weeks, the moisture content decreased smoothly because of supply of air. The drop in moisture content was slow. Because hay is the rigid material, that retains its wet strength for a long time until most of the wall fibers have been degraded.

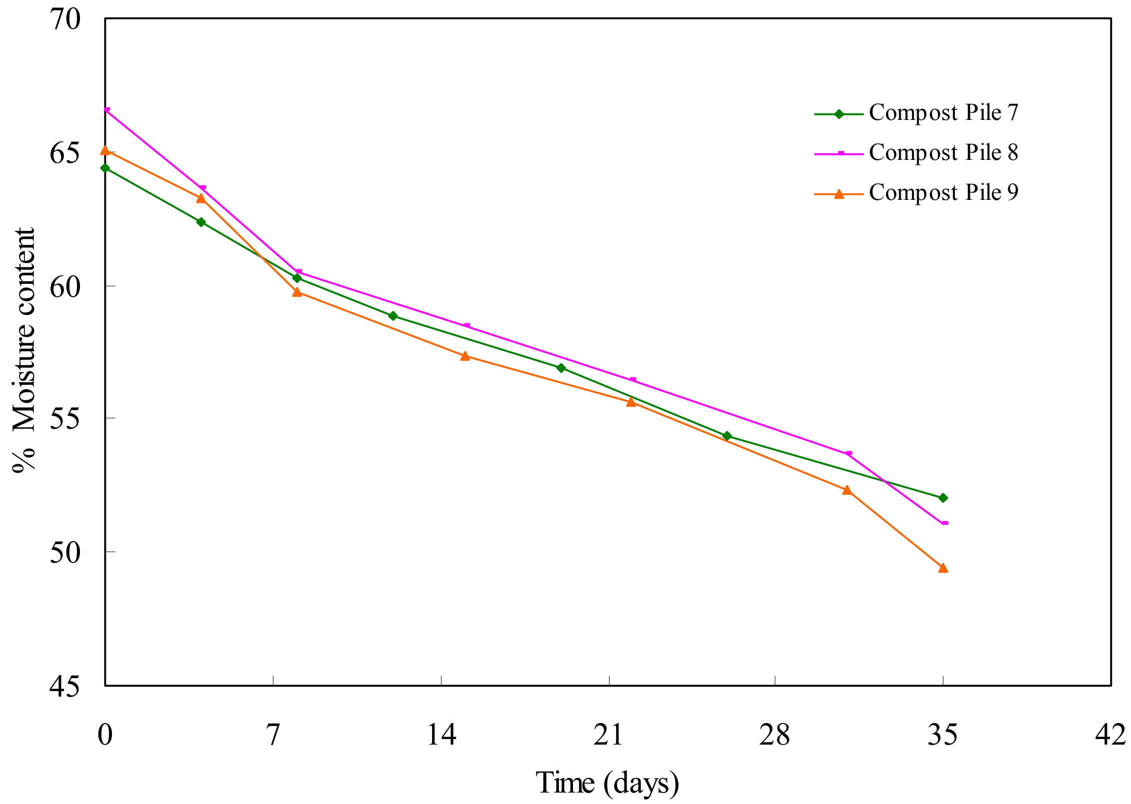

Figure 4-2. Time variation curves of moisture content (experiment set 2).

The pile with more aeration time i.e., pile 2, ended up with less moisture content than the other piles with same C/N ratio but with less aeration time. This is because through air was used in the decomposition process continiously and more moisture was evaporated. Moisture content measurement was stopped once the composting process was complete (for details see chapter II). Composting process was completed for pile 1 in 35 days and for piles 2, 3, 4, 5, and 6 it was completed in 28, 42, 35, 84, and 77 days, respectively. Similarly, for piles 7, 8 and 9 composting process was completed in 35 days.

From the statistical analysis (ANOVA method) as shown in Appendix C Table C1-1, it is noticed that there is no significant difference (p = 0.932) in overall moisture contents among the compost piles 1, 2, 7, 8 and 9 (with same C/N ratio but different aeration periods). However, there is significantly difference (p = 0.004) in overall moisture contents among the control piles with different C/N ratio (i.e., 1, 3 and 5). Similarly, moisture contents among the piles 2, 4 and 6 are also significantly different (p = 0.04).

Therefore, it can be summerized that aeration helps in decreasing the moisture content in the compost piles. This means that aerated piles are dryer than non-aerated piles. Other affecting factors are metabolic activities of microorganisms, activation surface or contact area of the compost piles and the rate of air that is added into the piles during the increasing temperature conditions. The moisture content decrease is due to metabolism of microorganisms within the compost piles and the rate of aeration applied onto the piles. Increasing temperature is also an important factor for the rate of decreasing moisture content. This factor is, however, more relevant for aerated compost piles (i.e., piles 2, 4, 6, 7, 8 and 9) than for non-aerated piles (1, 3 and 5).

4.1.2 Temperature

The temperature profile with time is a key factor, not only from safety, but also from the successful composting point of view. High temperatures for many consecutive days indicate a successful composting process (Georgacakis et al, 1996).

Figure 4-3 and 4-4 (experimental data shown in Appendix B Tables B1-1 to B1-9). show the time variation curves of temperature representing experiment sets 1 and 2, respectively. The variations of temperature on those graphs were the average temperatures measured at locations 15 cm, 30 cm and 45 cm from the base of each pile at 9 AM and 3 PM daily throughout the entire composting period. The detail of the temperatures has been given in Appendix B Tables B2-1 to B2-5.

The initial temperature of compost pile 1 was 35^{o}C and then the temperature increased to 69^{o}C after 3 days. After 10 days, temperature decreased to mesophilic range. After 20 days, the temperature decreased to ambient air temperature level, and the final temperature of 31^{o}C reached after about 30 days of composting.

The initial temperature in compost pile 2 was 36°C. The temperature than increased to the maximum of about 67°C after 3 days, and decreased to mesophilic temperature range after 10 days. After 11 days, temperature fluctuated just a little and reached to 30°C in about 28 days of composting.

The initial temperature in compost pile 3 was 33°C, and reached to the maximum temperature of 67°C after 3 days of composting. The temperature was maintained over 50°C for about 13 days and fell to mesophilic temperature range after 20 days till the end of experiment. The final temperature of this experiment was 32°C.

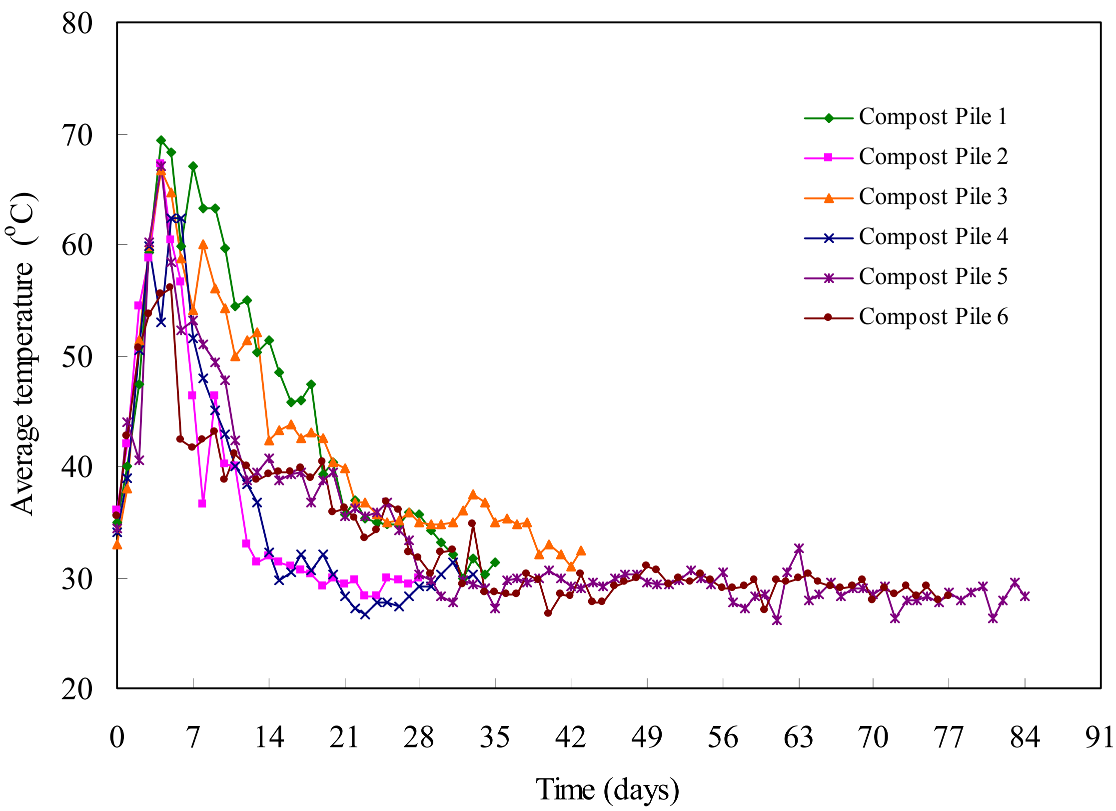

Figure 4-3. Time variation curves of temperature (experiment set 1).

The initial temperature in pile 4 was 34°C. It rose to the maximum temperature of 62°C after 4 days and remained in thermophilic phase for 10 days of composting. Thereafter, it decreased rapidly to 38°C on 8th day. Temperature was further decreased rapidly and it was 31°C on the 9th day. Thereafter, the fluctuation in the temperature was a little and the final temperature was 29°C.

In pile 5, the initial temperature was 35°C which rose to the maximum temperature of 67°C in 4 days and dropped to mesophilic phase after 9 days. The temperature remained in the range of 38 to 40°C for the composting period of 10 to 20 days, and on 21st day, temperature fell to 36°C. Then, there was a gradual decrease in temperature and the final temperature was 28°C at the end of composting (i.e., 84th day).

In pile 6, the initial temperature was 36°C which then rose to a maximum temperature of 56°C on 5th day of composting. On 6th day, temperature fell to 42°C and thereafter, temperature was in the range of 37°C to 40°C till 19th day of composting. Temperature then gradually decreased with some fluctuations till the end of the experiment. The final temperature was about 28°C at the end.

The variation of temperature in the second set of experiment (piles 7, 8, 9) is shown in Figure 4-4.

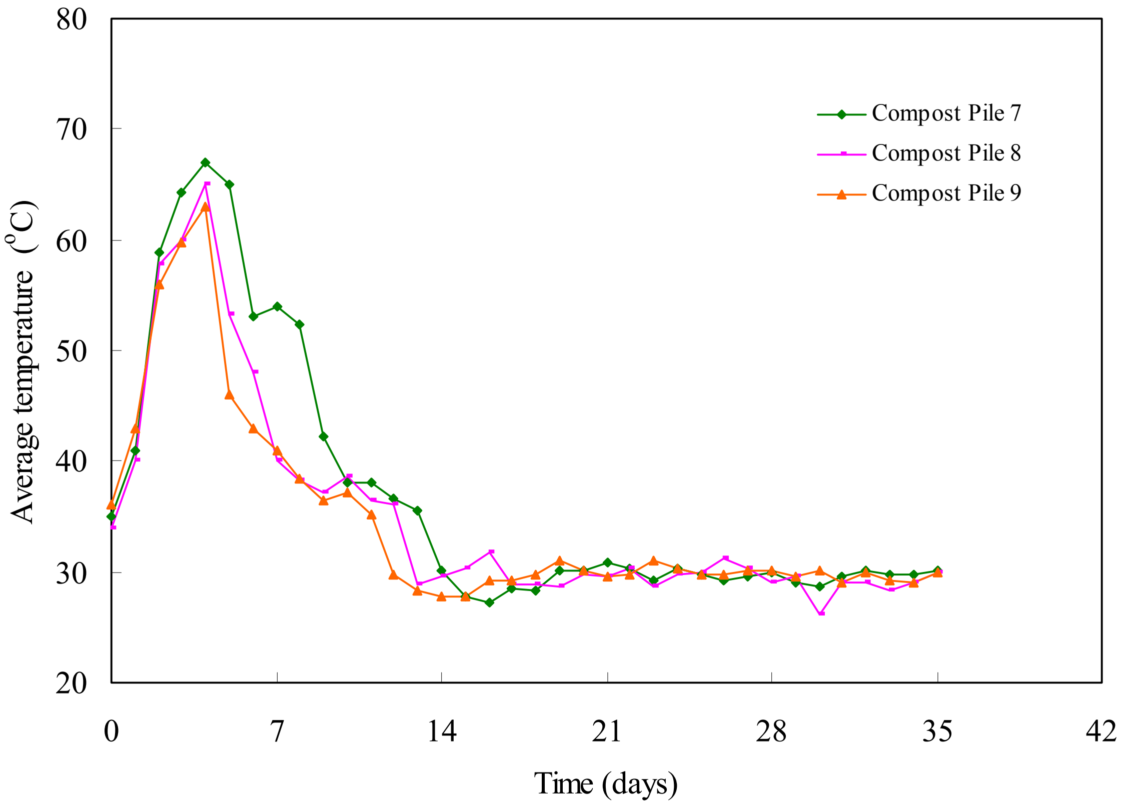

Figure 4-4. Time variation curves of temperature (experiment set 2).

The initial temperature in pile 7 was 35°C. This rose to maximum temperature of about 67°C after 3 days of composting, and fell to mesophilic phase after 8 days. There was a gradual decrease in temperature with little fluctuations. The initial temperature in pile 8 was 34°C which increased to a maximum temperature of 65°C on 4th day. The temperature, then, fell to mesophilic range after 7 days of composting. During the composting period of 12 to 35 days, temperature was in the range of 26 to 30°C. The initial temperature in pile 9 was 36°C which rose to temperature of 56°C after 2 days of composting, and maximum temperature was 63°C on 4th day of composting. Temperature was at the mesophilic phase after 6 days of composting.

The curves in Figures 4-3 and 4-4 showed that the temperature in all compost piles reached maximum within a week of composting. In the piles with forced-aeration, temperature decreased rapidly than in the control piles.

The starting temperatures in each composting pile for both sets of experiment were found in the mesophilic phase (33 to 36°C). Normally the pile temperature should start in mesophilic phase and then the thermophilic phase (50-65°C) (Polprasert, 1996). At thermophilic phase, temperature has increased the rate of biodegradation of compost materials in piles and reduced the number of potentially pathogenic organism in both experiments.

The temperature in the aerated piles rised lower than control compost piles. This is because the air added from the bottom of the compost piles blows to all parts of the forced-aerated compost piles. This makes the piles maximum temperature lower in the forced-aerated piles than in the control piles. After the thermophillic stage of the composting system, the temperature within the aerated compost piles decreased slowly. In aerated compost piles (2, 4, 6, 7, 8 and 9), temperature fell to ambient level rapidly than control compost piles, i.e., 1, 3 and 5. The tendency of temperature decrease in all piles were similar. The temperature of the compost pile with higher C/N ratio decrease rapidly than the compost piles with lower C/N ratio. This is because the pile with higher C/N ratio contains more hay that absorbs more water. Compost pile 7, having an aeration rate of 6 hours a day, has slower temperature decrease than the ones with aeration rates of 12 hours a day, 18 hours a day, and 24 hours a day. This is because the amount of air received by compost pile 7 is less than compost piles 8, 9 and 2.

From the statistical analysis (Appendix C Table C1-2), it is noteworthy that temperatures among the pile 1, 2, 7, 8 and 9 were found not significantly difference. Temperature among piles 1 and 2, and piles 3 and 4 were significantly different (p =

0.021) and (p = 0.004), respectively. However, temperatures among piles 5 and 6 were not significantly different.

Based on the above discussion, it can be summarized that the temperature increase in each pile is due to the rapid growth of microorganisms at the beginning stage of compost (energy produced due to metabolism). Then as the microbes decrease in population, the temperature decreases gradually. The highest temperatures in the aerated piles were less, compared to the same in the corresponding non-aerated piles indicating that aeration influences temperature changes (decrease) in the compost piles. Thus, temperature variations during composting period as shown in the Figures 4-3 and 4-4 have followed a typical pattern exhibited by many composting systems (Jimenez and Barcia, 1992; Inbar et al, 1993; Lo et al, 1993; Tiquia et al, 1997). The temperature variation curves for aerated piles in this research are especially comparable to the findings of Lo et al (1993). In their experiment, the aeration rate was 0.04 to 0.08 L/min/kg of volatile matter, and they found maximum temperature (i.e., about 70 ^{o}C) after 4 days and a graduate decline after a week for the aeration rate of 0.04 L/min/kg of volatile matter. In this study, the aeration rate was similar (0.042 L/min/kg of volatile matter) to that of Lo et al (1993) and, near too, the maximum temperatures (56 to 69 ^{o}C) were obtained after 4 days and a gradual decrease thereafter. Heat balance for pile 2 has been presented in appendix A1-4.

4.1.3 pH

The initial pH values in the first set of experiment (compost piles 1 to 6) were 7.4 , 7.4 , 7.8 , 7.7 , 7.6 and 7.7, respectively. For the second set of experiment (compost piles 7, 8 and 9), the initial pH values were 7.6, 7.5 and 7.7, respectively. The starting pH values in all compost piles were in the range of 7.4 to 7.8. As shown in Figures 4-5 and 4-6 (experimental data shown in Appendix B Tables B1-1 to B1-9), the pH variation in each pile was found to be in the same trend. In all the compost piles, during the first week, pH increase was slow and after a week, it has fast increase.

At lower C/N ratio, the pH level increased slowly because the quantity of pig manure differs in piles with different C/N ratio. In the 1st and 2nd compost piles, the C/N ratio is 20:1. This ratio requires more pig manure than the compost piles with 30:1 and 40:1 ratios. Control piles have slightly more decrease of pH than forced-aerated piles. At

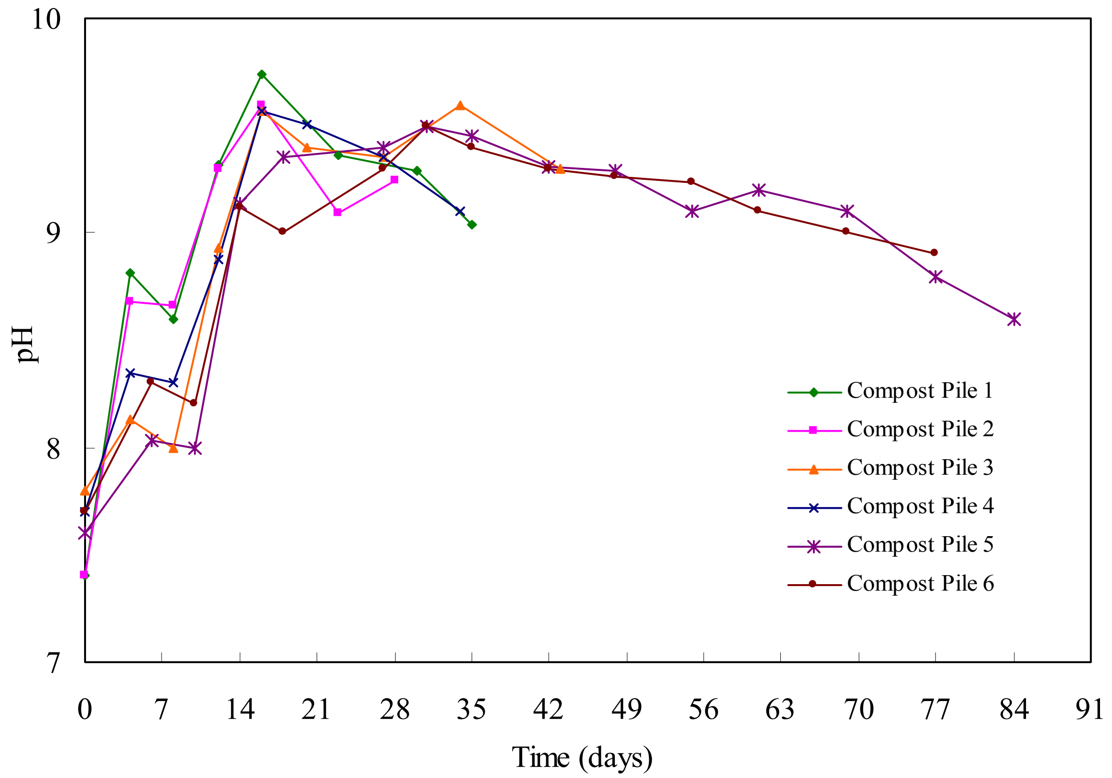

Figure 4-5. Time variation curves of pH (experiment set 1).

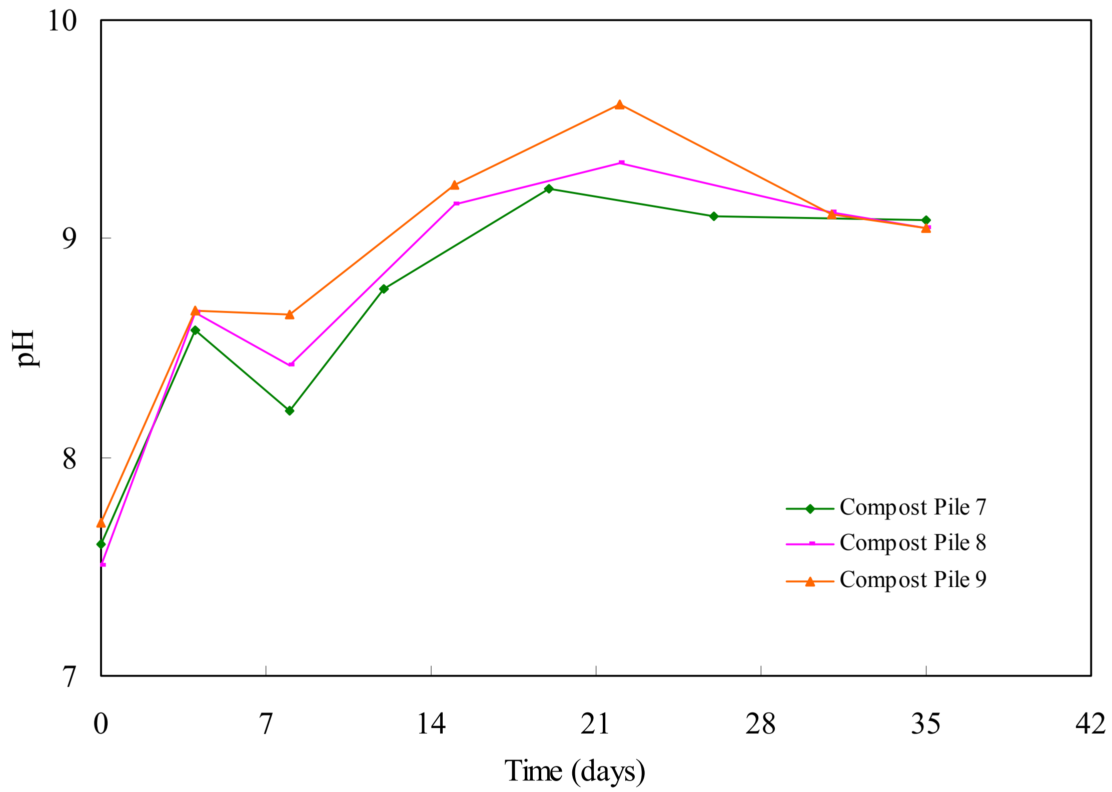

Figure 4-6. Time variation curves of pH (experiment set 2).

the same C/N ratio (20:1) but under different aeration rates, no such difference in the pH change behaviour has been noticed, (Appendix C Table 1-3). In conclusion, the pH level slowly increased during the first week of compost period. Then after nitrogen is lost to the air in the form of NH_3 gas (due to aeration), some minor but visible changes occured to the pH level in the compost piles.

According to Htay (1995), the initial pH level in compost piles should be in the basic range of 6-8. Then in the first week, it increases and at the end of the compost period the pH would be around 8-9. Lindrasirikul (1988) found the initial pH of compost in the basic range of 7-8. After the first week, the pH level changed. However this change was very little and the resulting pH stayed nearly constant. The result of this study were similar to that of Htay (1995) and Lindrasirikul (1988).

4.1.4 Total Coliform Bacteria

The initial concentrations (number/g) of total coliform bacteria in compost piles 1, 2, 3, 4, 5 and 6 (i.e., first set of experiment) were 6×10^8, 6.4×10^8, 4.5×10^8, 4.6×10^8, 2.4×10^8 and 2.7×10^8, respectively and at the end of the experiment, they were not noticed. Similarly the initial concentrations of total coliform bacteria in compost piles 7, 8 and 9 (i.e., second set of experiments) were 6×10^8, 6.3×10^8 and 6.1×10^8, respectively. At the end of the experiment, they were not noticed. In compost pile 2, no total coliform bacteria was noticed on the 28th day of composting. In the rest piles, they were not found from the 35th day of composting.

Since most literature has indicated a complete inactivation of the *Ascaris lumbricoids* eggs at a temperature of 50^{o}C and an exposure time of two hours (Gotass, 1956), no attempt was made to further examine their survival in all compost piles. A very important point is that the temperature of composting must be over 55^{o}C for at least 3 consecutive days for safety reasons (Lau et al, 1992). In this study, almost all the compost piles had temperature over 55^{o}C for 3 consecutive days. The time variation curves of total coliform bacteria during the composting period are shown in Figures 4-7 and 4-8 (experimental data shown in Appendix B Table B1-10).

From statistical analysis as shown in Appendix C Table C1-4, it is found that total coliform bacteria in the compost piles 1, 2, 7, 8 and 9 were not significantly different (p = 0.988). Similarly, total coliform bacteria among piles 2, 4 and 6 (p = 0.166), piles 1, 3

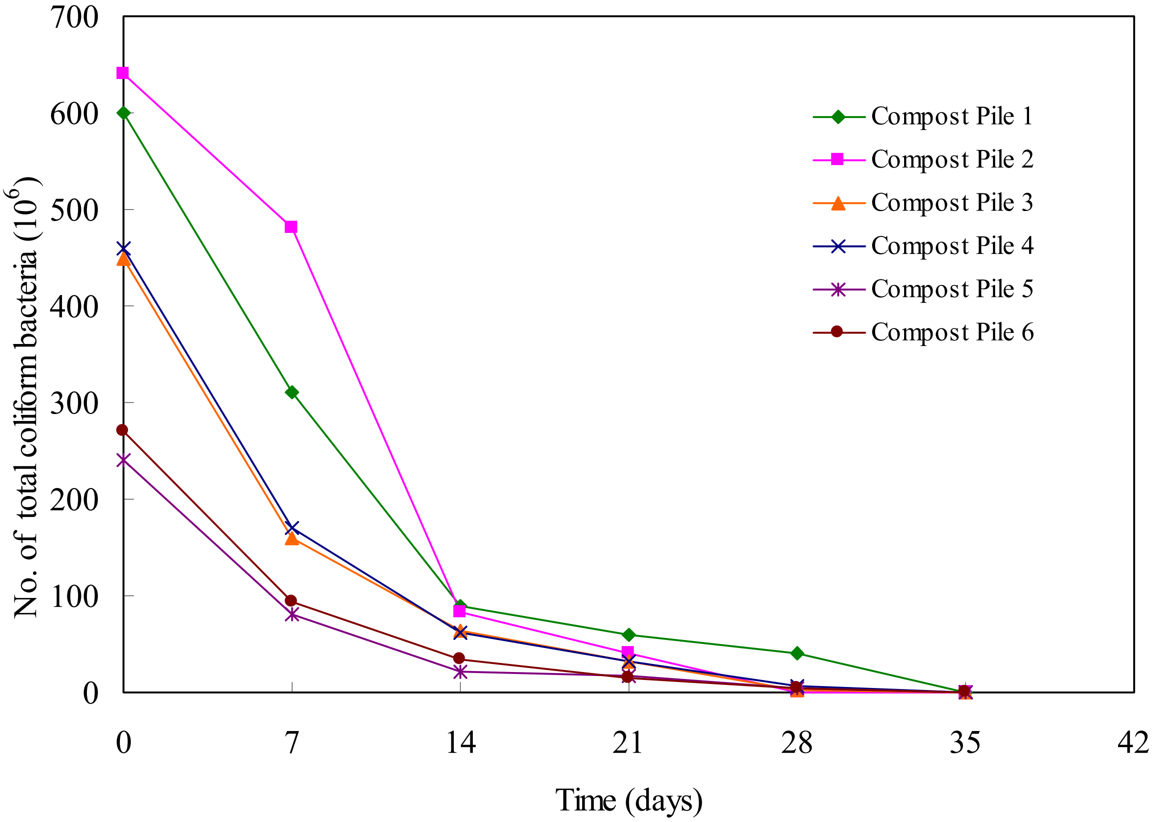

Figure 4-7. Time variation curves of total coliform bacteria (experiment set 1).

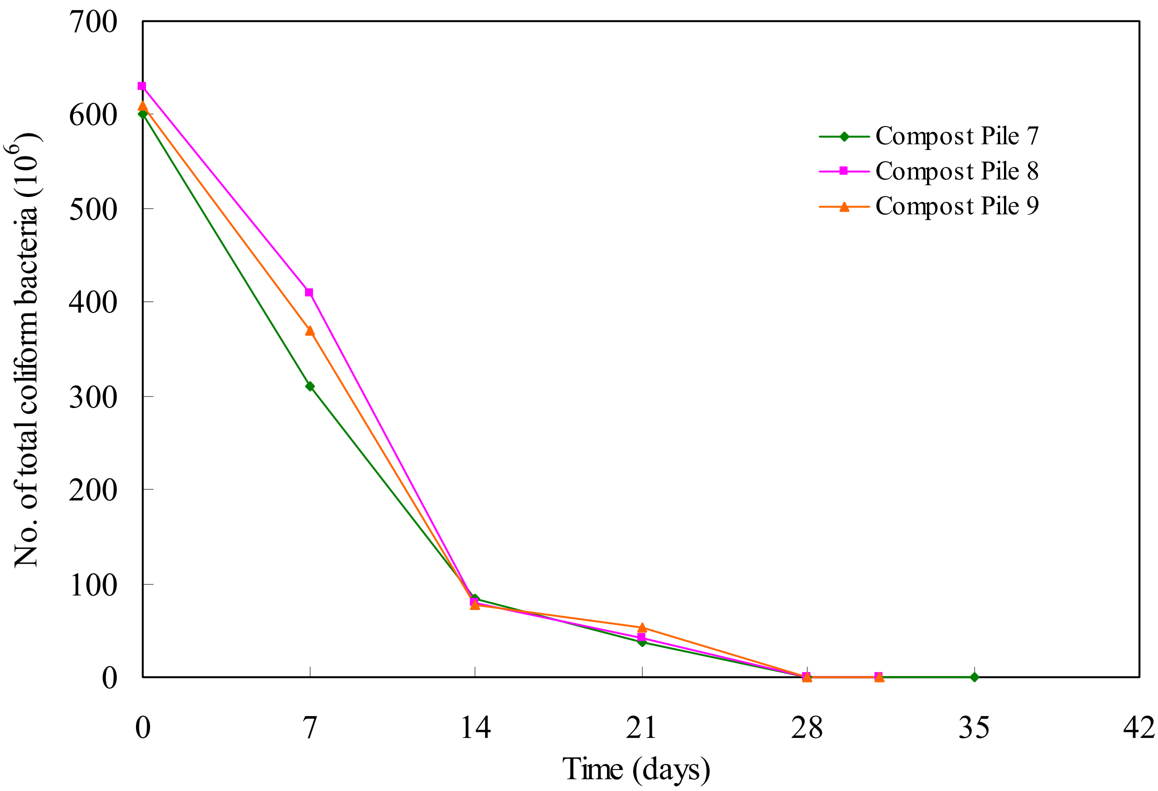

Figure 4-8. Time variation curves of total coliform bacteria (experiment set 2).

and 5 (p = 0.315), piles 1 and 2 (p = 0.649), piles 3 and 4 (p = 0.833), and piles 5 and 6 (p = 0.880) were found not significantly different. In Appendix A1-2, calculation for the evaluation of total coliform bacteria decay rate (k_d) has been done using the results of pile 2 of experiment set 1.

4.2 Nutrient Content

4.2.1 Nitrogen Content

The variations of nitrogen content as TKN in experiments 1 and 2 are shown in Figures 4-9 and 4-10 (experimental data shown in Appendix B, Tables B1-1 to B1-9)., respectively.

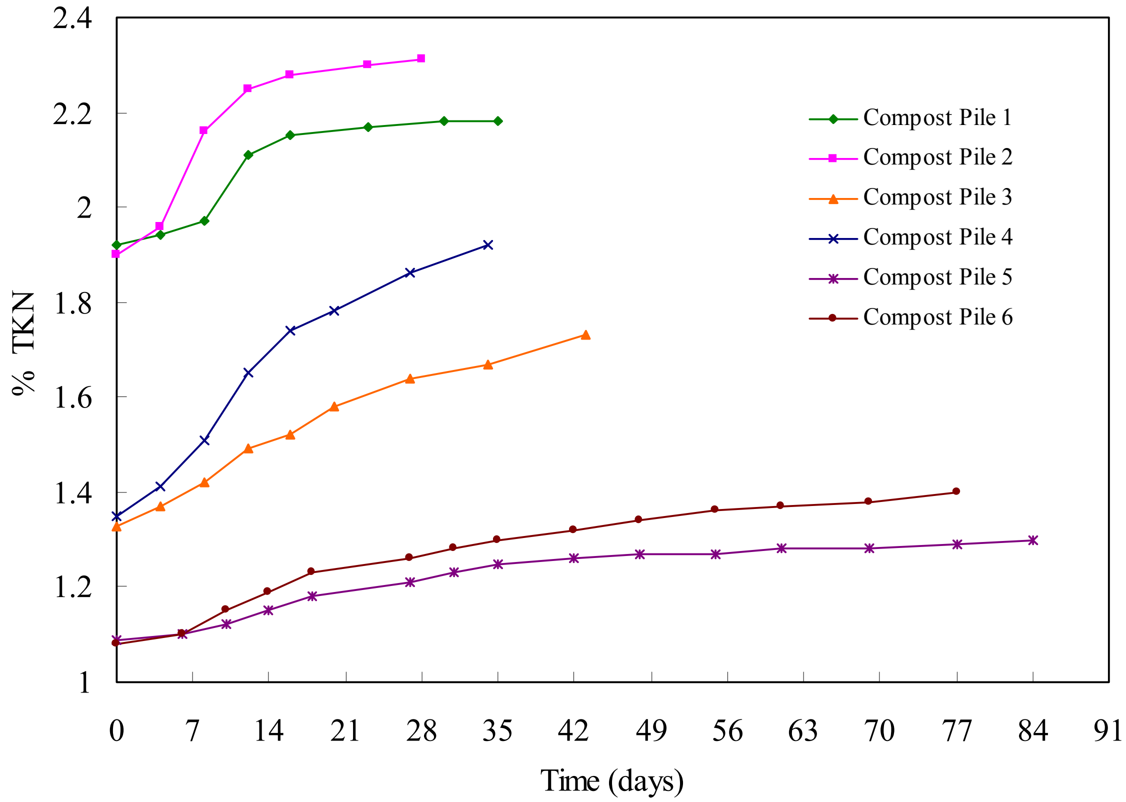

Figure 4-9. Time variation curves of nitrogen content (experiment set 1).

For experiment 1, the initial nitrogen content in the control piles 1, 3 and 5 were 1.92 %, 1.33 % and 1.09 %, respectively. In the forced-aerated piles 2, 4 and 6, the initial nitrogen content were 1.9 %, 1.35 % and 1.08 %, respectively. For experiment 2, the initial nitrogen content in compost piles 7, 8 and 9 were 1.95 %, 1.94 % and 1.98 %, respectively. During the composting, certain increment in nitrogen content has been found in all piles because of loss of carbon by the metabolic reactions of aerobic microorganisms, though a part of nitrogen content may escape in the form of NH_3 (gas) or other volatile nitrogen gas to atmosphere or partly as a leachate (Rabbani et al, 1983).

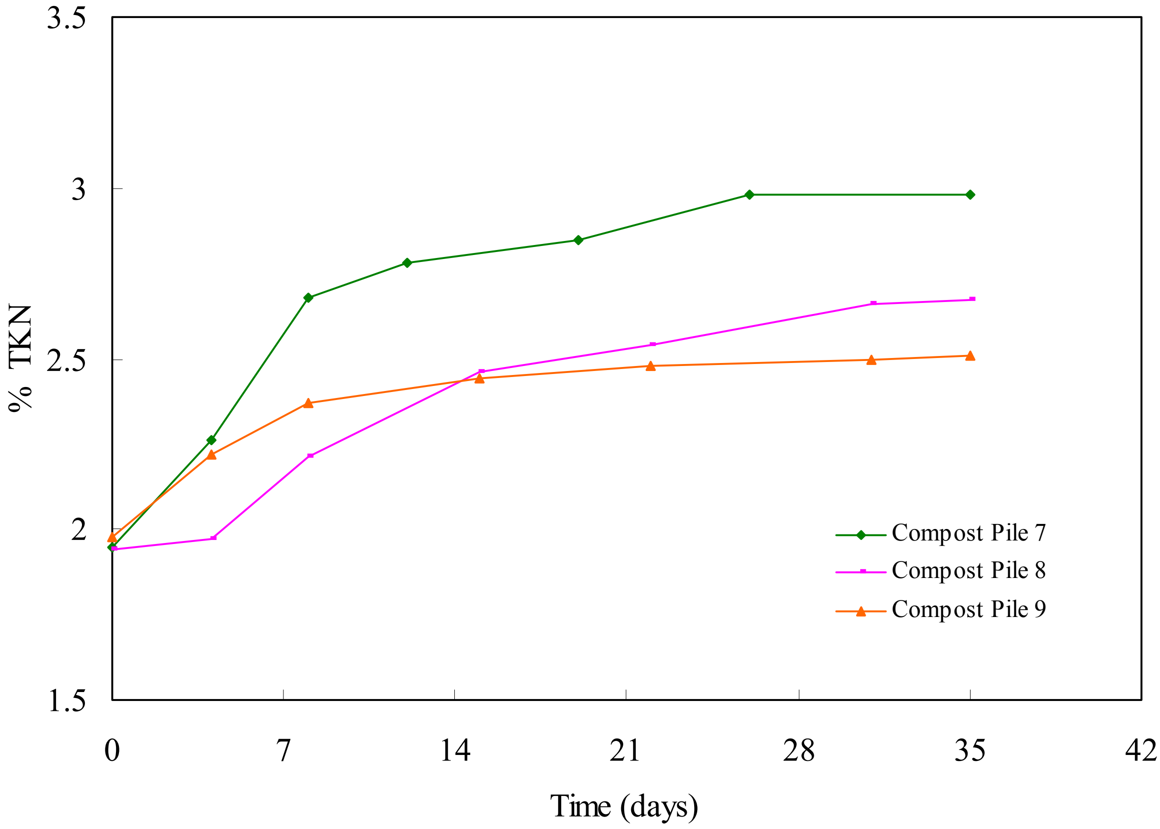

Figure 4-10. Time variation curves of nitrogen content (experiment set 2).

The oxidation of the nitrogen finally gives nitrate, and this would not be normally lost from the compost piles. Another possible factor contributing to the increase of nitrogen (especially in the forced-aerated piles) could be the presence of *Azobactor* organisms during the mesophilic phase which were found capable of fixing nitrogen from air up-to a concentration of 1050 μg/ml of culture medium (Alexander, 1961). A calculations of nitrogen content see (Appendix A1-3 for details) in the compost piles clearly show that there is an increase in total nitrogen contents in each compost pile although net nitrogen contents is become different due to the reasons explained earlier.

While comparing the amount of nitrogen present in the control piles with respective forced aerated compost piles, it was noticed that the control piles may loose more nitrogen in the form of NH_3 (gas) due to the turning of the piles. The nitrogen content in forced aerated piles is more than in the corresponding control piles because of possible fixation of nitrogen from air in these piles.

At different C/N ratio, the nitrogen value was found different. The nitrogen content was more in the piles with C/N ratio of 20:1 than in 30:1 and 40:1. The compost piles with C/N ratio of 20:1 have higher degradation rate of carbon than the compost piles with C/N ratios of 30:1 and 40:1 respectively. When the content in the compost piles with the same C/N ratio (20:1), but having different aeration period (i.e., piles 2, 7, 8, 9) were compared, the result obtained showed that the compost piles with less aeration period looses slightly less nitrogen in form of NH_3 (gas).

4.2.2 Phosphorus Content

Figure 4-11 (experimental data shown in Appendix B Tables B1-1 to B1-6). shows time variation curves of phosphorus content in compost piles 1, 2, 3, 4, 5 and 6 in the first set of experiment. In compost piles 1, 2, 3, 4, 5 and 6, respectively the initial phosphorus contents were 0.34 %, 0.33 %, 0.26 %, 0.25 %, 0.22 % and 0.24 %, respectively. The compost piles with a high C/N ratio had a low phosphorus content and vice-versa. At the end of the experiment, the phosphorus contents were 0.41 %, 0.41 %, 0.36 %, 0.25 % and 0.27 % in those compost piles (1, 2, 3, 4, 5 and 6), respectively. Figure 4-12 (experimental data shown in Appendix B Tables B1-7 to B1-9). shows the variations of phosphorus content at the initial C/N ratio of 20:1, the result of the second set of experiment. Here, the initial phosphorus contents were 0.34 %, 0.32 % and 0.31 % in compost piles 7, 8 and 9, respectively. At the end of the experiment, phosphorus contents in those piles were 0.39 %, 0.36 % and 0.38 %, respectively.

The increase in phosphorus content has been found in both experiment sets. Such an increase in phosphorus contents is mainly, due to loss of carbon or organic matter's mineralization in each compost pile (Arja et al, 1997; Traore et al, 1999) though a part of phosphorus may be lost as a leachate. However such a loss has been found less than 1 % (Petersen et al, 1998). Georgacakis et al (1996) has also found increase in phosphorus in the final compost product as found by Arja et al (1997), Petersen et al (1998), Traore et al (1999) that support the results found in this study.

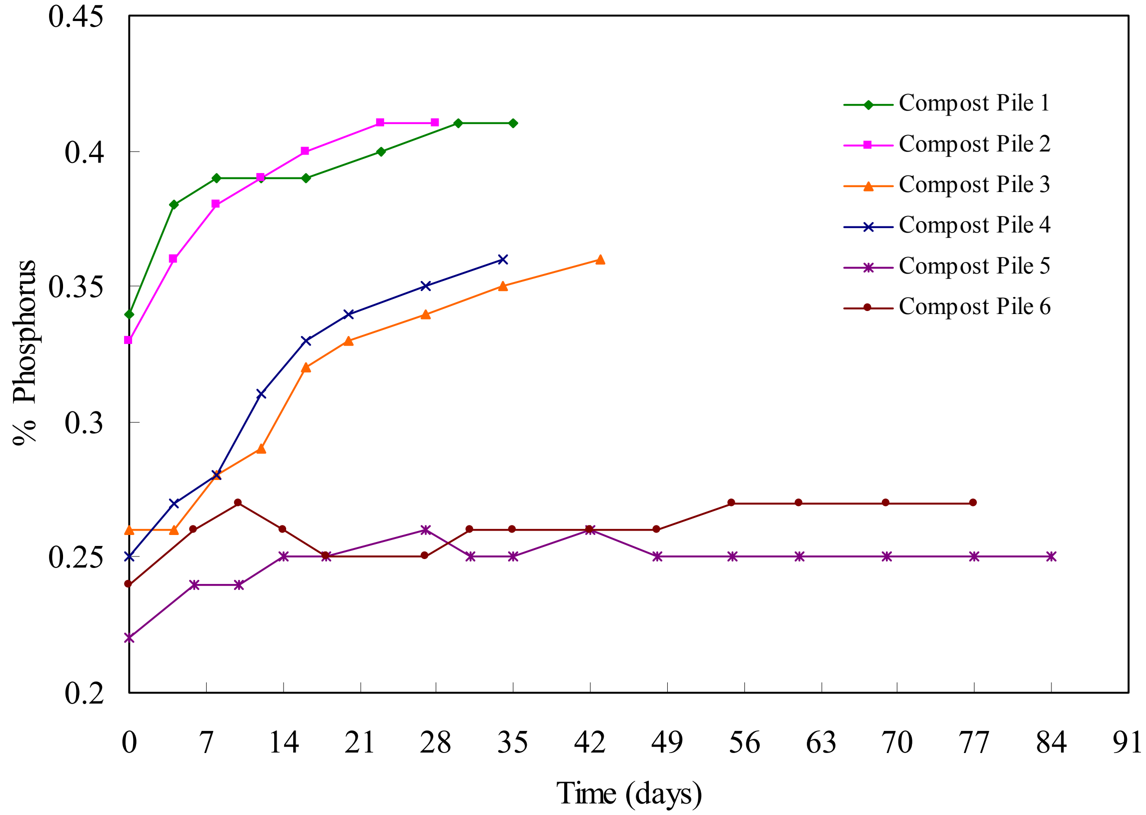

Figure 4-11. Time variation curves of phosphorus content (experiment set 1).

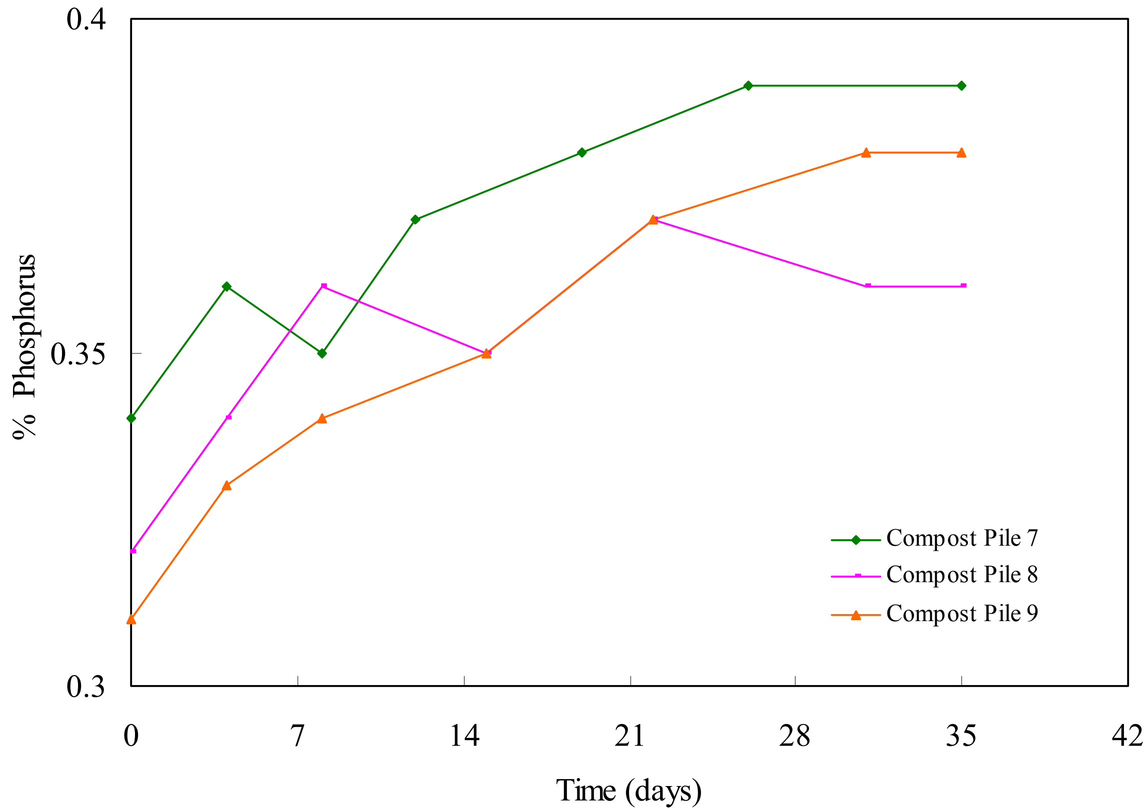

Figure 4-12. Time variation curves of phosphorus content (experiment set 2).

From statistical analysis, difference in phosphorus content was found significant among compost piles 1, 3 and 5 (i.e., control or a minor difference piles). However, almost no difference (p = 0.049) in phosphorus content has been observed among the aerated compost piles (2, 4, and 6). A details of the statistical analysis of phosphorus has been given in Appendix C Table C1-6. While comparing the content of phosphorous in between control piles and forced aerated piles, the later piles have more phosphorus content than the former piles. Forced-aerated piles loose more phosphorus but at the same time, these piles receive more oxygen, controlling the soluble phosphorus from leaching. When comparing phosphorus content in the compost piles with different C/N ratio, it has been noticed that the piles with higher C/N ratio had higher phosphorus content. The initial amount of phosphorus found in pig manure was 0.4 % and in hay, it was just 0.2 %. Little difference was noticed in the content of phosphorus in the compost piles with the same C/N ratio (20:1) but with different aeration period (Figure 4-12).

4.2.3 Potassium Content

In the first set of experiment, the initial potassium contents were 1.08 %, 1.10 %, 1.20 %, 1.19 %, 1.25 % and 1.23 %, respectively and at the end of the experiment, they were 1.11 %, 1.15 %, 1.28 %, 1.28 %, 1.34 % and 1.36 %, respectively in compost piles 1, 2, 3, 4, 5 and 6. Initial potassium contents in the second set of experiment were 1.08 %, 1.09 % and 1.09 % and at the end of the experiment, they were 1.13 %, 1.15 % and 1.14 %, respectively in the compost piles 7, 8 and 9, respectively. The increase in potassium content is just a little in every compost pile.

4.3 Decomposition Rate

4.3.1 Carbon Content

Chemical and physical changes occurring during the composting of the materials has been well understood (Mathur et al, 1993; Schnitzer et al, 1993; Dinel et al, 1996a, b; Pare et al, 1997). Time variation curves of carbon content for all the six compost piles of the first set of experiment are shown in Figure 4-13 (experimental data shown in Appendix B Tables B1-1 to B1-6). The initial carbon contents in those piles (1, 2, 3, 4, 5 and 6) were 41.56 %, 40.11 %, 42.02 %, 43.85 %, 44.01 % and 43.97 %, respectively for the compost piles 1, 2, 3, 4, 5 and 6.

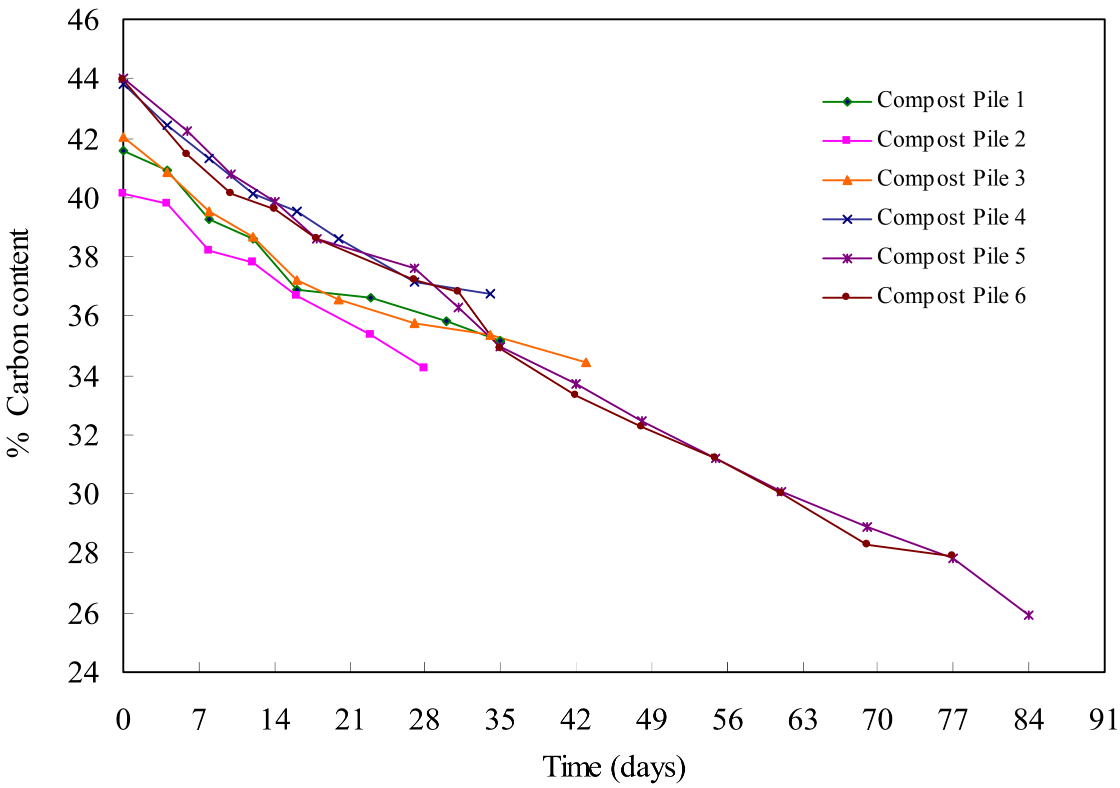

Figure 4-13. Time variation curves of carbon content (experiment set 1).

In the second set of experiment as shown in Figure 4-14 (experimental data shown in Appendix B Tables B1-7 to B1-9)., initial carbon contents were 40.68 %, 40.11 %, 40.93 % in the piles 7, 8 and 9, respectively. During the composting process, carbon contents in all compost piles gradually decreased until the end of the experiment. At the end of the composting process, the carbon contents were 35.84 %, 34.26 %, 34.41 %, 36.78 %, 25.90 % and 27.90 % in the compost piles 1, 2, 3, 4, 5 and 6, respectively and 36.68 %, 35.80 % and 36.49 % in compost piles 7, 8 and 9, respectively. The rate of decomposition of organic carbon was higher in the forced-aerated piles than in the control piles. This can be seen through the comparison of the rate of decrease in the volume of the control compost piles and the forced aerated compost piles. The microorganisms were effectively able to use the oxygen obtained through the forced-air from the bottom of the piles for their activities. This allows more reaction for organic carbon decomposition. While comparing the rate of decomposition of organic carbon under different C/N ratio condition, it was found that higher the C/N ratio, the more time needed in decomposing the organic materials.

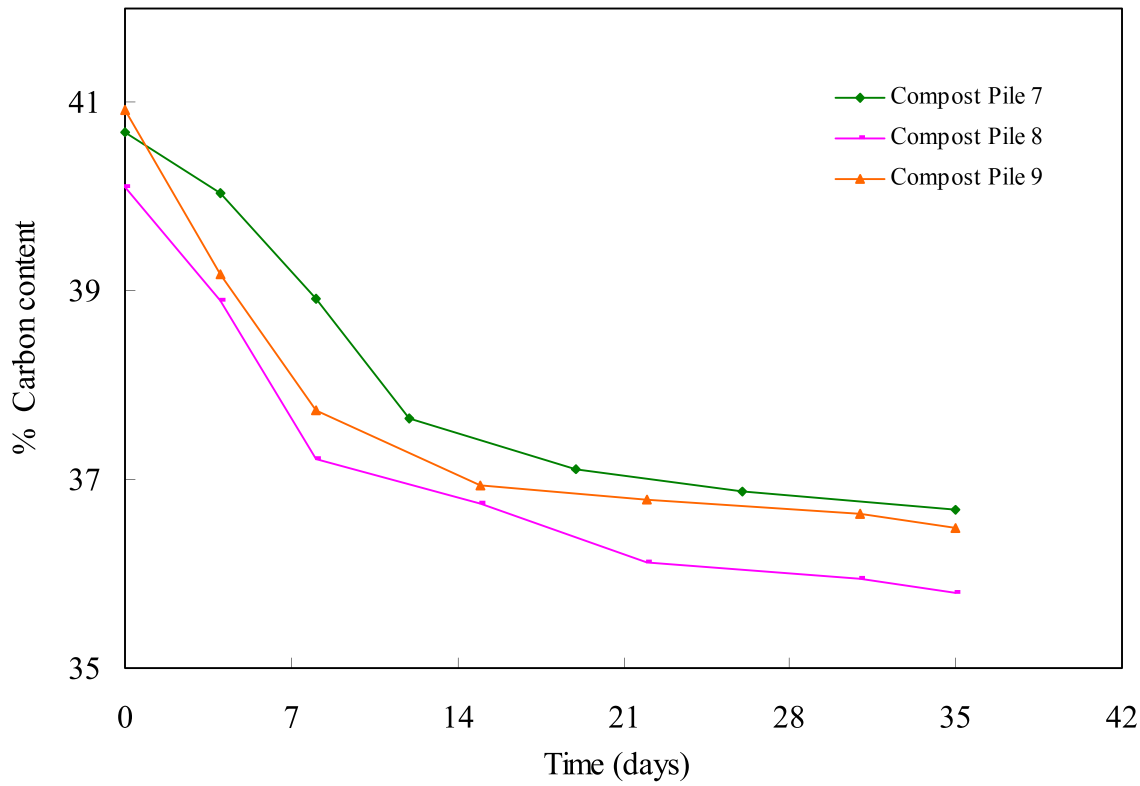

Figure 4-14. Time variation curves of carbon content (experiment set 2).

This means that the compost piles with high C/N ratio took more time to decompose than the compost piles with low C/N ratio. The general carbon elimination rates in the thermophilic phase (40^{o}C-65^{o}C) were more than the variation of carbon in the mesophilic phase. This is due to the presence of *cellulytic, fungus, thermopile chaetomium,* the predominant thermophilic species, reported to be more active in the decomposition process in the thermophilic range than the actinomycetes, the dominant organisms in the mesophilic phase (Chang, 1967; Fergus, 1964). The rate of decomposition ultimately depends upon the capability of microorganisms to break-down the materials by making appropriate use of oxygen added into the system. The capability of microorganisms also depends upon their genetics make-up where the environment permits their expression of the genetic make-up (Rabbani et al, 1983).

The rate of decomposition of organic carbon of pig manure with the same C/N ratio (20:1), but with different aeration time resulted that more the aeration time, more decomposition of organic materials. This means, the compost piles having aeration rate of 24 hours a day have greater decrease in organic carbon than the compost piles with aeration rate of 18 hours a day, 12 hours a day, and 6 hours a day, respectively. Aeration rate and aeration period are important factors in the efficiency of carbon decomposition. In the absence of aeration in the compost pile, oxygen often becomes a limiting factor and reduces the carbon decomposition rate (Finstein et al, 1983; Itavaara et al, 1997). Thus, carbon decomposition rate was largest in the piles with initial C/N ratio of 20:1 followed by the piles with initial C/N ratio of 30:1, and this was smallest in the piles with initial C/N ratio of 40:1.

From statistical analysis as shown in Appendix C Table C1-7, no major difference in carbon decomposition rate was noticed among the compost piles 2, 7, 8 and 9 (p = 0.725). Similarly, no difference (p = 0.156) was noticed among the control piles with different C/N ratio (1, 3 and 5). However, significantly difference (p = 0.047) in carbon decomposition rate was observed in compost piles 2, 4 and 6.

4.3.2 Carbon to Nitrogen Ratio

The initial C/N ratios in the first set of experiment (i.e., in compost piles 1, 2, 3, 4, 5 and 6) were nearly 22, 21, 32, 32, 40 and 41, respectively. At the end of the experiment, the C/N ratio gradually decreased to about 16, 15, 20, 19, 20 and 20 for the compost piles 1, 2, 3, 4, 5 and 6, respectively. As shown in the Figure 4-15 (experimental data shown in Appendix B Tables B1-1 to B1-6)., forced-aerated compost piles (2, 4 and 6) have higher decline rate of C/N ratio compared to control piles (no forced-air supply, i.e., piles 1, 3 and 5).

In the second set of experiment, the initial C/N ratio were nearly 21, 21 and 21, i.e., for piles 7, 8 and 9, respectively. At the end of the experiment, C/N ratios in those piles were around 12, 13 and 15, respectively. As shown in the Figure 4-16 (experimental data shown in Appendix B Tables B1-7 to B1-9)., the decrease in C/N ratio in the compost piles with more aeration period have higher value of C/N ratios at the end compared with the piles with air supply for lesser periods. In fact, longer the aeration period, more decomposition of carbon. But at the same time, nitrogen (%) increases.

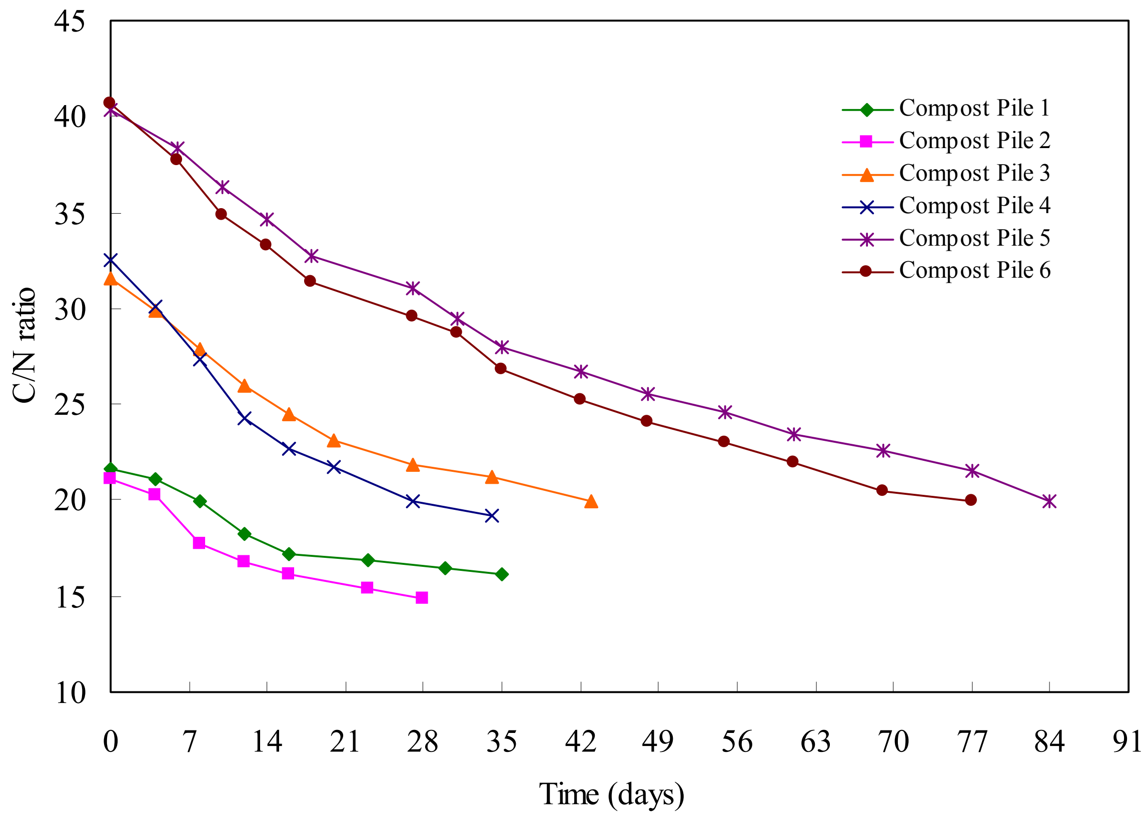

Figure 4-15. Time variation curves of C/N ratio (experiment set 1).

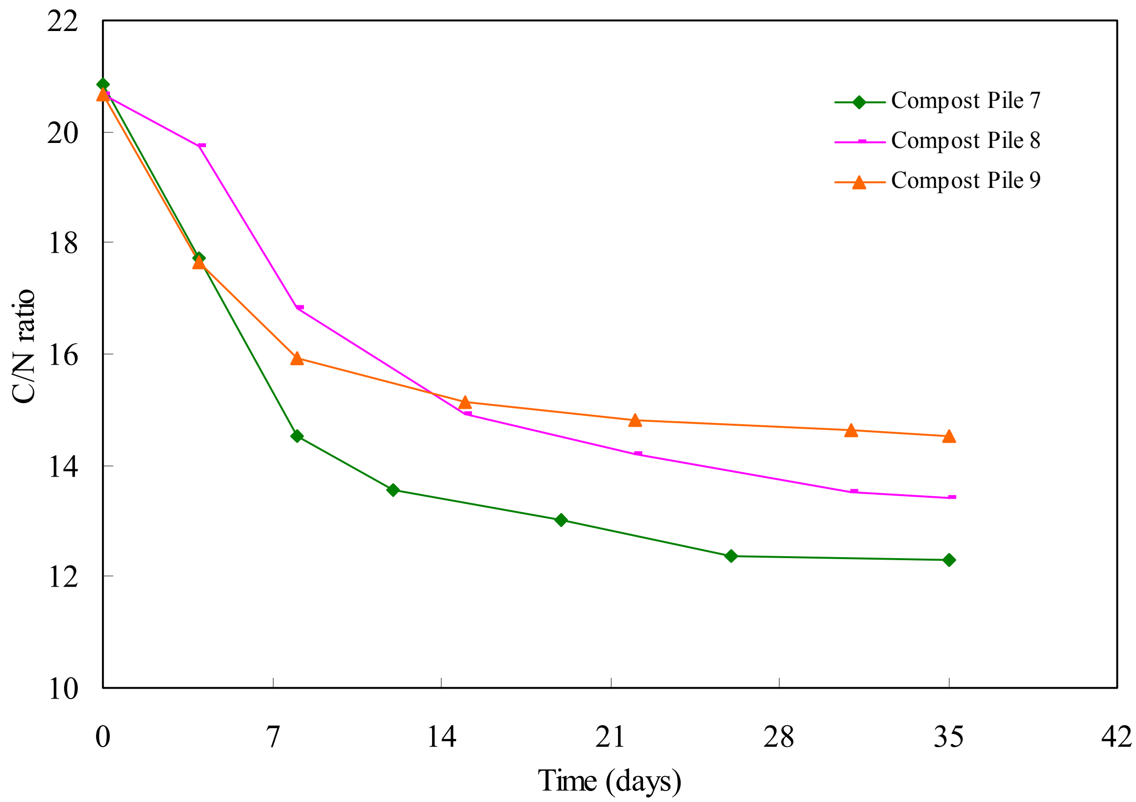

Figure 4-16. Time variation curves of C/N ratio (experiment set 2).

The carbon to nitrogen ratio (C/N) is one of the main characteristic that describes the composting process. While comparing the rate of decrease of C/N ratio between the control piles and forced-aerated piles, it was noticed that forced aerated piles have higher rate of decrease of the C/N ratio than the respective control piles. Statistic analysis as shown in Appendix C Table C1-8.

Htay (1995) mentioned that C/N values of compost piles decrease in different rate because loss of nitrogen and carbon is not at the same rate. Too high a C/N ratio slows the process, whereas, too low a C/N leads to a nitrogen loss in the form of ammonia (Daiz et al, 1993). The carbon to nitrogen (C/N) ratio is very important in the nutrient balance of all organisms. Carbon is a source of energy for the micro-organisms and nitrogen is necessary for the synthesis of protoplasm. More carbon than nitrogen is required, but when there is a too great excess of either, biological activity diminishes and the completion of the process is delayed. Two-thirds of the carbon consumed by micro-organisms is given off as CO_2, and the rest is combined with nitrogen in the cell. When there is insufficient carbon to convert the nitrogen into protoplasm, micro-organisms make full use of the small amount of carbon available and eliminate the excess nitrogen as ammonia. Large amounts of ammonia can be formed, and if the compost is applied during this phase of active composting, it may prove toxic to plants (Lardinois and Van De Klundert, 1993).

4.4 Finished Compost Products

The compositions of the finished compost products from both sets of experiments are presented in Tables 4-3 and 4-4.

In the first set of experiment (Table 4-3), the nitrogen, phosphorus and potassium contents (%) in the finished compost products have been found in the range 1.3 to 2.18 %, 0.25 to 0.41 %, and 1.15 to 1.36 %, respectively. In the compost piles with lower initial C/N ratio has lower final C/N ratio and higher content of nitrogen.

In the second set of experiment, (i.e., with the same C/N ratio but with different aeration period), the nitrogen, phosphorus and potassium contents (%) have been found in the range 2.51 to 2.98 %, 0.36 to 0.39 %, and 1.13 to 1.15 %, respectively.

Table 4-3. The composition of finished compost products of the first set of experiment (% dry weight basis).

Composition	Compost Pile					
	1	2	3	4	5	6
Moisture content (%)	50.17	48.39	44.75	43.62	30.11	33.16
Carbon (%)	35.14	34.26	34.41	36.78	25.90	27.90
TKN (%)	2.18	2.31	1.73	1.92	1.3	1.4
C/N ratio	16.12	14.83	19.89	19.16	19.92	19.93
Phosphorus (%)	0.41	0.41	0.36	0.36	0.25	0.27
Potassium (%)	1.11	1.15	1.28	1.28	1.34	1.36
pH	9.04	9.25	9.3	9.1	8.6	8.9
Total coliform bacteria	nf	nf	nf	nf	nf	nf

Note : nf = not found or nearly 100 % die-off.

Table 4-4. The composition of finished compost products of second set of experiment (% dry weight basis).

Composition	Compost Piles		
	7	8	9
Moisture content (%)	52.01	51.03	49.38
Carbon (%)	36.68	35.80	36.49
TKN (%)	2.98	2.67	2.51
C/N ratio	12.31	13.41	14.54
Phosphorus (%)	0.39	0.36	0.38
Potassium (%)	1.13	1.15	1.14
pH	9.08	9.05	9.05
Total coliform bacteria	nf	nf	nf

Note : nf = not found or nearly 100 % die-off.

According to the standard of Thailand, finished compost product should contain nitrogen not less than 1 %, phosphorus not less than 1 %, and potassium not less than 0.5 % (Charungroung et al, 1998). The nitrogen contents and potassium contents found in the finished compost products in all piles of both experiment sets in this study have clearly met the corresponding standards though phosphorus contents were, somehow do not meet the corresponding standard. These compost products can be partly, used as soil conditioner and/or plant nutrient source.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Composting is not only a better method to deal with the problem of pollution, it also results in the production of a valuable soil conditioner/organic fertilizer which is in large demand in the developing countries of Asia. The results obtained from the experiments suggested that forced-aerated static pile composting method is the most appropriate method for the composting of pig manure mixed with hay at the initial C/N ratio of 20:1.

While comparing the forced-aerated compost piles with the control piles, more carbon degradation was found in the former than that in the latter. Accordingly, nitrogen content was found higher in the former than in the latter. This suggests that organisms present in the compost piles were capable of fixing more nitrogen in the better aerobic environment. In compost pile 2 (forced-aerated 24 hours a day and initial C/N ratio of 20:1), total coliform bacteria was not found on the 28^{th} day of composting, and in the rest piles, no total coliform bacteria was not found from the 35^{th} day of composting. The nutrient values obtained in the compost products showed that nitrogen and potassium contents meet the required standards and therefore, they can be partly used in the agriculture field as soil conditioner/fertilizer.

5.2 Recommendations

1. In any future study, composting efficiency of pig-manure mixed with hay and other materials such as water hyacinth should be compared.

2. Mechanisms of nutrients and carbon balance during the composting should be studied as it is, still, not fully investigated.

3. Identification, and counting of organisms responsible for successfully converting the waste material into compost product should be done at different composting stages.

4. Finally, isolation of the efficient microorganisms should be done and applied in the composting process to further improve the quality of the compost products and reduce the composting period or improve the composting efficiency.

APPENDIX A

Calculation methods

A1-1. Determination of the quantity of pig manure and hay for different C/N ratio.

Pig-manure
C/N = 15.47

Total solid = 98 %

Total volatile solids = 70.74 %

Nitrogen content = 2.54 %

Bulk density = 0.4 kg/L

Hay
C/N = 50.06

Total solid = 94 %

Bulk density = 0.1 kg/L

Nitrogen content = 0.89 %

Percentage C = (100 – percentage ash)/1.8

Percentage ash = 100 – total volatile solids = 100-70.74 = 29.26

%C = (100-29.26) / 1.8 = 39.3% of total solids

Let X be kg dry weight of hay needed to be mixed with 1 kg dry weight of pig-manure.

For 1 kg dry weight of pig manure

carbon content = 1(0.39) kg ; nitrogen content = 1 (0.39)(1/15.47) kg.

For X kg dry weight of Hay

Nitrogen content = X (0.89/100) kg ; Carbon content = X (0.89/100)(50.06/1)kg.

Thus, $(C_p + C_h)/(N_p + N_h) = (C/N)_m$

Where,

C_p = Carbon content of pig-manure

N_p = Nitrogen content of pig-manure

N_h = Carbon content of hay

C_h = Nitrogen content of hay

$(C/N)_m$ = C/N ratio of mixture between pig-manure and hay

(a) For C/N ratio of 20:1

Let X = quantity of hay

Then, we get

$$\frac{1(0.39) + X(0.89/100)(50.06/1)}{1(0.39)(1/15.47) + X(0.89/100)} = \frac{20}{1}$$

$$X = 0.40 \text{ kg.}$$

Volume of hay required = 0.40 kg./(0.94 × 0. 1kg/L)

= 4.25 L

1 kg dry weight of pig-manure = 1 kg./(0.98 × 0.4 kg/L)

= 2.55 L

Therefore 2.55 L pig-manure is required to mix with 4.25 L of for the ratio 20:1.

(b) For C/N ratio of 30:1

$$\frac{1(0.39) + X (0.89/100)(50.06/1)}{1(0.39)(1/15.47) + X (0.89/100)} = \frac{30}{1}$$

X = 1.96 kg.

Volume of hay required = 1.96 kg./(0.94 × 0. 1kg/L)

= 20.85 L

1 kg dry weight of pig-manure = 1 kg./(0.98 × 0.4 kg/L)

= 2.55 L

Therefore 2.55 L pig-manure is required to mix with 20.85 L of hay for the C/N ratio of 30:1.

(c) For C/N ratio of 40:1.

$$\frac{1(0.39) + X (0.89/100)(50.06/1)}{1(0.39)(1/15.47) X (0.89/100)} = \frac{40}{1}$$

X = 6.48 kg.

Volume of hay required = 6.48 kg./(0.94 × 0. 1kg/L)

= 68.93 L

1 kg dry weight of pig-manure = 1 kg./(0.98 × 0.4 kg/L)

= 2.55 L

Therefore 2.55 L pig-manure is required to mix with 68.93 L of hay for the C/N ratio of 40:1.

A1-2. Calculation of thermal inactivation coefficient.

Kinetics are often modeled assuming first order decay (Haug, 1993) as follows:

$$dn / dt = -k_d n \qquad \text{(A1-2.1)}$$

Where n = viable cell population

k_d = thermal inactivation coefficient

If k_d is constant, integration of equation (A1-2.1) from an initial cell population, n_o to a later population, n_t, at time, t, yields

$$n_t = n_o e^{(-kdt)} \qquad \text{(A1-2.2)}$$

Taking the log of both sides and rearranging, one can get

$$k_d = [\ln(n_o / n_t)]/t \qquad \text{(A1-2.3)}$$

$$t = [\ln(n_o / n_t)]/k_d$$

Converting to base 10 logs and considering a one log reduction in cell concentration (i.e., a reduction of 90%, and 99%), one can obtain

$$t_{90} = 2.303 / k_d$$

$$t_{99} = 4.605 / k_d$$

Since, the value of k_d is a function of temperature, the effect of which is most often modeled by the familiar Arrhenius form:

$$K_d = Ce^{(-Ed/RTk)} \qquad \text{(A1-2.4)}$$

Where T_k = temperature, ^oK

Logarithmic transformation of equation (A1-3.4) yields

$$Log_{10}\, k_d = Log_{10}\, C - (E_d/R)(1/T_k) \qquad \text{(A1-2.5)}$$

Thus, plot of the logarithm of k_d vs. 1/ T_k allows determination of the constant, C, and the inactivation energy, E_d.

From statistic analysis (ANOVA), it has been found that total coliform baceria in all the compost piles were not significantly different. Thus, pile 2 has been chosen for calculating the decay rate using equation (A1-2.3) which are shown in Table A1-2.1.

Table A1-2.1. Value for plot of Log k_d and 1 / T_k

Time (days)	Total coliform bactria (number/100mL)	k_d	Log k_d	Temperature (^oC)	T_k	1 / T_k
0	6.4×10^5	0	0	36	309	3.24×10^{-3}
7	4.8×10^5	0.041	-1.387	46	319	3.13×10^{-3}
14	8.3×10^4	0.15	-0.824	32	305	3.28×10^{-3}
21	4.0×10^4	0.13	-0.886	29	302	3.31×10^{-3}

From the plot of the logarithm of k_d vs 1/ T_k as shown in Figure A1-2.1, one can obtain

$$\text{Log}_{10} C = 7.3482$$

$$C = 2 \times 10^8$$

$$E_d/R = 1969.6 = 1.97 \times 10^3$$

Where $R = 1.99$ cal/deg-mol

$$E_d = 1.97 \times 10^3 \times 1.99 = 3.9 \times 10^3 \text{ cal/mol}$$

Note that the value of E_d is consistent with the previously reported range of values for heat inactivation of total coliform bacteria. Substituting these values into equation (A1-2.4), one can obtain.

$$K_d = 2 \times 10^8 \, e^{-(1.97 \text{ x } 10 /Tk)} \qquad \text{(A1-2.6)}$$

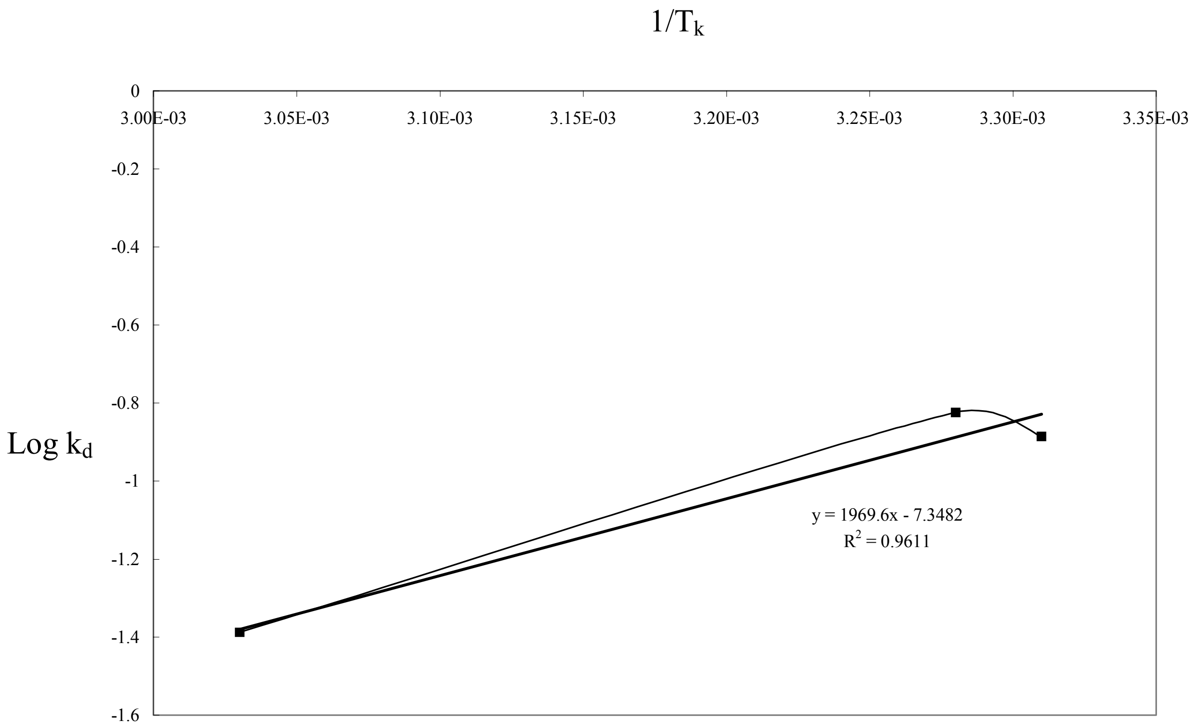

Figure A1-2.1. Plot of the logarithm of k_d vs $1/T_k$

A1-3. Calculation of total nitrogen increase.

Analysis of total nitrogen has been done by using total kjedahl method (titrimetric). This method is based on the titration of basic ammonia with standard sulfuric acid using methyl red and bromocresol green indicator mixed with boric acid indicator solution to pale lavender end point. Detail has been given in the book by Patnaik (1997).

Calculation of nitrogen concentration in a sample of compost can be done by using the following formula.

$$\text{mg N/L} = \frac{(V_s - V_b)\ 14000X}{\text{mL sample}} \quad \text{(A1-3.1)}$$

Where V_s = mL of H_2SO_4 required for the titration of sample distillate

V_b = mL of H_2SO_4 required in the blank titration

X = Normality of H_2SO_4

$$\text{Normality (X)} = \frac{\text{molarity of } H_2SO_4 \times \text{weight of } H_2SO_4 \text{ in one mole}}{\text{mL sample}} \quad \text{(A1-3.2)}$$

Where molarity (M) = 0.045 mole/L for the first titrant standardization (H_2SO_4), and for the second titrant standardization 0.042 mole/L

From equation (A-3.2), one can get

$$X = \frac{(0.045\ mole/L)\times(98\ g/mole)}{(98\ g/mole)/(6\ eq/mole)} \quad \text{(A1-3.3)}$$

= 0.27 eq/L for concentration of H_2SO_4 = 0.045 mole/L

$$X = \frac{(0.042\ mole/L)\times(98\ g/mole)}{(98\ g/mole)/(6\ eq/mole)} \quad \text{(A1-3.4)}$$

= 0.25 eq/L for concentration of H_2SO_4 = 0.045 mole/L

Substituting the values of X in equation (A1-3.1), one can get

$$\text{mg N/L} = \frac{(V_s - 1)\,3780}{\text{mL sample}}, \text{ for concentration of } H_2SO_4 = 0.045 \text{ mole/L} \qquad \text{(A1-3.5)}$$

$$\text{mg N/L} = \frac{(V_s - 2.9)\,3500}{\text{mL sample}}, \text{ for concentration of } H_2SO_4 = 0.042 \text{ mole/L} \qquad \text{(A1-3.6)}$$

Where V_b = 1 mL , for concentration of H_2SO_4 = 0.045 mole/L

V_b = 2.9 mL , for concentration of H_2SO_4 = 0.042 mole/L

mL sample = 75 mL.

From equations (A1-3.5) and (A1-3.6), using different values of V_s obtained from the titration of sample distillate of each compost pile, the TKN values were evaluated as shown in Table A1-3.1.

Table A1-3.1. TKN evaluation

Pile no.	V_s (mL)	V_b (mL)	mL sample (mL)	X (mole/L)	N (µg/mL)	Total TKN increase (µg/mL)
1	76.2	1	75	0.27	3,790	
	92.71	1	75	0.25	4,280	490
2	75.4	1	75	0.27	3,750	
	98.32	1	75	0.25	4,542	792
3	52.8	1	75	0.27	2,611	
	73.5	1	75	0.25	3,383	773
4	53.6	1	75	0.27	2,651	
	81.6	1	75	0.25	3,761	1,110
5	43.2	1	75	0.27	2,127	
	55.3	1	75	0.25	2,534	407
6	48.2	1	75	0.27	2,379	
	59.5	1	75	0.25	2,730	351
7	77.5	1	75	0.27	3,856	
	126.85	1	75	0.25	5,873	2,017
8	76.59	2.9	75	0.27	3,714	
	113.74	2.9	75	0.25	5,173	1,459
9	78.5	2.9	75	0.27	3,810	
	106.7	2.9	75	0.25	4,844	1,034

A 1-4. Heat balance for composting

Theoretical O_2 requirement can be calculated as

$$\underset{(201)}{C_{10}H_{19}O_3N} + 12.5O_2 \longrightarrow 10CO_2 + 8H_2O + NH_3 \qquad \text{----- (1)}$$

$$\Delta H = 10\, H_f(CO_2) + 8\, H_f(H_2O) + 18\, H_f(NH_3) - H_f(C_{10}\, H_{19}\, O_3N) - \cancelto{0}{12.5\, H_f(O_2)} \qquad \text{----- (2)}$$

H_f = Enthalpy of formation

Du-Long formula is generally used in the utility field (C.C. Lee, 2000). Thus,

H_f [Btu/lb] = 14,455 [C] + 62,028[H] + 2,700[N]-7,753[O]

H_f (CO_2) = 14,455[C] –7753[O] ----- (3)

Weight formula of C = 1, O = 2
Weight fractions of C = [C] : 1 mole at 12 = 12/44 = 0.27
Weight fractions of O = [O] : 2 moles at 16 = 32/44 = 0.73

After Substituting value of weight fractions of C and O into equation (3),one can obtain
Then H_f (CO_2) = 14,455 [0.27] –7753[0.73] = -1,756.84 Btu/lb

$H_f(H_2O)$ = 62,028[H] – 7,753[O] ----- (4)

Weight formula of H = 2, O = 1
Weight fractions of H = [H] : 2 moles at 1 = 2/18 = 0.11
Weight fractions of O = [O] : 1 mole at 16 = 16/18 = 0.88
Substituting value of weight fractions of H and O into equation (4), then
$H_f(H_2O)$ = 62,028[0.11] – 7,753[0.88]= 0.44 Btu/lb

$H_f(NH_3)$ = 2,700[N] + 62,028[H] ----- (5)

Weight formula of N = 1, H = 3
Weight fractions of N = [N] : 1 mole at 14 = 14/17 = 0.82
Weight fractions of H = [H] : 3 moles at 1 = 3/17 = 0.18
Substituting value of weight fractions of N and H in to equation (5), one can obtain
$H_f(NH_3)$ = 2,700[0.82] + 62,028[0.18] = 13,379.04 Btu/lb

$H_f(C_{10}\, H_{19}\, O_3N)$ = 14,455 [C] + 62,028[H]]-7,753[O] + 2,700[N] ----- (6)

Weight formula of C = 10, H = 19, O = 3, N = 1
Weight fractions of C = [C] : 10 moles at 12 = 120/201 = 0.597

Weight fractions of H = [H] : 19 moles at 1 = 19/201 = 0.095
Weight fractions of O = [O] : 3 moles at 16 = 48/201 = 0.239
Weight fractions of N = [N] : 1 moles at 14 = 14/201 = 0.070

Substituting value of weight fractions of C, H, N and O in to equation (6), one can obtain
$H_f(NH_3)$ = 14,455 [0.597] + 62,028[0.095]]-7,753[0.239] + 2,700[0.070]

= 12,858.33 Btu/lb

Substitution of all value of H_f into equation (2) ginves

ΔH = 10 (-1,756.84) + 8 (0.44) + 18 (13,379.04) - 12,858.33
ΔH = 210,399.51 Btu/lb

1 Btu/lb = 2.3241 kJ/kg

ΔH = 488,989.50 kJ/kg = 488,989.50 J/g

1 J = 0.2388 cal

ΔH = 116.770 kcal/g

Then equation (1) is

$$C_{10}H_{19}O_3N + 12.5O_2 \longrightarrow 10CO_2 + 8H_2O + NH_3 + 116.77\ kcal/g$$

APPENDIX B

Experimental data

Table B1-1. Experimental data of compost pile 1 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	65.70	41.56	1.92	21.65	0.34	1.08	7.40
4	62.75	40.89	1.94	21.08	0.38	*	8.81
8	58.93	39.25	1.97	19.92	0.39	*	8.60
12	56.15	38.58	2.11	18.28	0.39	*	9.32
16	54.17	36.86	2.15	17.14	0.39	*	9.74
23	52.46	36.64	2.17	16.88	0.40	*	9.36
30	51.40	35.84	2.18	16.44	0.41	*	9.29
35	50.17	35.14	2.18	16.12	0.41	1.11	9.04

Table B1-2. Experimental data of compost pile 2 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	66.31	40.11	1.90	21.11	0.33	1.10	7.40
4	62.36	39.76	1.96	20.29	0.36	*	8.68
8	59.74	38.18	2.16	17.68	0.38	*	8.66
12	56.51	37.81	2.25	16.80	0.39	*	9.30
16	54.49	36.68	2.28	16.09	0.40	*	9.60
23	51.50	35.34	2.30	15.37	0.41	*	9.09
28	48.39	34.26	2.31	14.83	0.41	1.15	9.25

Table B1-3. Experimental data of compost pile 3 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	65.59	42.02	1.33	31.59	0.26	1.20	7.80
4	62.84	40.87	1.37	29.83	0.26	*	8.13
8	59.64	39.52	1.42	27.83	0.28	*	8.00
12	56.42	38.64	1.49	25.93	0.29	*	8.93
16	53.19	37.21	1.52	24.48	0.32	*	9.57
20	50.68	36.52	1.58	23.11	0.33	*	9.40
27	47.48	35.76	1.64	21.80	0.34	*	9.35
34	46.63	35.38	1.67	21.19	0.35	*	9.60
42	44.75	34.41	1.73	19.89	0.36	1.28	9.30

Table B1-4. Experimental data of compost pile 4 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	64.36	43.85	1.35	32.48	0.25	1.19	7.70
4	61.60	42.41	1.41	30.08	0.27	*	8.35
8	58.84	42.32	1.51	28.03	0.28	*	8.30
12	56.07	40.11	1.65	24.31	0.31	*	8.88
16	51.76	39.54	1.74	22.72	0.33	*	9.57
20	49.06	38.60	1.78	21.69	0.34	*	9.51
27	46.32	37.18	1.86	19.99	0.35	*	9.35
35	43.62	36.78	1.92	19.16	0.36	1.28	9.10

Table B1-5. Experimental data of compost pile 5 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	62.96	44.01	1.09	40.38	0.22	1.25	7.60
6	59.96	42.23	1.10	38.39	0.24	*	8.03
10	57.06	40.75	1.12	36.38	0.24	*	8.00
14	54.01	39.84	1.15	34.64	0.25	*	9.14
18	50.16	38.60	1.18	32.71	0.25	*	9.35
27	47.16	37.62	1.21	31.09	0.26	*	9.40
31	43.96	36.29	1.23	29.50	0.25	*	9.50
35	41.23	34.99	1.25	27.99	0.25	*	9.45
42	39.67	33.71	1.26	26.75	0.26	*	9.31
48	37.47	32.46	1.27	25.56	0.25	*	9.29
55	34.69	31.22	1.27	24.58	0.25	*	9.10
61	34.01	30.05	1.28	23.48	0.25	*	9.20
69	32.99	28.90	1.28	22.58	0.25	*	9.10
77	30.74	27.80	1.29	21.55	0.25	*	8.80
84	30.11	25.90	1.30	19.92	0.25	1.34	8.60

Table B1-6. Experimental data of compost pile 6 (experiment set 1).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	65.25	43.97	1.08	40.71	0.24	1.23	7.70
6	62.25	41.45	1.10	37.68	0.26	*	8.30
10	58.44	40.12	1.15	34.89	0.27	*	8.20
14	54.71	39.60	1.19	33.28	0.26	*	9.12
18	52.23	38.60	1.23	31.38	0.25	*	9.00
27	50.07	37.20	1.26	29.52	0.25	*	9.30
31	46.87	36.80	1.28	28.75	0.26	*	9.50
35	43.77	34.89	1.30	26.84	0.26	*	9.40
42	40.79	33.32	1.32	25.24	0.26	*	9.30
48	37.55	32.23	1.34	24.05	0.26	*	9.26
55	36.41	31.22	1.36	22.96	0.27	*	9.24
61	35.54	30.00	1.37	21.90	0.27	*	9.10
69	34.25	28.31	1.38	20.51	0.27	*	9.00
77	33.16	27.90	1.40	19.93	0.27	1.36	8.90

Table B1-7. Experimental data of compost pile 7 (experiment set 2).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	64.35	40.68	1.95	20.86	0.34	1.08	7.60
4	62.39	40.03	2.26	17.71	0.36	*	8.58
8	60.28	38.93	2.68	14.53	0.35	*	8.21
12	58.85	37.65	2.78	13.54	0.37	*	8.77
19	56.93	37.11	2.85	13.02	0.38	*	9.23
26	54.39	36.88	2.98	12.38	0.39	*	9.10
35	52.01	36.68	2.98	12.31	0.39	1.13	9.08

Table B1-8. Experimental data of compost pile 8 (experiment set 2).

Time (days)	**Moisture content (%)**	**Carbon content (%)**	**Nitrogen content (%)**	**C/N ratio**	**Phosphorus (%)**	**Potassium (%)**	**pH**
0	66.59	40.11	1.94	20.68	0.32	1.09	7.50
4	63.64	38.89	1.97	19.74	0.34	*	8.66
8	60.53	37.22	2.21	16.84	0.36	*	8.42
12	58.50	36.74	2.46	14.93	0.35	*	9.16
19	56.42	36.12	2.54	14.22	0.37	*	9.34
31	53.70	35.95	2.66	13.52	0.36	*	9.12
35	51.03	35.80	2.67	13.41	0.36	1.15	9.05

Table B1-9. Experimental data of compost pile 9 (experiment set 2).

Time (days)	Moisture content (%)	Carbon content (%)	Nitrogen content (%)	C/N ratio	Phosphorus (%)	Potassium (%)	pH
0	65.08	40.93	1.98	20.67	0.31	1.09	7.70
4	63.26	39.18	2.22	17.65	0.33	*	8.67
8	59.77	37.74	2.37	15.92	0.34	*	8.65
12	57.37	36.93	2.44	15.14	0.35	*	9.25
19	55.60	36.78	2.48	14.83	0.37	*	9.61
31	52.31	36.63	2.50	14.65	0.38	*	9.11
35	49.38	36.49	2.51	14.54	0.38	1.14	9.05

Table B1-10. Experimental data of total coliform bacteria (number/g) for all compost piles.

Time (days)	**Compost pile**								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	6×10^{8}	6.4×10^{8}	4.5×10^{8}	4.6×10^{8}	2.4×10^{8}	2.7×10^{8}	6.0×10^{8}	6.3×10^{5}	6.1×10^{8}
7	3.1×10^{8}	4.8×10^{8}	1.6×10^{8}	1.7×10^{8}	8.0×10^{8}	9.4×10^{8}	3.1×10^{8}	4.1×10^{5}	3.7×10^{8}
14	9×10^{7}	8.3×10^{7}	6.4×10^{7}	6.2×10^{7}	2.1×10^{7}	3.3×10^{7}	8.3×10^{7}	7.9×10^{4}	7.6×10^{7}
21	6×10^{7}	4×10^{7}	3.2×10^{7}	3.2×10^{7}	1.7×10^{7}	1.5×10^{7}	3.7×10^{7}	4.1×10^{4}	5.2×10^{7}
28	4×10^{7}	0	22×10^{5}	56×10^{5}	44×10^{5}	52×10^{5}	5.0×10^{5}	6.1×10^{2}	7.7×10^{5}
35	0	*	0	0	0	0	0	0	0
42	*	*	0	*	0	0	*	*	*

Note : * = not measured

Table B2-1.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding	Pile 1			Pile 2		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
9/30/99	9 AM	27	33	36	34			
	3 PM	33	35	36	35			
10/1/99	9 AM	27	36	48	41	35	37	36
	3 PM	29	37	40	39	35	37	36
10/2/99	9 AM	28	37	55	45	38	47	42
	3 PM	34	40	53	49	37	46	41
10/3/99	9 AM	28	52	62	60	47	58	52
	3 PM	37	55	63	60	55	59	57
10/4/99	9 AM	27	68	71	69	54	59	56
	3 PM	35	69	70	69	58	65	60
10/5/99	9 AM	28	70	71	69	67	70	67
	3 PM	36	66	67	65	66	68	65
10/6/99	9 AM	30	66	69	58	52	64	53
	3 PM	36	56	56	54	63	65	64
10/7/99	9 AM	29	65	69	68	51	59	54
	3 PM	35	66	69	66	55	63	60
10/8/99	9 AM	30	59	68	63	43	52	48
	3 PM	30	57	67	65	43	51	41
10/9/99	9 AM	28	58	67	60	40	51	48
	3 PM	33	60	68	63	42	53	47
10/10/99	9 AM	29	55	63	62	39	53	48
	3 PM	32	56	63	59	41	51	45
10/11/99	9 AM	27	55	62	59	35	46	38
	3 PM	35	49	52	50	38	49	36
10/12/99	9 AM	28	53	62	58	33	45	45
	3 PM	37	50	54	53	36	43	39
10/13/99	9 AM	28	44	58	55	31	38	31
	3 PM	35	41	54	49	30	35	33
10/14/99	9 AM	27	42	56	51	30	30	27
	3 PM	30	45	56	47	35	33	33
10/15/99	9 AM	28	40	57	52	30	32	30
	3 PM	32	41	54	47	33	34	32
10/16/99	9 AM	26	40	55	46	31	31	31
	3 PM	30	43	49	44	32	31	32
10/17/99	9 AM	26	43	51	42	28	29	30
	3 PM	32	40	52	46	33	33	33
10/18/99	9 AM	25	42	51	48	28	29	28
	3 PM	30	41	52	47	33	33	33
10/19/99	9 AM	24	43	40	37	30	29	30
	3 PM	30	41	41	34	32	30	31

Table B2-1.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding Temperature	Pile 1			Pile 2		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/20/99	9 AM	22	42	42	36	29	29	26
	3 PM	24	43	40	39	30	30	31
10/21/99	9 AM	25	35	37	35	29	28	28
	3 PM	26	35	36	36	33	32	30
10/22/99	9 AM	25	37	37	36	27	27	28
	3 PM	25	38	39	35	32	32	30
10/23/99	9 AM	25	35	37	35	28	28	27
	3 PM	24	35	36	34	33	32	30
10/24/99	9 AM	26	36	36	34	28	28	27
	3 PM	25	35	34	35	27	29	28
10/25/99	9 AM	24	35	35	34	29	27	27
	3 PM	26	36	34	34	30	28	28
10/26/99	9 AM	26	35	34	34	28	30	29
	3 PM	28	35	36	35	30	32	31
10/27/99	9 AM	25	37	38	36	29	29	31
	3 PM	31	34	35	35	31	31	31
10/28/99	9 AM	27	37	36	35	29	30	29
	3 PM	30	37	37	35	29	30	29
10/29/99	9 AM	26	36	37	33	28	30	28
	3 PM	32	36	32	30	31	32	29
10/30/99	9 AM	27	36	33	29			
	3 PM	33	33	36	29			
10/31/99	9 AM	28	34	33	34			
	3 PM	27	29	33	29			
11/1/99	9 AM	27	33	33	27			
	3 PM	30	30	30	28			
11/2/99	9 AM	28	33	30	33			
	3 PM	32	32	32	29			
11/3/99	9 AM	26	28	33	30			
	3 PM	28	30	32	29			
11/4/99	9 AM	25	33	36	28			
	3 PM	27	28	32	31			

Table B2-2.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding Temperature	Pile 3			Pile 4		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
9/29/99	9 AM	26	29	35	30	31	36	33
	3 PM	30	31	37	35	32	38	34
9/30/99	9 AM	27	28	37	32	33	42	37
	3 PM	33	40	49	42	34	44	40
10/1/99	9 AM	27	44	57	47	45	53	47
	3 PM	29	41	56	52	48	55	54
10/2/99	9 AM	28	59	61	65	57	68	61
	3 PM	34	54	60	57	58	66	50
10/3/99	9 AM	28	57	70	66	50	58	54
	3 PM	37	70	69	68	49	57	51
10/4/99	9 AM	27	60	68	69	55	65	64
	3 PM	35	59	69	62	58	66	61
10/5/99	9 AM	28	56	64	60	59	64	62
	3 PM	36	52	63	61	62	65	60
10/6/99	9 AM	30	48	58	55	54	58	54
	3 PM	36	49	57	55	46	52	48
10/7/99	9 AM	29	55	63	58	45	53	48
	3 PM	35	55	64	62	43	53	45
10/8/99	9 AM	30	50	62	56	40	51	40
	3 PM	30	52	64	52	42	52	45
10/9/99	9 AM	28	47	60	54	38	48	45
	3 PM	33	50	61	53	40	46	39
10/10/99	9 AM	29	43	58	51	35	43	43
	3 PM	32	44	56	50	37	42	41
10/11/99	9 AM	27	44	60	52	36	42	38
	3 PM	35	43	55	50	35	41	36
10/12/99	9 AM	28	45	61	49	36	40	31
	3 PM	37	44	56	56	34	41	38
10/13/99	9 AM	28	38	48	43	28	34	32
	3 PM	35	39	46	40	35	34	31
10/14/99	9 AM	27	38	49	41	29	30	29
	3 PM	30	41	47	41	31	29	30
10/15/99	9 AM	28	39	52	44	30	29	29
	3 PM	32	38	48	40	32	31	32
10/16/99	9 AM	26	39	46	44	30	32	32
	3 PM	30	39	45	42	33	33	32
10/17/99	9 AM	26	38	47	41	31	30	29
	3 PM	32	42	46	43	32	31	31
10/18/99	9 AM	25	40	45	43	31	33	31
	3 PM	30	42	45	42	34	33	30

Table B2-2.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding Temperature	Pile 3			Pile 4		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/19/99	9 AM	24	38	43	41	31	29	28
	3 PM	30	38	44	38	32	31	31
10/20/99	9 AM	22	37	41	38	28	29	27
	3 PM	24	42	42	40	29	29	28
10/21/99	9 AM	25	36	39	38	29	27	25
	3 PM	26	35	37	36	29	26	27
10/22/99	9 AM	25	37	39	38	27	24	25
	3 PM	25	35	36	35	28	27	29
10/23/99	9 AM	25	35	36	35	29	27	26
	3 PM	24	37	36	35	29	28	27
10/24/99	9 AM	26	36	36	33	30	26	26
	3 PM	25	35	36	34	29	28	28
10/25/99	9 AM	24	34	35	35	29	26	25
	3 PM	26	37	36	34	30	27	27
10/26/99	9 AM	26	35	36	35	28	27	28
	3 PM	28	36	37	36	29	30	28
10/27/99	9 AM	25	35	35	36	29	28	29
	3 PM	31	36	34	34	29	30	30
10/28/99	9 AM	27	36	36	35	27	29	29
	3 PM	30	33	35	34	31	31	30
10/29/99	9 AM	26	35	35	34	30	30	29
	3 PM	32	35	35	35	31	31	31
10/30/99	9 AM	27	34	35	34	32	30	29
	3 PM	33	36	36	35	33	32	32
10/31/99	9 AM	28	36	36	35	31	31	29
	3 PM	27	38	37	34	29	30	28
11/1/99	9 AM	27	36	36	34	30	29	30
	3 PM	30	36	37	35	31	30	32
11/2/99	9 AM	28	37	36	35	28	29	29
	3 PM	32	39	40	33	29	30	30
11/3/99	9 AM	26	35	34	34			
	3 PM	28	35	36	36			
11/4/99	9 AM	25	33	34	36			
	3 PM	27	37	35	37			
11/5/99	9 AM	25	32	31	33			
	3 PM	26	36	38	38			
11/6/99	9 AM	28	35	36	35			
	3 PM	30	36	34	34			
11/7/99	9 AM	28	29	30	32			
	3 PM	30	34	33	34			

Table B2-2.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding Temperature	Pile 3			Pile 4		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
11/8/99	9 AM	29	29	30	32			
	3 PM	30	34	33	34			
11/9/99	9 AM	30	29	32	30			
	3 PM	30	33	35	33			
11/10/99	9 AM	30	31	30	29			
	3 PM	30	34	36	33			

Table B2-3.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding	Pile 5			Pile 6		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
8/3/99	9 AM	30	33	36	34	36	40	36
	3 PM	30	34	36	33	33	38	35
8/4/99	9 AM	28	38	47	45	36	46	44
	3 PM	30	40	49	43	39	47	43
8/5/99	9 AM	31	39	44	41	45	56	49
	3 PM	36	41	43	40	48	56	49
8/6/99	9 AM	31	53	66	58	48	58	50
	3 PM	33	50	67	65	50	59	56
8/7/99	9 AM	29	66	67	66	55	62	55
	3 PM	33	64	70	69	49	60	56
8/8/99	9 AM	28	57	58	57	54	63	53
	3 PM	34	58	60	59	52	61	55
8/9/99	9 AM	28	50	53	51	38	49	42
	3 PM	31	48	56	53	37	52	35
8/10/99	9 AM	28	49	56	53	39	50	44
	3 PM	33	50	57	55	38	42	40
8/11/99	9 AM	30	49	55	50	36	50	42
	3 PM	32	45	54	51	38	47	37
8/12/99	9 AM	28	47	51	50	34	48	45
	3 PM	35	48	50	50	39	49	41
8/13/99	9 AM	29	45	50	48	38	44	38
	3 PM	34	48	48	47	36	42	38
8/14/99	9 AM	28	41	47	45	40	42	39
	3 PM	37	38	44	39	42	43	40
8/15/99	9 AM	30	36	42	39	37	43	37
	3 PM	33	38	41	37	41	42	38
8/16/99	9 AM	28	36	43	39	37	40	39
	3 PM	33	36	48	38	36	43	40
8/17/99	9 AM	27	39	46	42	36	39	38
	3 PM	36	36	45	37	36	44	39
8/18/99	9 AM	27	36	43	38	36	43	40
	3 PM	39	35	44	39	37	42	41
8/19/99	9 AM	29	37	42	40	39	38	41
	3 PM	36	36	40	41	37	42	40
8/20/99	9 AM	35	39	42	43	36	39	40
	3 PM	36	37	40	38	39	42	43
8/21/99	9 AM	37	37	40	39	37	38	39
	3 PM	36	34	37	35	38	43	39
8/22/99	9 AM	28	36	41	38	39	40	38
	3 PM	36	39	42	38	40	44	41

Table B2-3.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding Temperature	Pile 5			Pile 6		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
8/23/99	9 AM	28	37	40	39	36	35	35
	3 PM	34	41	40	39	36	37	36
8/24/99	9 AM	28	35	37	34	34	36	37
	3 PM	31	35	40	36	36	38	37
8/25/99	9 AM	28	35	37	36	34	36	34
	3 PM	32	35	39	36	34	38	36
8/26/99	9 AM	29	34	37	34	34	37	32
	3 PM	31	35	40	37	36	36	31
8/27/99	9 AM	29	34	38	37	35	35	32
	3 PM	34	35	36	35	32	38	34
8/28/99	9 AM	31	36	37	36	34	38	37
	3 PM	36	37	36	38	35	39	38
8/29/99	9 AM	30	33	34	34	35	37	36
	3 PM	36	36	36	32	38	35	35
8/30/99	9 AM	29	31	35	32	34	32	32
	3 PM	30	33	36	33	32	32	32
8/31/99	9 AM	29	32	31	31	32	33	34
	3 PM	31	30	29	28	31	30	30
9/1/99	9 AM	29	30	30	29	30	29	32
	3 PM	35	30	31	28	29	32	30
9/2/99	9 AM	27	27	31	25	33	35	31
	3 PM	30	26	31	30	31	32	31
9/3/99	9 AM	28	28	27	29	36	36	34
	3 PM	34	29	27	27	31	29	29
9/4/99	9 AM	29	31	29	29	32	31	28
	3 PM	30	30	29	30	28	29	28
9/5/99	9 AM	29	30	28	28	35	35	31
	3 PM	31	31	29	30	37	38	32
9/6/99	9 AM	29	27	26	28	30	28	29
	3 PM	35	30	32	31	29	28	28
9/7/99	9 AM	30	27	28	26	28	28	29
	3 PM	36	27	27	28	30	29	28
9/8/99	9 AM	28	30	29	30	28	29	29
	3 PM	36	31	29	30	29	29	28
9/9/99	9 AM	27	30	30	29	27	28	30
	3 PM	34	31	29	31	29	28	29
9/10/99	9 AM	28	28	28	29	31	29	30
	3 PM	31	30	31	31	32	30	29
9/11/99	9 AM	27	30	28	29	30	29	29
	3 PM	31	31	32	30	31	30	30

Table B2-3.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding	Pile 5			Pile 6		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
9/12/99	9 AM	27	31	36	30	26	26	26
	3 PM	32	29	29	29	29	27	26
9/13/99	9 AM	28	29	28	30	27	26	27
	3 PM	31	30	30	33	30	32	29
9/14/99	9 AM	28	30	28	28	27	28	27
	3 PM	31	32	29	28	32	29	27
9/15/99	9 AM	29	30	28	27	32	30	29
	3 PM	31	30	29	30	31	30	29
9/16/99	9 AM	29	30	28	30	26	25	26
	3 PM	31	30	29	30	30	30	30
9/17/99	9 AM	26	30	28	31	29	27	28
	3 PM	34	29	29	28	29	27	27
9/18/99	9 AM	26	29	29	29	31	28	28
	3 PM	31	32	31	30	30	29	29
9/19/99	9 AM	29	30	28	31	29	29	30
	3 PM	32	30	32	30	29	30	30
9/20/99	9 AM	29	29	31	30	30	29	29
	3 PM	33	30	30	32	31	31	30
9/21/99	9 AM	27	29	30	29	31	30	30
	3 PM	33	30	30	29	32	32	31
9/22/99	9 AM	28	30	28	29	32	32	32
	3 PM	31	30	30	29	29	30	29
9/23/99	9 AM	26	30	28	30	29	29	28
	3 PM	33	30	29	29	31	30	29
9/24/99	9 AM	29	31	28	29	30	29	30
	3 PM	33	31	29	30	31	30	30
9/25/99	9 AM	28	31	30	32	29	28	30
	3 PM	31	31	30	30	31	30	29
9/26/99	9 AM	28	30	30	31	32	29	30
	3 PM	32	29	30	30	32	29	30
9/27/99	9 AM	26	30	25	32	31	30	29
	3 PM	31	29	30	30	32	29	28
9/28/99	9 AM	28	33	29	29	28	30	28
	3 PM	33	34	29	29	29	30	29
9/29/99	9 AM	29	31	27	25	30	30	29
	3 PM	31	30	28	26	30	27	28
9/30/99	9 AM	27	26	27	28	30	28	29
	3 PM	31	27	26	29	31	27	30
10/1/99	9 AM	26	30	30	25	32	26	31
	3 PM	30	29	29	26	30	28	32

Table B2-3.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding	Pile 5			Pile 6		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/2/99	9 AM	28	30	30	27	28	24	27
	3 PM	34	31	25	28	29	25	29
10/3/99	9 AM	28	25	28	24	30	31	32
	3 PM	37	27	28	25	29	31	29
10/4/99	9 AM	27	29	30	27	31	33	27
	3 PM	35	30	39	28	26	29	30
10/5/99	9 AM	28	30	34	30	30	31	29
	3 PM	36	32	39	33	29	33	29
10/6/99	9 AM	30	27	26	27	31	33	27
	3 PM	36	27	31	30	31	32	28
10/7/99	9 AM	29	28	31	32	31	32	27
	3 PM	35	24	26	30	32	30	29
10/8/99	9 AM	30	25	31	30	27	30	28
	3 PM	30	28	32	31	30	32	29
10/9/99	9 AM	28	30	27	28	25	28	29
	3 PM	33	30	27	27	30	33	29
10/10/99	9 AM	29	30	29	26	27	33	29
	3 PM	32	30	29	30	28	30	29
10/11/99	9 AM	27	28	25	29	27	32	28
	3 PM	35	30	29	33	29	32	30
10/12/99	9 AM	28	26	30	30	31	33	27
	3 PM	37	27	29	29	29	33	29
10/13/99	9 AM	28	30	34	28	27	30	28
	3 PM	35	29	29	25	30	33	28
10/14/99	9 AM	27	30	29	26	28	31	27
	3 PM	30	31	25	27	30	33	27
10/15/99	9 AM	28	31	25	28	30	31	27
	3 PM	32	30	27	27	28	33	27
10/16/99	9 AM	26	30	26	26	28	29	29
	3 PM	30	31	28	27	28	28	28
10/17/99	9 AM	26	32	26	27	28	32	30
	3 PM	32	30	27	28	28	29	29
10/18/99	9 AM	25	26	28	27	27	29	28
	3 PM	30	27	28	29	28	29	26
10/19/99	9 AM	24	28	27	28	27	27	28
	3 PM	30	31	33	26	29	28	28
10/20/99	9 AM	22	26	26	28			
	3 PM	24	29	31	29			
10/21/99	9 AM	25	29	29	28			
	3 PM	26	30	30	27			

Table B2-3.Experimental data of temperature (experiment set 1).

Date	Time	Surrounding	Pile 5			Pile 6		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/22/99	9 AM	25	29	31	30			
	3 PM	25	29	29	28			
10/23/99	9 AM	25	25	27	25			
	3 PM	24	25	28	26			
10/24/99	9 AM	26	26	30	26			
	3 PM	25	27	29	27			
10/25/99	9 AM	24	27	33	29			
	3 PM	26	31	32	29			
10/26/99	9 AM	26	28	29	27			
	3 PM	28	29	29	26			

Table B2-4.Experimental data of temperature (experiment set 2).

Date	Time	Surrounding Temperature	Pile 7			Pile 8			Pile 9		
			15 cm	30 cm	45 cm	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/5/99	9 AM	28	33	35	33	32	36	34	33	39	34
	3 PM	36	35	38	36	33	36	34	36	37	37
10/6/99	9 AM	30	38	45	40	39	40	40	39	46	39
	3 PM	36	36	47	39	40	41	40	40	48	45
10/7/99	9 AM	29	50	67	56	50	63	56	45	63	56
	3 PM	35	52	69	59	55	65	55	46	65	60
10/8/99	9 AM	30	54	69	68	56	63	60	50	62	61
	3 PM	30	59	70	61	57	66	60	49	66	58
10/9/99	9 AM	28	60	71	66	67	68	68	56	67	65
	3 PM	33	65	71	66	58	67	59	57	68	63
10/10/99	9 AM	29	60	71	66	45	63	53	41	54	47
	3 PM	32	59	70	65	44	59	51	40	50	45
10/11/99	9 AM	27	45	63	53	45	55	43	39	44	42
	3 PM	35	43	60	54	43	49	51	38	48	44
10/12/99	9 AM	28	48	64	53	39	41	40	38	41	38
	3 PM	37	46	62	51	37	43	41	44	46	40
10/13/99	9 AM	28	44	63	53	37	40	36	36	40	38
	3 PM	35	40	58	52	37	41	39	37	45	39
10/14/99	9 AM	27	38	46	43	36	39	37	35	39	36
	3 PM	30	41	44	42	35	40	36	34	40	36
10/15/99	9 AM	28	38	41	40	41	40	39	37	40	39
	3 PM	32	36	38	35	36	42	35	32	36	36
10/16/99	9 AM	26	36	40	39	36	37	36	33	37	35
	3 PM	30	37	40	38	36	40	39	34	38	35
10/17/99	9 AM	26	37	40	36	35	38	37	28	32	29
	3 PM	32	35	39	35	35	37	36	30	34	29
10/18/99	9 AM	25	35	38	36	29	30	30	28	30	28
	3 PM	30	33	40	36	27	30	29	29	28	27
10/19/99	9 AM	24	30	31	30	28	32	29	27	28	27
	3 PM	30	29	32	30	30	31	30	27	31	30
10/20/99	9 AM	22	28	29	27	27	29	28	26	27	27
	3 PM	24	26	28	27	31	33	32	28	26	31
10/21/99	9 AM	25	28	28	26	30	33	33	28	32	30
	3 PM	26	26	29	27	31	33	32	26	29	30
10/22/99	9 AM	25	26	30	27	28	30	29	28	28	28
	3 PM	25	29	32	30	29	30	29	29	30	30
10/23/99	9 AM	25	27	28	27	27	30	28	29	28	28
	3 PM	24	27	32	29	29	31	31	29	31	32
10/24/99	9 AM	26	30	32	29	27	30	30	33	32	28
	3 PM	25	31	30	29	28	31	30	33	29	29

Table B2-4.Experimental data of temperature (experiment set 2).

Date	Time	Surrounding	Pile 7			Pile 8			Pile 9		
		Temperature	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm	15 cm	30 cm	45 cm
10/25/99	9 AM	24	31	31	28	30	32	30	29	30	28
	3 PM	26	30	31	30	29	30	30	30	29	32
10/26/99	9 AM	26	29	31	30	28	30	29	28	31	29
	3 PM	28	32	32	31	31	29	30	29	29	31
10/27/99	9 AM	25	29	32	32	30	29	31	29	28	30
	3 PM	31	30	30	29	29	30	29	31	32	32
10/28/99	9 AM	27	28	30	28	27	31	30	32	34	30
	3 PM	30	32	29	29	29	30	27	30	28	33
10/29/99	9 AM	26	29	32	30	28	30	29	29	30	30
	3 PM	32	31	30	30	31	29	32	30	31	29
10/30/99	9 AM	27	29	30	30	28	32	31	29	30	29
	3 PM	33	31	29	29	29	30	31	31	32	29
10/31/99	9 AM	28	32	32	28	31	33	30	30	30	31
	3 PM	27	27	28	29	30	30	32	30	32	29
11/1/99	9 AM	27	30	31	29	30	31	30	29	30	28
	3 PM	30	30	30	28	32	30	29	33	32	30
11/2/99	9 AM	28	28	30	32	28	31	30	29	30	29
	3 PM	32	30	31	29	28	31	28	30	31	32
11/3/99	9 AM	26	26	27	28	29	29	30	28	29	28
	3 PM	28	30	30	33	32	31	30	31	31	30
11/4/99	9 AM	25	26	27	28	25	28	26	30	30	28
	3 PM	27	28	32	30	26	27	26	32	29	32
11/5/99	9 AM	25	28	33	27	28	29	28	28	29	28
	3 PM	26	30	29	30	31	30	30	31	30	30
11/6/99	9 AM	28	31	27	30	29	30	28	28	29	28
	3 PM	30	29	30	33	30	29	28	33	31	30
11/7/99	9 AM	28	29	30	30	28	27	28	32	30	31
	3 PM	30	30	29	30	30	29	28	26	27	29
11/8/99	9 AM	29	29	30	30	26	26	28	29	30	31
	3 PM	30	30	29	30	33	31	30	30	27	28
11/9/99	9 AM	30	28	28	29	32	30	31	31	33	31
	3 PM	30	30	32	31	29	30	29	30	27	26

Table B2-5. Experimental data of temperature (Average).

Time (days)	Average Temperature (^oC)								
	pile 1	**pile 2**	**pile 3**	**pile 4**	**pile 5**	**pile 6**	**pile 7**	**pile 8**	**pile 9**
0	35	36	33	34	35	36	35	34	36
1	40	42	38	39	44	43	41	40	43
2	47	55	51	51	41	51	59	58	56
3	59	59	60	60	60	54	64	60	60
4	69	67	67	53	67	56	67	65	63
5	68	60	65	62	58	56	65	53	46
6	60	57	59	62	52	42	53	48	43
7	67	46	54	52	53	42	54	40	41
8	63	47	60	48	51	42	52	38	39
9	63	46	56	45	49	43	42	37	37
10	60	40	54	43	48	39	38	39	37
11	55	40	50	40	42	41	38	37	35
12	55	33	51	38	39	40	37	36	30
13	50	31	52	37	40	39	36	29	28
14	51	32	42	32	41	39	30	30	28
15	49	31	43	30	39	40	28	30	28
16	46	31	44	31	39	40	27	32	29
17	46	31	43	32	40	40	29	29	29
18	47	30	43	31	37	39	28	29	30
19	39	29	43	32	39	40	30	29	31
20	40	30	40	30	40	36	30	30	30
21	36	29	40	28	36	36	31	30	30
22	37	30	37	27	36	35	30	30	30
23	35	28	37	27	36	34	29	29	31
24	35	28	36	28	36	34	30	30	30
25	35	30	35	28	37	37	30	30	30
26	35	30	35	27	34	36	29	31	30
27	36	29	36	28	33	32	30	30	30
28	36	30	35	29	30	32	30	29	30
29	34		35	29	30	30	29	30	30
30	33		35	30	28	32	29	26	30
31	32		35	31	28	33	30	29	29
32	30		36	30	30	29	30	29	30
33	32		38	30	29	35	30	28	29
34	30		37	29	29	29	30	29	29
35	31		35		27	29	30	30	30
36			35		30	29			
37			35		30	29			
38			35		30	30			
39			32		30	30			
40			33		31	27			
41			32		30	29			
42			31		29	28			
43			32		29	30			
44					30	28			
45					29	28			
46					30	29			
47					30	30			
48					30	30			
49					30	31			
50					29	31			
51					29	29			
52					30	30			
53					31	30			
54					30	30			

Table B2-5. Experimental data of temperature (Average).

Time (days)	Average Temperature (^oC)								
	pile 1	pile 2	pile 3	pile 4	pile 5	pile 6	pile 7	pile 8	pile 9
55					29	30			
56					31	29			
57					28	29			
58					27	29			
59					28	30			
60					29	27			
61					26	30			
62					31	30			
63					33	30			
64					28	30			
65					29	30			
66					30	29			
67					28	29			
68					29	29			
69					29	30			
70					29	28			
71					29	29			
72					26	29			
73					28	29			
74					28	28			
75					28	29			
76					28	28			
77					29	28			
78					28				
79					29				
80					29				
81					26				
82					28				
83					30				
84					28				

APPENDIX C

Analysis of variance (ANOVA) results

Table C1-1. Statistical analysis of moisture content (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.241	1	1.241	0.036	0.853
Within Groups	451.373	13	34.721		
Total	452.614	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	0.140	1	0.140	0.003	0.961
Within Groups	832.974	15	55.532		
Total	833.114	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	55.778	1	55.778	0.470	0.499
Within Groups	3202.854	27	118.624		
Total	3258.633	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1074.496	2	537.248	6.651	0.004
Within Groups	2339.038	29	80.656		
Total	3413.535	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	2.3307	4.3639	0.597	-6.5945	11.2559
	5	12.7209	3.9318	0.003	4.6795	20.7624
3	1	-2.3307	4.3639	0.597	-11.2559	6.5945
	5	10.3902	3.7867	0.010	2.6456	18.1348
5	1	-12.7209	3.9318	0.003	-20.7624	-4.6795
	3	-10.3902	3.7867	0.010	-18.1348	-2.6456

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	605.95	2	302.974	3.667	0.040
Within Groups	2148.16	26	82.622		
Total	2754.11	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	3.0891	4.7043	0.517	-6.5808	12.7590
	6	10.5221	4.2077	0.019	1.8731	19.1712
4	2	-3.0891	4.7043	0.517	-12.7590	6.5808
	6	7.4330	4.0286	0.076	-0.8478	15.1380
6	2	-10.5221	4.2077	0.019	-19.1712	-1.8731
	4	-7.4330	4.0286	0.076	-15.7138	0.8478

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	25.051	4	6.263	0.207	0.932
Within Groups	936.794	31	30.219		
Total	961.845	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-0.5766	2.8451	0.841	-6.3792	5.2260
	7	-1.9909	2.8451	0.489	-7.7935	3.8117
	8	-2.1638	2.8451	0.453	-7.9663	3.6388
	9	-1.0723	2.8451	0.709	-6.8749	4.7302
2	1	0.5766	2.8451	0.841	-5.2260	6.3792
	7	-1.4143	2.9384	0.634	-7.4071	4.5786
	8	-1.5871	2.9384	0.593	-7.5800	4.4057
	9	-0.4957	2.9384	0.867	-6.4886	5.4971
7	1	1.9909	2.8451	0.489	-3.8117	7.7935
	2	1.4143	2.9384	0.634	-4.5786	7.4071
	8	-0.7129	2.9384	0.953	-6.1657	5.8200
	9	0.9186	2.9384	0.757	-5.0743	6.9114
8	1	2.1638	2.8451	0.453	-3.6388	7.9663
	2	1.5871	2.9384	0.593	-4.4057	7.5800
	7	0.1729	2.9384	0.953	-5.8200	6.1657
	9	1.0914	2.9384	0.713	-4.9014	7.0843
9	1	1.0723	2.8451	0.709	-4.7302	6.8749
	2	0.4957	2.9384	0.867	-5.4971	6.4886
	7	-0.9186	2.9384	0.757	-6.9114	5.0743
	8	-1.0914	2.9384	0.713	-7.0843	4.9014

Table C1-2. Statistical analysis of temperature (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	802.317	1	802.317	5.636	0.021
Within Groups	8967.929	63	142.348		
Total	9770.246	64			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	922.704	1	922.704	9.014	0.004
Within Groups	7881.800	77	102.361		
Total	8804.504	78			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.178	1	1.178	0.022	0.883
Within Groups	8723.885	161	54.186		
Total	8725.063	162			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	4258.115	2	2129.058	22.926	0.000
Within Groups	15044.168	162	92.865		
Total	19302.283	164			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	2.8081	2.1657	0.197	-1.4685	7.0847
	5	11.5211	1.9163	0.000	7.7370	15.3052
3	1	-2.8081	2.1657	0.197	-7.0847	1.4685
	5	8.7130	1.7897	0.000	5.1788	12.2472
5	1	-11.5211	1.6163	0.000	-15.3052	-7.7370
	3	-8.7130	1.7897	0.000	-12.2472	-5.1788

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	466.752	2	233.376	3.081	0.049
Within Groups	10529.446	139	75.751		
Total	10996.198	141			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	2.6203	2.1855	0.233	-1.7008	6.9414
	6	4.6235	1.8930	0.016	0.8808	8.3662
4	2	-2.6203	2.1855	0.233	-6.9414	1.7008
	6	2.0032	1.7707	0.260	-1.4978	5.5043
6	2	-4.6235	1.8930	0.016	-8.3662	-0.8808
	4	-2.0032	1.7707	0.260	-5.5043	1.4978

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	2998.226	4	749.556	6.251	0.000
Within Groups	20145.975	168	119.917		
Total	23144.201	172			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	7.0677	2.7324	0.011	1.6734	12.4620
	7	8.9639	2.5811	0.001	3.8683	14.0594
	8	11.0111	2.5811	0.000	5.9156	16.1067
	9	11.0361	2.5811	0.000	5.9406	16.1317
2	1	-7.0677	2.7324	0.011	-12.4620	-1.6734
	7	1.8962	2.7324	0.489	-3.4981	7.2805
	8	3.9434	2.7324	0.151	-1.4509	9.3377
	9	3.9684	2.7324	0.148	-1.4259	9.3627
7	1	-8.9639	2.5811	0.001	-14.0594	-3.8683
	2	-1.8962	2.7324	0.489	-7.2905	3.4981
	8	2.0472	2.5811	0.429	-3.0483	7.1428
	9	2.0722	2.5811	0.423	-3.0233	7.1678
8	1	-11.0111	2.5811	0.000	-16.1067	-5.9156
	2	-3.9434	2.7324	0.151	-9.3377	-1.4509
	7	-2.0472	2.5811	0.429	-7.1428	3.0483
	9	0.0250	2.5811	0.992	-5.0706	5.1206
9	1	-11.0361	2.5811	0.000	-16.1317	-5.9406
	2	-3.9684	2.7324	0.148	-9.3627	1.4259
	7	-2.0722	2.5811	0.423	-7.1678	3.0233
	8	-0.0250	2.5811	0.992	-5.1206	5.0708

Table C1-3. Statistical analysis of pH (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	3.072E-02	1	3.072E-02	0.059	0.812
Within Groups	6.747	13	0.519		
Total	6.778	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.180E-02	1	1.180E-02	0.024	0.878
Within Groups	7.307	15	0.487		
Total	7.319	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	5.186E-03	1	5.19E-03	0.016	0.899
Within Groups	8.547	27	0.317		
Total	8.552	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1074.496	2	4.81E-03	0.011	0.989
Within Groups	2339.038	29	0.440		
Total	3416.535	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	4.722E-03	0.3225	0.885	-0.6123	0.7068
	5	2.033E-03	0.2905	0.945	-0.5739	0.6146
3	1	-4.722E-03	0.3225	0.885	-0.7068	0.6123
	5	-2.689E-03	0.2798	0.924	-0.5992	0.5454
5	1	-2.033E-03	0.2905	0.945	-0.6146	0.5739
	3	2.689E-03	0.2798	0.924	-0.5454	0.5992

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	7.850E-02	2	3.790E-02	0.100	0.905
Within Groups	9.829	26	0.378		
Total	9.905	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	9.286E-03	0.3182	0.977	-0.6448	0.6634
	6	-9.714E-02	0.2846	0.736	-0.6822	0.4879
4	2	-9.286E-03	0.3182	-0.977	-0.6634	0.6448
	6	-0.1064	0.2725	0.699	-0.6666	0.4537
6	2	-9.714E-02	0.2846	0.736	-0.4879	0.6822
	4	0.1064	0.2725	0.699	-0.4537	0.6666

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	0.376	4	9.389E-02	0.216	0.927
Within Groups	13.448	31	0.434		
Total	13.823	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	9.071E-02	0.3409	0.792	-0.6045	0.7859
	7	0.2921	0.3409	0.398	-0.4031	0.9874
	8	0.1950	0.3409	0.571	-0.5002	0.8902
	9	8.214E-02	0.3409	0.811	-0.6131	0.7774
2	1	9.0714E-02	0.3409	0.792	-0.7859	0.6045
	7	0.2014	0.3521	0.571	-0.5166	0.9195
	8	0.1043	0.3521	0.769	-0.6137	0.8223
	9	-8.571E-03	0.3521	0.981	-0.7266	0.7095
7	1	-0.2921	0.3409	0.398	-0.9874	0.4031
	2	-0.2014	0.3521	0.571	-0.9195	0.5166
	8	-9.0714E-02	0.3521	0.784	-0.8152	0.6209
	9	-0.2100	0.3521	0.555	-0.9280	0.5080
8	1	-0.1950	0.3409	0.571	-0.8902	0.5002
	2	-0.1043	0.3521	0.769	-0.8223	0.6137
	7	9.0714E-02	0.3521	0.784	-0.6209	0.8152
	9	-0.1129	0.3521	0.751	-0.8309	0.6052
9	1	8.2143E-02	0.3409	0.811	-0.7774	0.6131
	2	-8.571E-03	0.3521	0.981	-0.7095	0.7266
	7	2.100E-01	0.3521	0.555	-0.5080	0.9280
	8	0.1129	0.3521	0.751	-0.6052	0.8309

Table C1-4. Statistical analysis of total coliform bacteria (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	15354.548	1	15354.548	0.221	0.649
Within Groups	624528.83	9	69392.093		
Total	639883.38	10			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1348.286	1	1348.286	0.047	0.833
Within Groups	318255.23	11	28932.294		
Total	319603.52	12			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	166.836	1	166.836	0.023	0.880
Within Groups	113894.22	16	7118.389		
Total	114061.06	17			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	64242.572	2	32121.286	1.229	0.315
Within Groups	496781.59	19	26146.399		
Total	561024.16	21			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	72.3952	89.9607	0.341	-115.8947	260.6852
	5	133.3000	85.2226	0.134	-45.0729	311.6729
3	1	-72.3952	89.9607	0.431	-260.6852	115.8947
	5	60.9048	81.4884	0.464	-109.6524	231.4619
5	1	-133.3000	85.2226	0.134	-311.6729	45.0729
	3	-60.9048	81.4884	0.464	-231.4619	109.6524

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	131511.50	2	65755.748	1.997	0.166
Within Groups	55896.70	17	32935.100		
Total	691408.20	19			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	127.0000	109.8918	0.264	-104.8514	358.8514
	6	202.2444	101.2249	0.062	-11.3214	415.8103
4	2	-127.0000	109.8918	0.264	-358.8514	104.8514
	6	75.2444	95.6485	0.442	-126.5563	277.0452
6	2	-202.2444	101.2249	0.062	-415.8103	11.3214
	4	-75.2444	95.6485	0.442	-277.0452	126.5563

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	20831.59	4	5207.897	0.079	0.988
Within Groups	1572903.9	24	65537.664		
Total	1593735.5	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-75.0333	155.0177	0.633	-394.9741	244.9074
	7	1.8167	147.8035	0.990	-303.2349	306.8682
	8	-19.8683	147.8035	0.894	-324.9199	285.1832
	9	-11.2283	147.8035	0.940	-316.2799	293.8232
2	1	75.0333	155.0177	0.633	-244.9074	394.9741
	7	76.8500	155.0177	0.625	-243.0907	396.7907
	8	55.1650	155.0177	0.725	-264.7757	375.1057
	9	63.8050	155.0177	0.684	-256.1357	383.7457
7	1	-1.8167	147.8035	0.990	-306.8682	303.2349
	2	-76.8500	155.0177	0.625	-396.7907	243.0907
	8	-21.6850	147.8035	0.885	-326.7365	283.3665
	9	-13.0450	147.8035	0.930	-318.0965	292.0065
8	1	19.8683	147.8035	0.894	-285.1832	324.9199
	2	-55.1650	155.0177	0.725	-375.1057	264.7757
	7	21.6850	147.8035	0.885	-273.3665	326.7367
	9	8.6400	147.8035	0.954	-296.4115	313.6915
9	1	11.2283	147.8035	0.940	-293.8232	316.2799
	2	-63.8050	155.0177	0.684	-383.7457	256.1357
	7	13.0450	147.8035	0.930	-292.0065	318.0965
	8	-8.6400	147.8035	0.954	-313.6915	296.4115

Table C1-5. Statistical analysis of nitrogen content (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	2.905E-02	1	2.905E-02	1.435	0.252
Within Groups	0.263	13	2.024E-02		
Total	0.292	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	6.588E-02	1	6.588E-02	2.136	0.165
Within Groups	0.463	15	3.085E-02		
Total	0.529	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.803E-02	1	1.803E-02	2.245	0.146
Within Groups	0.217	27	8.035E-03		
Total	0.235	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	3.849	2	1.925	175.132	0.000
Within Groups	0.319	29	1.099E-02		
Total	4.168	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	0.5497	5.094E-02	0.000	0.4455	0.6539
	5	0.8588	4.589E-02	0.000	0.7650	0.8071
3	1	-0.5497	5.094E-02	0.000	-0.6539	-0.4455
	5	0.3091	4.420E-02	0.000	0.2187	0.3992
5	1	-0.8588	4.589E-02	0.000	-0.9527	-0.7650
	3	-0.3091	4.420E-02	0.000	-0.3995	-0.2187

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	3.80	2	1.899	79.109	0.000
Within Groups	0.62	26	2.400E-02		
Total	4.42	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	0.5132	8.018E-02	0.000	0.3484	0.6780
	6	0.8971	7.172E-02	0.000	0.7497	1.0446
4	2	-0.5132	8.018E-02	0.000	-0.6780	-0.3484
	6	0.3839	6.867E-02	0.000	0.2428	0.5251
6	2	-0.8971	7.172E-02	0.000	-1.0446	-0.7497
	4	-0.3839	6.867E-02	0.000	-0.5251	-0.2428

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.367	4	0.342	5.335	0.002
Within Groups	1.986	31	6.406E-02		
Total	3.353	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	-8.821E-02	0.1310	0.506	-0.3554	0.1789
	7	-0.5625	0.1310	0.000	-0.8297	-0.2953
	8	-0.2725	0.1310	0.046	-0.5397	-5.340E-03
	9	-0.2796	0.1310	0.041	-0.5468	-1.250E-02
2	1	8.821E-02	0.1310	0.506	-0.1789	0.3554
	7	-0.4743	0.1353	0.001	-0.7802	-0.1984
	8	-0.1843	0.1353	0.183	-0.4602	9.164E-02
	9	-0.1914	0.1353	0.167	-0.4674	8.449E-02
7	1	0.5625	0.1310	0.000	0.2953	0.8297
	2	0.4743	0.1353	0.001	0.1984	0.7502
	8	0.2900	0.1353	0.040	1.408E-02	0.5659
	9	0.2829	0.1353	0.045	6.935E-03	0.5588
8	1	0.2725	0.1310	0.046	5.340E-03	0.5397
	2	0.1843	0.1353	0.183	-9.160E-02	0.4602
	7	-0.2900	0.1353	0.040	-0.5659	-1.410E-02
	9	-7.143E-03	0.1353	0.958	-0.2831	0.2688
9	1	0.2798	0.1310	0.041	1.248E-02	0.5468
	2	0.1914	0.1353	0.167	-8.450E-02	0.4674
	7	-0.2829	0.1353	0.045	-0.5588	-6.940E-03
	8	7.143E-03	0.1353	0.958	-0.2688	0.2831

Table C1-6. Statistical analysis of phosphorus (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.296E-04	1	1.296E-04	0.195	0.666
Within Groups	8.630E-03	13	6.639E-04		
Total	8.760E-03	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	6.618E-06	1	6.618E-06	0.004	0.949
Within Groups	2.329E-02	15	1.552E-03		
Total	2.329E-02	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.717E-03	1	1.717E-03	13.548	0.001
Within Groups	2.333E-03	27	8.640E-05		
Total	3.503E-03	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	0.104	2	5.223E-02	91.645	0.000
Within Groups	1.653E-02	29	5.699E-04		
Total	0.121	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	7.875E-02	1.160E-02	0.000	5.503E-02	0.1025
	5	0.1408	1.045E-02	0.000	0.1194	0.1621
3	1	-7.875E-02	1.160E-02	0.000	-0.1025	5.500E-02
	5	6.200E-02	1.007E-02	0.000	4.141E-02	8.259E-02
5	1	-0.1408	1.045E-02	0.000	-0.1621	-0.1194
	3	-6.200E-02	1.007E-02	0.000	-8.260E-02	4.140E-02

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	7.018E-02	2	3.059E-02	51.477	0.000
Within Groups	1.772E-02	26	6.817E-04		
Total	8.790E-02	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	7.161E-02	1.351E-02	0.000	4.383E-02	9.938E-02
	6	0.1221	1.209E-02	0.000	9.730E-02	0.1470
4	2	-7.161E-02	1.351E-02	0.000	-9.940E-02	-4.380E-02
	6	5.054E-02	1.157E-02	0.000	2.675E-02	7.432E-02
6	2	-0.1221	1.209E-02	0.000	-0.1470	-9.730E-02
	4	5.054E-02	1.157E-02	0.000	-7.430E-02	-2.680E-02

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	8.788E-03	4	2.197E-03	4.033	0.010
Within Groups	1.689E-02	31	5.448E-04		
Total	2.568E-02	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	5.893E-03	1.208E-02	0.629	-1.870E-02	3.053E-02
	7	2.018E-02	1.208E-02	0.105	-4.460E-03	4.482E-02
	8	3.732E-02	1.208E-02	0.004	1.268E-02	6.196E-02
	9	3.732E-02	1.208E-02	0.004	1.268E-02	6.196E-02
2	1	-5.893E-03	1.208E-02	0.629	-3.050E-02	1.874E-02
	7	1.429E-02	1.248E-02	0.261	-1.120E-02	3.973E-02
	8	3.143E-02	1.248E-02	0.017	5.984E-03	5.687E-02
	9	3.143E-02	1.248E-02	0.017	5.984E-03	5.687E-02
7	1	-2.018E-02	1.208E-02	0.105	-4.480E-02	4.458E-03
	2	-1.429E-02	1.248E-02	0.261	-3.970E-02	1.116E-02
	8	1.714E-02	1.248E-02	0.179	8.300E-03	4.259E-02
	9	1.714E-02	1.248E-02	0.179	8.300E-03	4.259E-02
8	1	-3.732E-02	1.208E-02	0.004	-6.200E-02	-1.270E-02
	2	-3.143E-02	1.248E-02	0.017	-5.690E-02	-5.980E-03
	7	-1.714E-02	1.248E-02	0.179	-4.260E-02	8.302E-03
	9	0.000	1.248E-02	1.000	-2.540E-02	2.544E-02
9	1	-3.732E-02	1.208E-02	0.004	-6.200E-02	-1.270E-02
	2	3.143E-02	1.248E-02	0.017	-5.690E-02	-5.980E-03
	7	-1.714E-02	1.248E-02	0.179	-4.260E-02	8.302E-03
	8	0.000	1.248E-02	1.000	-2.540E-02	2.544E-02

Table C1-7. Statistical analysis of carbon content (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.560	1	1.560	0.302	0.592
Within Groups	67.142	13	5.165		
Total	68.702	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	19.747	1	19.747	3.045	0.101
Within Groups	97.264	15	6.484		
Total	117.011	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	1.419	1	1.419	0.050	0.824
Within Groups	763.362	27	28.273		
Total	764.781	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	71.502	2	35.751	1.981	0.156
Within Groups	523.409	29	18.049		
Total	594.911	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	0.2806	2.0643	0.893	-3.9415	4.5026
	5	3.1370	1.8599	0.102	-0.6670	6.9410
3	1	-0.2806	2.0643	0.893	-4.5026	3.9415
	5	2.8564	1.7913	0.122	-0.8071	6.5200
5	1	-3.1370	1.8599	0.102	-6.9410	0.6670
	3	-2.8564	1.7913	0.122	-6.5200	0.8071

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	107.251	2	53.626	3.448	0.047
Within Groups	404.359	26	15.552		
Total	511.610	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	-2.5252	2.0410	0.227	-6.7206	1.6702
	6	2.0479	1.8255	0.272	-1.7046	5.8003
4	2	2.5252	2.0410	0.227	-1.6702	6.7206
	6	4.5730	1.7478	0.015	-0.9803	8.1658
6	2	-2.0479	1.8255	0.272	-5.8003	1.7046
	4	-4.5730	1.7478	0.015	-8.1658	-0.9803

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	5.200	4	1.300	0.349	0.843
Within Groups	115.458	31	3.724		
Total	120.658	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	0.6464	0.9988	0.522	-1.3907	2.6835
	7	-0.1850	0.9988	0.854	-2.2221	1.8521
	8	0.8336	0.9988	0.410	-1.2035	2.8707
	9	0.2836	0.9988	0.778	-1.7535	2.3207
2	1	-0.6464	0.9988	0.522	-2.6835	1.3907
	7	-0.8314	1.0316	0.426	-2.9353	1.2725
	8	0.1871	1.0316	0.857	-1.9167	2.2910
	9	-0.3629	1.0316	0.727	-2.4667	1.7410
7	1	0.1850	0.9988	0.854	-1.8521	2.2221
	2	0.8314	1.0316	0.426	-1.2725	2.9353
	8	1.0186	1.0316	0.331	-1.0853	3.1225
	9	0.4686	1.0316	0.653	-1.6353	2.5725
8	1	-0.8336	0.9988	0.410	-2.8707	1.2035
	2	-0.1871	1.0316	0.857	-2.2910	1.9167
	7	-1.0186	1.0316	0.331	-3.1225	1.0853
	9	-0.5500	1.0316	0.598	-2.6539	1.5539
9	1	-0.2836	0.9988	0.778	-2.3207	1.7535
	2	0.3629	1.0316	0.727	-1.7410	2.4667
	7	-0.4686	1.0316	0.653	-2.5725	1.6353
	8	0.5500	1.0316	0.598	-1.5539	2.6539

Table C1-8. Statistical analysis of C/N ratio (by ANOVA method).

Pile 1 and 2	Sum of Squares	df	Mean Square	F	Sig.
Between groups	3.62	1	3.62	0.692	0.421
Within Groups	68.019	13	5.232		
Total	71.639	14			

Pile 3 and 4	Sum of Squares	df	Mean Square	F	Sig.
Between groups	0.514	1	0.514	0.026	0.873
Within Groups	292.847	15	19.523		
Total	293.361	16			

Pile 5 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	2.878	1	2.878	0.069	0.794
Within Groups	1120.429	27	41.497		
Total	1123.307	28			

Pile 1, 3 and 5	Sum of Squares	df	Mean Square	F	Sig.
Between groups	586.257	2	293.128	11.601	0.000
Within Groups	732.741	29	25.267		
Total	1318.998	31			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	3	6.6347	2.4425	0.011	-11.6302	-1.6392
	5	-10.5958	2.2006	0.000	-15.0967	-6.0950
3	1	6.6347	2.4425	0.011	1.6392	11.6302
	5	-3.9611	2.1194	0.072	-8.2958	0.3736
5	1	10.5958	2.2006	0.000	6.0950	15.0967
	3	3.9611	2.1194	0.072	-0.3736	8.2958

Pile 2, 4 and 6	Sum of Squares	df	Mean Square	F	Sig.
Between groups	559.550	2	279.775	9.718	0.001
Within Groups	748.554	26	28.791		
Total	1308.104	28			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
2	4	-7.2709	2.7770	0.015	-12.9791	-1.5627
	6	-10.9500	2.4838	0.000	-16.0556	-5.8444
4	2	7.2709	2.7770	0.015	1.5627	12.9791
	6	-3.6791	2.3781	0.134	-8.5673	1.2091
6	2	10.9500	2.4838	0.000	5.8444	16.0556
	4	3.6791	2.3781	0.134	-1.2091	8.5673

Pile 1, 2, 7, 8 and 9	Sum of Squares	df	Mean Square	F	Sig.
Between groups	54.468	4	13.617	1.964	0.125
Within Groups	214.910	31	6.933		
Total	269.378	35			

(I) Pile	(J) Pile	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1	2	0.9846	1.3627	0.475	-1.7946	3.7639
	7	3.5361	1.3627	0.014	0.7568	6.3153
	8	2.2675	1.3627	0.106	-0.5117	5.0467
	9	2.2375	1.3627	0.111	-0.5417	5.0167
2	1	-0.9846	1.3627	0.475	-3.7639	1.7946
	7	2.5514	1.4074	0.080	-0.3190	5.4218
	8	1.2829	1.4074	0.369	-1.5875	4.1532
	9	1.2529	1.4074	0.382	-1.6175	4.1232
7	1	-3.5361	1.3627	0.014	-6.3153	-0.7568
	2	-2.5514	1.4074	0.080	-5.4218	0.3190
	8	-1.2686	1.4074	0.374	-4.1390	1.6018
	9	-1.2986	1.4074	0.363	-4.1690	1.5718
8	1	-2.2675	1.3627	0.106	-5.0467	0.5117
	2	-1.2829	1.4074	0.369	-4.1532	1.5875
	7	1.2686	1.4074	0.374	-1.6018	4.1390
	9	-3.00E-02	1.4074	0.983	-2.9004	2.8404
9	1	-2.2375	1.3627	0.111	-5.0167	0.5417
	2	-1.2529	1.4074	0.380	-4.1232	1.6175
	7	1.2986	1.4074	0.353	-1.5718	4.1690
	8	3.00E-02	1.4074	0.983	-2.8404	2.9004

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