KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI

COLLEGE OF ENGINEERING

FACULTY OF CHEMICAL AND MATERIALS ENGINEERING

DEPARTMENT OF MATERIALS ENGINEERING

# CO-COMPOSTING OF DEWATERED SEWAGE SLUDGE AND SAWDUST FROM TWO WOOD SPECIES FOR AGRICULTURAL USE AS AN ORGANIC FERTILIZER

(A CASE STUDY AT THE KNUST SEWAGE TREATMENT PLANT)

BY:

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MAY, 2010

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## (A CASE STUDY AT THE KNUST SEWAGE TREATMENT PLANT)

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## DECLARATION

It is hereby declared that this thesis is the outcome of research work undertaken by the author, any assistance obtained has been duly acknowledged. It is neither in part nor whole been presented for another degree elsewhere.

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## ABSTRACT

Saw Millers around the country generate a lot of sawdust in their operations. Disposal of the sawdust is a major problem faced by these Saw Millers. Currently sawdust is burnt or thrown into streams and rivers. These methods of disposal are environmentally unfriendly. Composting which serves as a method that turns the waste into a resource is an appropriate means of disposing of sawdust. The goal of the research was to study the viability of managing cedrela and teak sawdust through composting with dewatered sewage sludge. The study was conducted at the sewage treatment site of Kwame Nkrumah University of Science and Technology. Two different heaps of materials for composting were prepared using dewatered sewage sludge and sawdust from Cedrela and Teak in the ratios, 1:1 and 1:2 (v/v) respectively. The ratios were replicated and allowed to undergo windrow composting for a period of 120 days. The levels of estimated organic matter, nutrient and microbiological parameters showed reduction as the composting process progressed. The composts had pH between 6.1 and 6.3. The contents of organic matter, carbon, nitrogen, C/N ratio, phosphorous and potassium decreased substantially over the 120 days in all the heaps of sludge/cedrela and sludge/teak heaps. The organic matter reduction was as a result of its decomposition and transformation into stable humic compounds. This resulted in about 50% reduction in heap volume. The concentrations of nutrients also reduced as they were used by the micro-organisms for their metabolic and physiologic processes. Total coliforms, faecal coliforms and salmonella levels in the heaps declined as well. At the end of the composting period, the mean log10 of total coliforms, faecal coliforms and salmonella were all below the minimum standard of less than 3.00 log 10 MPN set by the Canadian Council of

Ministers. Salmonella levels were also below the recommended standard of 3MPN set by the United States of America Environmental Protection Agency (USEPA). The lettuce cultivated with the finished composts and dried sewage sludge had mean dry weight between 6.9g and 8.17g and 5.23g for the control. Lettuce on plots fertilised with dried sludge produced the highest mean wet weight of 87.1g per the five (5) plants sampled due to the high nutrient content of the dried sludge. The studies revealed that the ratios 1:1 and 1:2 of sludge/cedrela and sludge/teak were of the same quality.

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**LIST OF ABBREVIATIONS**

MC – Moisture Content

TS – Total Solids

OM – Organic Matter

C – Carbon Content

N – Nitrogen Content

C/N – Carbon/Nitrogen Ratio

P – Phosphorous

K – Potassium

pH – Hydrogen Ion Concentration

TC – Total Coliforms

FC – Faecal Coliforms

Sal - Salmonella

S/C – Sludge Cedrela ratio

S/T – Sludge Teak ratio

# CHAPTER ONE

# INTRODUCTION

## 1.1 BACKGROUND

Composting is a managed system that uses microbial activity to degrade raw organic materials. This result in an end-product which is relatively stable and reduced in quantity (when compared to the initial waste volume). It is normally free from offensive odour (Cole, 1985). Composting is one of the several available alternatives to handling and disposal of organic wastes for recycling. Some organic materials (such as sewage sludge) are not good to be composted alone aerobically. This is because of their physical or intrinsic characteristics such as high moisture content and low air spaces. They are therefore co-composted with other organic material(s). Co-composting is a waste treatment method in which different types of wastes are digested together (Ahring *et al.* 1992). Co-composting is an attractive and interesting example of integrated waste management. An example is the composting of sawdust and sewage sludge. This method of composting is advantageous because the two waste materials complement each other very well. The sewage sludge is high in nitrogen content and moisture and the sawdust is high in organic carbon content and has good bulking quality. Proper mixing of the two ensures an optimum carbon-nitrogen ratio that enhances the biodegradation process.

Sewage sludge is nutrient-rich organic matter produced during conventional treatment of sewage. The composition of sewage sludge is specific. Sewage sludge from an industrialized community contains higher concentrations of heavy metals and other materials than that of a rural community (Sommers, 1977). Generally, sewage sludge is rich in nutrient and trace elements. The presence of pathogens demands pre-treatment of the sewage sludge before its application in agriculture (Veeken and Hamelers, 1999; Tiquia *et al.*, 2002). The three primary methods of sludge handling are landfill, incineration and land application as organic fertilizer. Landfill has the potential for groundwater contamination due to leaching. Incineration contributes to air pollution and therefore may require expensive equipment for emissions control (Veeken and Hamelers, 1999). Land application after composting is preferable since it produces both a useful and an ecologically compatible product (Hansen and Mancl, 1988).

The use of compost helps improve soil structure, texture and aeration. It increases the soil's water-holding capacity (Martin and Gershuny, 1992). Compost loosens clay soils and helps sandy soils retain water by binding soil particles together. Addition of compost improves soil fertility and stimulates healthy root development in plants.

## 1:2 PROBLEM STATEMENT

Vegetable farmers in Ghana, especially, those farming close to sewage treatment plant apply dewatered sewage sludge directly to the land. Some of the problems associated with sewage sludge are the presence of trace elements, toxic organics, and pathogens such as bacteria and viruses (Linden *et al.*, 1995). This can be very harmful especially when they are applied on vegetables that are consumed in raw state. Co-Composting sewage sludge with other organic materials at the thermophilic phase serves to destroy all pathogens in the sludge (Scott, 1952). The health problems associated with the consumption of contaminated vegetables is therefore minimized when the sludge is co-

composted. Furthermore, the success and the adoption of co-composting of sewage sludge and sawdust will curtail the dumping of these organic materials at unauthorized places. Once more, the overall cost of fertilizing agricultural land would be reduced drastically, if farmers use compost instead of the more expensive mineral fertilizers.

## 1.3 AIM

To assess the effects of sawdust of different wood species on the co-composting process and the quality of compost produced.

## 1.4 OBJECTIVES

1. To determine the suitable ratio of dewatered sewage sludge and sawdust compost and its impact on vegetable production.
2. To determine the Nitrogen, Phosphorous, Potassium, organic carbon, pH, ash content, C/N ratio, organic matter and microbial concentrations of each compost type (mixture) and assess their levels at the various stages of the composting process.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 COMPOSTING

Composting is a managed system that uses microbial activity to degrade raw organic materials (such as sewage sludge, yard trimmings etc.), so that the end-product is relatively stable, reduced in quantity (when compared to the initial amount of waste), and free from offensive odour (Cole *et al.*, 1995). Composting is one of the several available alternatives in the handling and disposal of organic wastes. It leads to stabilization, and utilization of organic waste.

## 2.2 TYPES OF COMPOSTING

There are two basic types of composting –aerobic and anaerobic composting.

### 2.2.1 Aerobic Composting

When organic material is decomposed in the presence of oxygen the process is referred to as aerobic. Aerobic composting is the process in which, under suitable environmental conditions, facultative aerobic organisms, principally, in thermophilic condition, utilize considerable amounts of oxygen in decomposing organic matter to a fairly stable humus material (Gotaas, 1976). In aerobic composting the micro-organisms feed on the organic matter and develop cell protoplasm from the nitrogen, phosphorous and carbon. Much of the carbon serve as energy source for the organisms and is burned up and respired as carbon dioxide ($CO_2$). As the quickest way to produce high quality compost, aerobic composting is a widely accepted means of stabilizing organic wastes and converting them to a usable, and value added product. In this process, higher temperatures (above 60 $^0C$) can be reached. Research has pointed out that this process of aerated thermophilic composting can provide a high degree of pathogen inactivation. It produces a well-composted material which has been shown to be a useful and effective soil conditioner (Shuval *et al.*, 1981).

### 2.2.2 Anaerobic Composting

In anaerobic composting there is putrefactive breakdown of organic matter by reduction in the absence of oxygen. End products such as methane ($CH_4$) and hydrogen sulfide ($H_2S$) are released (Gotaas, 1976). The process is, however, often associated with the formation of foul smelling gasses such as indol, skatol and mercaptans (any sulfur-containing organic compound). This type of composting involves little or virtually no work. The maturation of the pile is usually prolonged and the process does not generate enough heat to safely kill plant pathogens and weed seeds. The process usually takes place at temperatures between 8 $^0C$ and 45 $^0C$, with mesophilic microorganisms which break down the soluble, readily degradable compounds.

## 2.3 CO-COMPOSTING

The term co-composting means the composting of two or more raw materials together. Human excreta provides a good fertilizer, but in order to reduce the health risk for workers, farmers, the nearby population and the consumer they have to be treated prior to their use in agriculture. Waste water treatment systems usually only remove pathogens from the sewage. However, the removed pathogens end up in the biosolids, which still have to be treated for safe use in agriculture (Strauss 2000). Treatment for faecal sludge usually use one or several of the following conditions leading to pathogen die-off: change of pH, UV radiation, chemical treatment, drying, storage for a long time, heat etc (Feachem *et al.* 1983). At present faecal sludge is co-composted with other organic materials to destroy these pathogens. Depending on the organism one or the other method is more effective. In the present study, a method was used that combines the effects of heat and time: the faecal sludge was co-composted with organic market waste. In the case of human waste and garbage (the organic part of refuse), this kind of composting is advantageous because the two materials complement each other well. Human waste is high in nitrogen content and moisture and the garbage is high in organic (carbon) content and has good bulking quality. The two waste materials can be converted into a useful product (Obeng and Wright 1987).

## 2.4 THE COMPOSTING PROCESS

Composting can be defined as the biological decomposition of the organic constituents of wastes under controlled conditions (Obeng and Wright, 1987). This process can take place in the presence or absence of oxygen. The former is termed aerobic composting and the latter anaerobic. When properly carried out, aerobic composting can rapidly produce a pathogen free product. Anaerobic composting requires much longer decomposition times and is seldom free of pathogens and odour problems. The decomposition occurs as a result of the activity of bacteria, fungi, actinomycetes and protozoa. These microbes are present in the waste material while some are seeded from the atmosphere. Table 2.1 shows typical numbers of some organisms present in various stages of composting.

Efficient composting depends on temperature since microbial succession occurs with temperature changes brought about by microbial activities. Figure 2.1 shows a typical temperature pattern in a compost pile over a period of 25 days.

**Table 2.1: Microbial Population during Aerobic Composting (Number per gram wet compost)**

| | Mesophilic intial temperature – 40 °C | Thermophilic 40 °C – 70 °C | Mesophilic 70 °C – initial temperatures | Numbers of micro-organisms identified (species) |
|---|---|---|---|---|
| Bacteria | | | | |
| Mesophilc | $10^8$ | $10^6$ | $10^{11}$ | 6 |
| Thermophilc | $10^4$ | $10^9$ | $10^7$ | 1 |
| Actinomycetes | | | | |
| Thermophilic | $10^4$ | $10^8$ | $10^5$ | 14 |
| Fungi | | | | |
| Mesophilic | $10^6$ | $10^3$ | $10^5$ | 18 |
| Thermophilic | $10^3$ | $10^7$ | $10^6$ | 16 |

Source: adapted from Poincelot (1974)

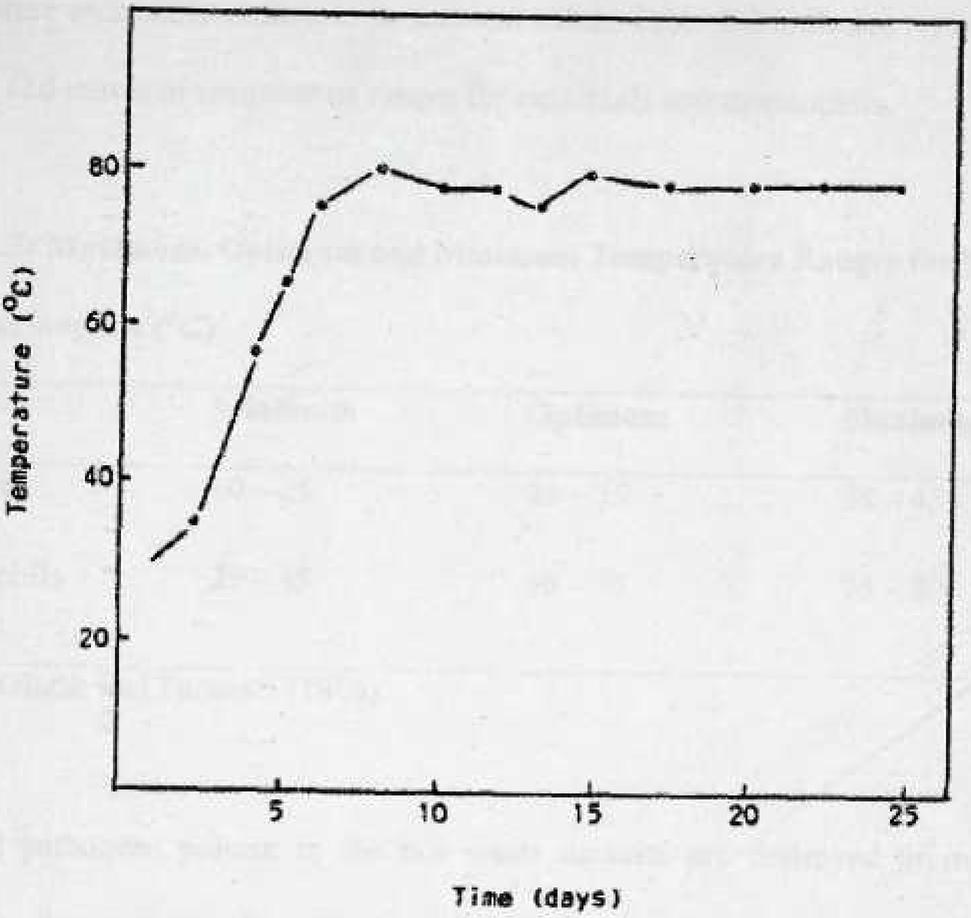


Figure 2.1: Typical time/temperature relationship using mode values of readings taken at 14 monitoring points within each of 12 static piles.

Source: Sikora *et al*. (1981).

According to Obeng and Wright (1987), when the compost mixture is prepared, mesophilic microbial activity within the mass generates heat. This raises the temperature within the mixture. When the temperature reaches a certain level, the mesophilic activity begins to subside and thermophilic activity begins to increase. A stage of temperature decline sets in. At this point mesophilic organisms once again increase. As the process approaches completion, the concentration of nutrients also becomes rate limiting and the temperature eventually returns to its ambient value. Table 2.2 indicates typical minimal, optimal and maximal temperature ranges for mesophils and thermophils.

**Table 2.2: Maximum, Optimum and Minimum Temperature Ranges for Mesophils and Thermophils (°C)**

| | Minimum | Optimum | Maximum |
|---|---|---|---|
| Mesophils | 10 – 25 | 25 – 35 | 35 – 45 |
| Thermophils | 25 – 45 | 50 – 55 | 75 – 80 |

Source: Glathe and Farkasdi (1966).

Excreted pathogens present in the raw waste material are destroyed or incapacitated during the thermophilic phase. Because the process is aerobic, the waste materials must have ample porosity and structure for thorough decomposition to take place. In the case of sewage sludge, organic or inorganic materials must be added to increase air spaces to allow for proper aeration. This will also provide structural support, reduce the bulk weight of the composting mixture and in the case of organic additives, increase the quantity of degradable materials.

## 2.5 METHODS OF COMPOSTING

### 2.5.1 Bin Composting

Bin Composting is the production of compost in a bin. The compost is produced by natural aeration through turning. The compost mix is turned using a tractor front-end loader. Bin composting represents a low technology, medium labour approach producing a medium quality product.

### 2.5.2 Passive Windrow Composting

Passive Windrow Composting is the production of compost in piles or windrows. Compost is produced by natural aeration, over long periods of time. Passive windrow composting represents a low technology and labour approach. Attention to details such as the porosity of the initial mix, uniform product mixing and particle size greatly improves the speed of the process and product quality. As illustrated in Figure 2.2, a windrow should measure about 3 metres (10 feet) wide and 1.5 metres (5 feet) high.

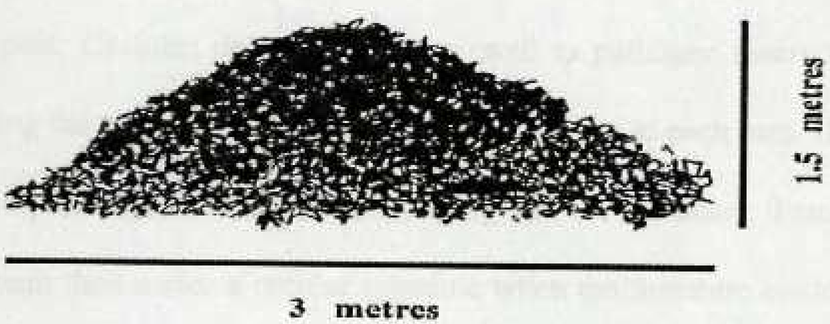


**Figure 2.2: Least dimension of a Windrow**

Aeration occurs naturally. As hot air rises, fresh air is drawn into the pile. Large passive windrows can be as wide as 7 metres (24 feet), and as high as 4 metres (12 feet) and of any length. The centre of a windrow of this size will quickly become anaerobic and only by turning can it receive a new oxygen supply. An unpleasant odour will develop in the anaerobic region and may begin to emanate from the composting heap; hence, a large land area is necessary to buffer residents and businesses from the odour. Since rapid composting can take place only in the presence of oxygen, the compost normally will require three years to stabilize. With both the small and large windrows used in passive windrow composting, there is no ability for process control. Therefore only medium product quality is produced.

### 2.5.3 Turned Windrow Composting

Turned Windrow Composting is the production of compost in windrows using mechanical aeration. The compost mix is aerated by a windrow turner, which can be powered by a farm tractor, self-powered or self-propelled. Turned windrow composting represents a low technology and medium labour approach and produces uniform compost. Uniform decomposition, as well as pathogen destruction, is best achieved by turning the outer edges into the centre of the pile at each turn. However, if this cannot be accomplished, the frequency of turning can be increased. Turning should also be more frequent than under a regular schedule when the moisture content of the pile is too high so as to minimize the development of anaerobic conditions. In areas that receive heavy rainfall, it may be necessary to cover the windrows so they do not become too wet; however, the cost of this may be prohibitive for certain operations.

### 2.5.4 Aerated Static Pile Composting

Aerated Static Pile Composting is the production of compost in piles or windrows with mechanical aeration. The windrow or pile is located above air ducts, and aeration is achieved by blowing or drawing air through the compost material. Aeration systems can be relatively simple, using electrical motors, fans and ducting, or sophisticated, incorporating various sensors and alarms. Aerated static pile composting offers a medium technology and low labour approach, sometimes resulting in a non-uniform product. Mechanical aeration may occur near the end of the active compost period.

### 2.5.5 In-Vessel Composting

In-Vessel Composting is the production of compost in drums, silos or channels using a high-rate controlled aeration system, designed to provide optimum conditions. Aeration of the material is accomplished by continuous agitation using aerating machines which operate in concrete bays, and/or fans providing air flow from ducts built into concrete floors. In-vessel composting represents a high technology and low labour approach, producing a uniform product.

## 2.6 RATE – RELATED FACTORS THAT AFFECT COMPOSTING

A number of rate related factors or parameters affect and influence the efficiency of the composting process and the quality of the product (Obeng and Wright, 1987). The factors include; moisture content, temperature, time, particle size, oxygen supply, nutrients/carbon: nitrogen ratio and pH control. To achieve compost maturity, environmental factors such as temperature, moisture content, pH and aeration should be appropriately controlled (Epstein, 1997).

### 2.6.1 Moisture Content

The moisture content of a composting mixture should be much greater than the lowest level at which bacterial activity will occur. The optimum moisture content for efficient composting is usually in the range of 50 – 60 percent (Obeng and Wright, 1987). In their untreated state, sewage sludge and night soil contain a great deal of moisture (typically > 92 percent). When dewatered, they may still be too wet (75 %) to be composted on their own. Therefore bulking agents will be required to reduce the moisture content and provide structural integrity as well as increase the carbon content. The bulking agents include sawdust, straw, garbage, grass, etc. As decomposition proceeds, the moisture content of the mass will tend to decrease. This is mainly due to evaporation losses during the thermophilic phase and in some cases water may be added to maintain optimal condition.

Too much moisture can quickly lead to anaerobic conditions as water fills in all the tiny spaces in the mixture. This leaves no room for air, a condition that is not favourable for microorganisms that require oxygen. At the same time ideal conditions are created for microorganisms that do not require oxygen. This can result in the production of offensive odours. When an actively composting mixture's moisture content falls to between 35 % and 40 %, decomposition rates slow significantly as microbes are less able to carry out their metabolic activities (Obeng and Wright, 1987). Below 30 % moisture content, they essentially stop. Gotass (1956) stated that if the initial moisture content is below 70 %, the first turn should be done about the 3rd day.

Thereafter turning should be done approximately as follows until the 10th or 12th day:

Moisture 60 % - 70 %: turn at 2-day intervals, approximate number of turns, 4 to 5.

Moisture 40 % - 60 %: turn at 3-day intervals, approximate number of turns, 3 to 4

Moisture below 40 %: add water.

### 2.6.2 Temperature

Temperature is directly proportional to the biological activity within the composting system. As the metabolic rate of the microbes accelerates the temperature within the system increases. Aerobic composting has different temperature stages, including the important thermophilic one. Most micro-organisms grow best between 20 °C and 35 °C. Excreted pathogens thrive at body temperature (37 °C). Temperatures above 50°C achieved during thermophilic composting should be high enough to destroy these pathogens if maintained for a sufficient period of time (Obeng and Wright, 1987). Scott (1952) demonstrated that the pathogens of faecal-borne diseases are rapidly destroyed by aerobic composting, if temperatures in all parts of the pile are maintained between 55 °C – 60 °C for longer than thirty minutes.

Many compost plant operators believe that it is important to maintain very high temperatures (>65 °C). This has been shown to be counterproductive because thermophilic microbial activity rapidly becomes limited at these temperatures (Obeng and Wright, 1987). It is now generally agreed that the temperature of the composting process should not exceed 60 °C to avoid rapid thermal inactivation of the desired microbial community (Bach *et al.*, 1984). Nakasaki *et al.* (1985) showed that the optimum temperature for microbial activity was below 60 °C. Weed seeds and fly larvae are also destroyed. This, however, is only possible if the temperature is maintained above 50 °C throughout the composting mass and there are no pockets of low temperature during that time (Obeng and Wright, 1987).

The temperature changes observed during the decomposition of organic matter can be used as an indication of the proper functioning or malfunctioning of the process. Temperature is perhaps a more reliable indicator than moisture, aeration, or nutrient concentrations. This is because temperature directly affects pathogen control, which is important to the production of good compost. The maximum temperatures achieved vary from system to system. This depends on the raw materials used and operational and design factors. Figure 2.3 shows typical time-temperature profiles for composting sewage sludge by the aerated pile method.

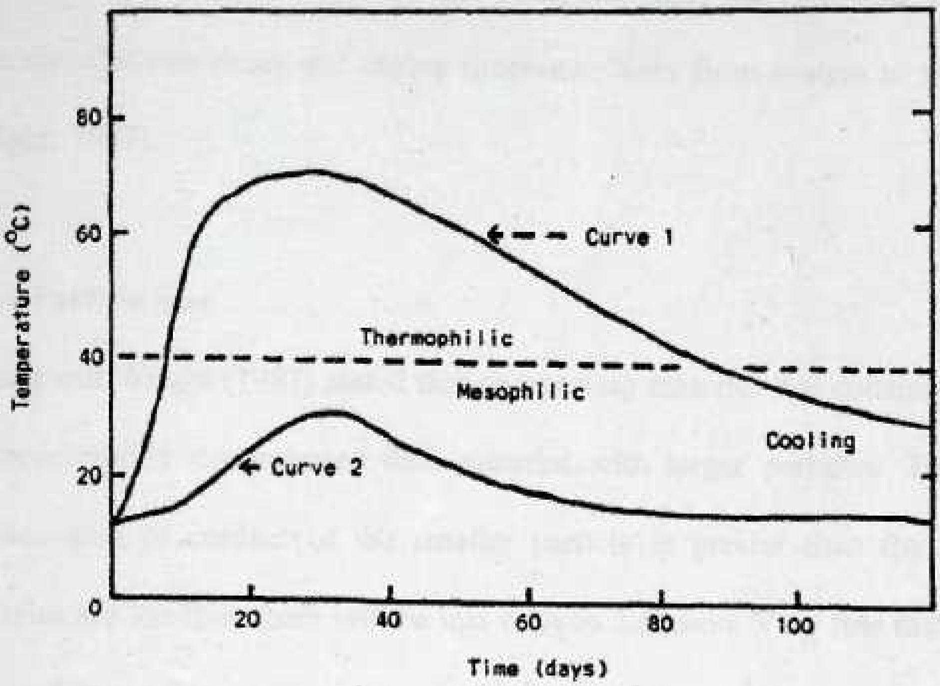


Figure 2.3: A typical time/temperature relationship for composting sewage sludge by the aerated pile method.
Source: Parr *et al*, 1978.

Curve 1 depicts a situation where conditions of moisture, temperature, and aeration are at optimum levels for rapid transition from the mesophilic into the thermophilic stage. Curve 2 represents a condition where certain parameters (such as moisture content, carbon/nitrogen ratio, etc) are deficient or outside their optimum range, resulting in adverse effects on the growth and activity of the indigenous organisms.

### 2.6.3 Time

Compost quality greatly depends on the length of time during which a mixture is composted. If high temperatures (optimum 50-55° C) are not maintained throughout the material for a sufficient length of time (> 2 days), pathogen destruction will not reach the required level. Some heat resistant pathogens may survive this temperature range. Reactor retention times and curing times may vary from system to system (Obeng and Wright, 1987).

### 2.6.4 Particle Size

Obeng and Wright (1987) stated that composting material that consists of small particles is more readily decomposed than material with larger particles. This is because the surface area of contact of the smaller particle is greater than the larger particle. If particles are too fine, there will be less oxygen diffusion. Very fine material tends to lose some of its usefulness as a soil amendment. Experiments have shown that the process of grinding compost materials can increase the decomposition rate by a factor of two (Gray and Sherman, 1970). Gray *et al*. (1971) recommend a particle size of 1.3 to 7.6 cm (0.5 to 2 inches). The lower end of this scale is suitable for forced aeration or continuously mixed systems, and the upper end for windrow and other passively aerated systems.

### 2.6.5 Oxygen Supply

Aeration is regarded as "the most important factor in composting systems" (Diaz *et al*., 2002). The optimum levels of oxygen required for the growth of aerobic micro-organisms range from 5 to 15 percent of the air (Obeng and Wright, 1987). The 5 percent being the minimum essential for the growth of mesophils. According to De Bertoldi *et al*. (1982), the oxygen content in the circulating air should not fall below 18% in windrows. Geris and Regan (1973) also suggested that 30 to 36% free air space is required to obtain adequate aeration for composting for a wide variety of materials. The oxygen consumption in a composting mass depends on several factors:

(a) The stage of the process

(b) Temperature

(c) Degree of agitation of the mass

(d) The composition of the composting mass

(e) The particle size of the mass

(f) The moisture content.

Oxygen consumption appears to increase and decrease logarithmically with changes in temperature. Moisture content affects the air spaces within the composting mass. The rate at which the compost material is aerated also affects the process. If the aeration rate is high (33-78 cubic feet of air per day per pound of volatile solids) the excess flow of air causes the compost mixture to cool down. If this rate is low (4-6 cubic feet of air per day per pound of volatile solids), aerobic activity will decline and the process may become anaerobic (Obeng and Wright, 1987).

### 2.6.6 Nutrients/Carbon – Nitrogen Ration

Carbon and nitrogen are two elements required for microbial growth. The microbes in compost use carbon for energy. Carbon also combines with nitrogen in building cell protoplasm. Nitrogen is used for protein synthesis. The carbon-to-nitrogen (C/N) ratio provides a useful indication of the rate of decomposition of organic matter. Microorganisms generally require 30 parts of carbon to each part of nitrogen for their metabolism. This ratio is therefore commonly used in composting operation. The most frequently used value is between 25 and 30. Sewage sludge is relatively high in nitrogenous compounds, and the C/N ratio is normally less than 15 (nitrogen content and C/N ratios of various wastes are presented by table 2.3). The addition of bulking materials that have a high C/N ratio can be used to adjust the final ratio to one within the optimal range. If the C/N ratio is too high, however, the decomposition process slows down as nitrogen becomes growth limiting. On the other hand if the ratio is too low, the large amount of nitrogen present is rapidly lost by volatilization as molecular ammonia. Since nitrogen is a valuable plant nutrient, its levels in mature compost need to be kept reasonably high. The C/N ratio is not constant during composting because of the removal of carbon as carbon dioxide upon microbial respiration.

**Table 2.3: Approximate Nitrogen and C/N ratios of some compostable materials (Dry basis)**

| Material | N % | (C/N) |
|---|---|---|
| Urine | 15-18 | 0.8 |
| Night Soil | 5.5-6.5 | 6-10 |
| Digested sewage sludge | 1.9 | 16 |
| Weeds | 2 | 19 |
| Cabbage | 3.6 | 12 |
| Rotted Sawdust | 0.25 | 208 |
| Raw Sawdust | 0.11 | 511 |
| Paper | 0.2 | 170 |

Source: Gotaas, 1956

### 2.6.7 pH Control

The optimal pH for the growth of bacteria and other composting organisms is in the range of 6.0 to 8.0. At a pH of 8-9, nitrogen may be lost through volatilization of molecular ammonia. If the pH is too acidic (< 5), microbial activity will cease. In some cases, pH may reflect process malfunction. If a composting mass begins to turn anaerobic, the pH may fall to about 4.5 owing to the accumulation of organic acids. Conversely, as the process approaches stability, the pH shifts toward neutrality (pH 7). The pH-buffering capacity increases as a result of humus formation (Poincelot, 1974.).

### 2.6.8 Odour

Odour is an indication of the efficiency of the process. It also affects public acceptance of and support for composting plants, especially in areas of high population density.

## 2.7 EXCRETED PATHOGENS IN SLUDGE AND NIGHT SOIL

Some of the problems associated with sewage sludge are the presence of trace elements, toxic organics, and pathogens such as bacteria and viruses (Linden *et al.* 1995). Excreted pathogens occur in sewage sludge at varying concentrations. This depends on their ability to survive the various sewage treatment processes and whether they accumulate in the sludge. Concentrations in night soil depend almost entirely on the levels being excreted at any one time and on the ability of the pathogens to survive in the external environment. Table 2.4 summarizes the survival times of pathogens excreted in faeces, night soil, and sludge. Table 2.5 summarizes survival times on crops.

**Table 2.4: Survival Times of Excreted Pathogens in Faeces, Night Soil and Sludge at 20° C -30° C**

| Pathogens | Survival time (days) |
|---|---|
| Viruses | |
| Enterovirus | <100 but usually <20 |
| Bacteria | |
| Fecal coliforms | <90 but usually <50 |
| Salmonella spp. | <60 but usually <30 |
| Shigella spp. | <30 but usually <10 |
| Vibrio cholerae | <30 but usually <5 |
| Protozoa | |
| Entamoeba histolytica cysts | <30 but usually <15 |
| Helminths | |
| Ascaris lumbricoides eggs | Many months |

Source: Feachem *et al*. (1983), p. 66.

**Table 2.5: Survival Times of Excreted Pathogens on Crops at 20-30 ° C**

| Pathogens | Survival time (days) |
|---|---|
| Viruses | |
| Enterovirus | <60 but usually <15 |
| Bacteria | |
| Fecal coliforms | <30 but usually <15 |
| Salmonella spp. | <30 but usually <15 |
| Shigella spp. | <10 but usually <5 |
| Vibrio cholerae | <5 but usually <2 |
| Protozoa | |
| Entamoeba histolytica cysts | <10 but usually <2 |
| Helminths | |
| Ascaris lumbricoides eggs | <60 but usually <30 |

Source: Feachem *et al.* (1983), p. 62.

Literature on the survival of enteric pathogens during various treatment processes has been thoroughly reviewed by Feachem *et al.* (1983). They present detailed information on health and other aspects of excreta-related infections. Some pathogens may not survive the sludge production process. In addition, open-air drying of sludge and night soil eliminates pathogens. This depends on the length of drying time. The key factors in determining the survival of pathogens are the temperature-time interactions. Feachem *et al.* (1983) have suggested various temperature-time regimes for selected pathogens to ensure their death in sewage sludge and night soil. Samples of sludge or night soil should be free of excreted pathogen if they are heated for 1 hour at temperature greater than 62° C, 1 day at temperatures greater than 50° C, or 1 week at temperatures greater than 46°C. Small-scale studies using 20-30 tons of compost material have shown that e. coli and *salmonella spp.* are destroyed by heat more easily than fecal streptococci, and that even c. perfringers numbers decrease during composting and maturation (Pereira-Neto, Stentiford, and Mara 1986)

### 2.7.1 Bacteria

The survival rate of excreted bacterial pathogens in night soil and sludge is variable and depends in part on the temperature and the length of time involved. At temperatures above 20° C, these pathogens will generally survive up to one month in samples of sludge and night soil. However, in general, when the composting mass was maintained at temperatures above 50° C, complete destruction was shown to occur within 2 weeks (Obeng and Wright, 1987).

## 2.8 QUALITY OF COMPOST

Mature compost is free from odour and easy to handle, store, and transport. Raw compost does not have these qualities, but will acquire them with time if it is allowed to mature. Table 2.6 lists some of the differences between raw and mature compost. Mature compost contains trace and essential elements, of which the most important are nitrogen, phosphorus, potassium, and sulphur. These are available to soil and plants, depending on their initial concentrations in the raw compost materials and on the degree of mineralization that occurs (Tester *et al.*, 1980). Concentration in compost from sludge/night soil and garbage compost are considered equivalent, although concentrations of other elements will vary depending on the raw materials. These elements are released by the compost and become available in the years following application. The compost can therefore be used in somewhat the same way as an inorganic fertilizer (except that in many cases the concentrations of these elements are so low that excessively large application rates would be required). As a result, compost is often considered a low analysis fertilizer or soil conditioner (Golueke 1972; Hand, Gershman, and Navarro 1977; Parr *et al.* 1978). However, the NPK values (and other mineral content) of compost can be fortified with chemicals to enhance its fertilizing capacity (Hileman 1982). Unlike inorganic fertilizers, compost has humus like quality that makes it even more useful. This is especially so in areas of the world where the humus content of soil is being rapidly depleted as a result of excessive cultivation and land erosion (Tietjen 1975; Pagliali *et al.* 1981). That is to say, compost can replace lost humus. Compost may contain high concentrations of heavy metals, depending on the source of the raw materials. If sludge from a mixed industrial-domestic source is used, concentrations of lead, zinc, and nickel may be very high. Garbage and human waste composting plants, utilizing night soil will produce compost low in heavy metals, especially if the refuse is largely organic. Other hazardous chemicals such as detergents and those in certain industrial wastes that may be composted will appear in the product if they are non-biodegradable.

**Table 2.6: Differences between Mature and Raw Compost**

| Mature Compost | Raw Compost |
|---|---|
| Nitrogen as nitrate ion | Nitrogen as ammonium ion |
| Sulphur as sulphate ion | Sulphur still in part as sulphide ion |
| Lower oxygen demand | Higher oxygen demand |
| No danger of putrefaction | Danger of putrefaction |
| Nutrient elements are in part available to plants | Nutrient elements not available |
| Higher concentrations of vitamins and antibiotics | Lower concentrations of vitamins and antibiotics |
| Higher concentrations of soil bacteria, fungi, which are decomposed, easily degradable Substances | Higher concentration of bacteria and fungi, which decompose organic materials |
| Mineralization is about 50 percent | High proportion of organic substances not mineralized |
| Higher water retention ability | Lower water retention ability |
| Clay-humus complexes are built | No clay-humus complexes generated |
| Compatible with plants | Not compatible with plants |

Source: Obeng and Wright, 1987

## 2.9 APPLICATION OF COMPOST TO LAND

The most important use of compost is its application to land. This takes several forms: It can be applied to land as a fertilizer, soil conditioner, or mulch, or can be used as a means of land reclamation. Land application of compost is preferable since it produces both a useful and an ecologically compatible product (Hansen and Mancl, 1988). The use of compost helps improve soil structure, texture and aeration. It also increases the soil's water-holding capacity (Martin and Gershuny, 1992).

Furthermore, the use of compost can range from domestic applications by the home gardener to large-scale applications by commercial farmers to their cropland or by municipalities for parklands. The application of compost to land has several advantages. Its positive effects on plant growth, fruit, crop yield, and other factors compared with the effects of chemical fertilizers alone are well documented. The advantages it has over inorganic fertilizers lie in its effects on the soil. Table 2.7 summarizes some of these effects with respect to clay or sandy soils. In both cases, the quality of the soil is improved and it is more productive. Compost may not only amend the physical properties of the soil, but may also have other beneficial effects, such as raising the pH of acid soils.

Compost may be used on land for the following purposes: agriculture, horticulture, home gardening, vegetable gardening, viticulture, landscaping, landfill, forestry, or commercial farming.

**Table 2.7: Physical Effects of the Addition of Compost to Clay or Sandy Soils**

| Sandy soil + compost | Clay soil + compost |
|---|---|
| Water content is increased | Aeration of soil increased |
| Water retention is increased | Permeability of soil to water increased |
| Aggregation of soil particles is enhanced | Potential crusting of soil surface is decreased |
| Erosion is reduced | Compaction is reduced |

Source: Obeng and Wright, 1987.

### 2.9.1 Other Uses of Compost

Sewage sludge or refuse compost can be fed to piglets. Pigs are omnivores and so compost is palatable to them. The compost has to be ground into a fine material (< 4mm) and is fed only to piglets. In Switzerland it is bagged and sold on the market (Helfer 1975). Compost from night soil and vegetable matter has been used in fish farming experiments, where the compost has acted not only as a nutrient for the growth of algae but also as fish feed (Polprasert *et al.* 1982). Compost has also been used to make bricks porous. It is incorporated into the bricking material before firing. During firing the organic matter burns, leaving the fired bricks porous, as desired.

## 2.10 SEWAGE SLUDGE

Waste that is flushed away into sewers is transported to sewage treatment plants. The solid waste matter produced in the treatment process is known as sludge. This material can be further treated by anaerobic digestion to produce digested sludge. The composition of sewage sludge is specific. Sewage sludge from an industrialized community contains higher concentrations of heavy metals and other materials than one from a rural community (Sommers, 1977). Generally, sewage sludge is rich in nutrient and trace elements. It has high odour, high levels of heavy metals and toxic organic compounds. The presence of pathogenic microorganisms, demand pretreatment of the sewage sludge before application in agriculture (Veeken and Hamelers, 1999; Tiquia *et al*., 2002). Over the last twenty years, sewage treatment technology has significantly improved the ability to remove toxins and contaminants. Therefore sewage sludge recovered from waste water treatment plants is relatively clean (Linden *et al*., 1995).

Many countries in Europe and in North America either use sewage sludge directly on the land or converted it into compost. The use of sewage sludge compost on land is restricted in some industrialized areas because it contains relatively high concentrations of heavy metals. Sewage sludge and night soil are similar in their moisture and nutrient content. The advantage of night soil over sludge is that it does not contain heavy metals, but there has been little experience in night soil composting (Obeng and Wright, 1987). Nevertheless, the experience with sewage sludge composting can provide some information that may be of use in night soil composting.

## 2.11 SAWDUST

Sawdust is generally a bi-product in the lumber industry and is readily available in large quantities. Nitrogen depletion by soil microorganisms, during the decomposition process, is one of the primary problems associated with these materials. However, supplemental applications of nitrogen to the growing media can make most wood residues valuable amendments. The species of tree from which sawdust is derived largely determines its quality and value for use in a growing medium. Several sawdust, such as walnut and non-composted redwood, are known to have direct phytotoxic effects. However, the C: N of sawdust is such that it is not readily decomposed. The high cellulose and lignin content along with insufficient N supplies creates depletion problems which can severely restrict plant growth.

## 2.12 CEDRELA

*Cedrela odorata* is softwood which belongs to the family Miliaceae. The species has been introduced in southern Florida, Nigeria, Tanzania, Ghana, Sierra Leone, and the Fiji Islands. *Cedrela odorata* is a deciduous tree that can reach 35 m in height and 60 cm diameter at breast height (d.b.h). In exceptional cases, specimens 40 m or more in height and 2 m in d.b.h. can be found. The trunk is straight and cylindrical, sometimes with small spurs. The leaves are paripinnate or imparipinnate, 15 to 50 cm long. The tree prospers in calcareous soils as well as in soils rich in organic matter. It grows in areas with an average annual temperature of 22 to 32 °C and an average annual precipitation of 1600 to 2500 mm. It requires a 3- to 4-month dry season and grows at elevations ranging from sea level to 1200 m. The wood from this tree is among the most sought-after in Latin America and elsewhere, primarily for its value in the manufacture of veneer and furniture. It is resistant to attacks by fungi and insects, and it keeps a pleasant fragrance for many years. It is used for belt rails, staves, musical instruments, and interior decoration. An infusion of its bark is used as a remedy for diarrhea, fever, vomiting, hemorrhages, dyspepsia, bronchitis, and indigestion.

## 2.13 TEAK

Teak (*Tectona grandis*) is a Hardwood. It is generally straight grained with a coarse, uneven texture, medium lustre and an oily feel. The colour ranges from yellow brown to dark golden brown heartwood and greyish or white sapwood. Plantation teak tends to be lighter in colour but contains the same dimensional stability properties. Teak has numerous uses including ship building (especially decks), indoor or outdoor furniture, high class joinery, flooring, panelling, plywood and decorative veneers. It is one of the hardest, strongest and most durable of all natural woods. It is very strong making it suitable for furniture. Its resistance to rotting and to the effects of hot sun, rain, frost or snow, makes it most suitable for external work. Teak can withstand almost all weather conditions the weather can throw at it. Teak is expensive and sometimes hard to come by.

## CHAPTER THREE

# MATERIALS AND METHODS

The research was in two stages;

1. Compost production from dewatered sewage sludge and sawdust from Teak (*Tectona grandis*) and Cedrela (*Cedrela odorata*).
2. Cultivation of lettuce with the compost produced.

## PHASE ONE – COMPOST PRODUCTION

### 3.1 EXPERIMENTAL SET-UP

The study area was the KNUST sewage treatment plant, where the dewatered sewage sludge was taken from the sludge drying beds. The Cedrela sawdust was transported from Poku Brothers' Timber Sawmill at Akropong in the Ashanti Region. Teak sawdust was also transported from the Angola Sawmill at Kaase in the Kumasi Metropolis. A 5 m x 5.5 m shade was constructed. A concrete floor was used to protect the composting process from excessive environmental conditions like rains, sunlight etc. (Plate 3.1) and soil characteristics.

Plate 3.1: The structure and initial state of material for composting

### 3.2 COMPOSTING PROCEDURE

Two different heaps of composts were prepared using dewatered sewage sludge and sawdust from Cedrela and Teak in the ratios, 1:1 and 1:2 by volume (v/v) respectively. Replication of each pile was done meaning every two piles had the same ratio. Each ratio was duplicated giving 1:1 a, 1:1 b, 1:2 a and 1:2 b respectively where 'a' and 'b' are the duplicates of the same ratio. The mixtures consisted of sludge that was taken directly from the drying beds and the sawdust in the right proportions. The windrow pile composting system of manual turning was adopted as it is the most common method of composting and it is less expensive.

| | | |
|---|---|---|
| Sludge and Cedrela 1:1a | Sludge and Cedrela 1:1b | Sludge and Cedrela 1:2a |
| Sludge and Cedrela 1:2b | | Sludge and Teak 1:1a |
| Sludge and Teak 1:1b | Sludge and Teak 1:2a | Sludge and Teak 1:2b |

Figure 3.1: Compost heaps lay out

### 3.3 TURNING AND WATERING OF THE HEAPS

For the first fifteen days the heaps were turned every three days. The frequency of turning was then reduced to once a week after the first fifteen days. The turnings were done to help aerate the heaps for the necessary aerobic conditions since consumption of oxygen is greatest during early stages of composting. They were also done to ensure that the entire compost mass was subjected to the optimum conditions during composting. The high oftenness of turning in the early stages was to enable all parts of the windrow to be heated sufficiently for efficient pathogen inactivation. Any time the windrows were turned they were watered except when the windrows were moist.

### 3.4 TEMPERATURE MEASUREMENT

The temperature of each heap was read three times a day at 8am, 12 noon and 4pm. This was done by inserting a glass thermometer at 20 cm and 40 cm depth in the heap for five minutes in each case and the average reading recorded. The ambient temperature was also recorded at the same time.

### 3.5 MOISTURE CONTENT DETERMINATION

During turning of the heaps, the moisture content was checked in the following manner: A fist full of compost is taken with the hand and squeezed tightly. If moist but no free water appears between the fingers, the moisture is ideal. If however, water flows out of the tightly clenched fist, it is too wet (Bokx 2002). If the material was too dry, water was sprinkled over the compost. On the other hand, any time the heap is turned, samples of the heaps were taken to the laboratory for moisture content determination. Each sample was weighed using Mettlar balance ($W_1$). The samples were then oven-dried at a temperature of 105°C for 24 hours and reweighed ($W_2$). The difference in weight was expressed as amount of moisture in the sample taken.

The percentage moisture content was then calculated using the formula:

$$Moisture\ (\%) = \frac{W_1 - W_2}{W_1} x\ 100$$

Where $W_1$ = Weight of sample before drying, $W_2$ = Weight of oven dried sample

### 3.6 HEAP VOLUME MEASUREMENT

Figure 3.2 shows the height (h) and the radius (r) from which the volume was estimated. The height (h) and the circumference (C) of the various heaps were measured with the help of a calibrated rod and a measuring tape.

Volume of compost heap, —, —Where r = radius of the heap,

h = height of the heap

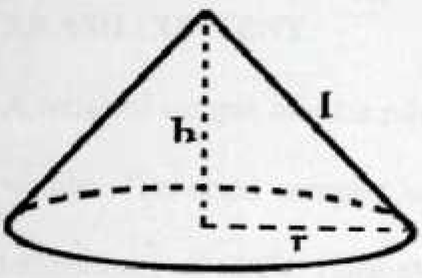


Figure 3.2: The shape of the compost heap, indicating parameters measured for heap Volume calculations

## 3.7 TOTAL SOLIDS (TS) DETERMINATION

A known quantity of each sample was weighed into a petri dish ($M_{before}$) and then dried for 24 hours at 105$^0$C in an oven. Thereafter, the sample was weighed again ($M_{after}$). The percentage of the Total Solids was then calculated using the formula:

—

## 3.8 ORGANIC MATTER CONTENT (OM)

A weighed sample of each pile was oven-dried at 105 $^0$C for 24 hours to obtain a constant weight. The dried samples were then burnt in an ignition furnace for one hour at the temperature of 600 $^0$C (Greenberg *et al.*, 1992). The resulting ash was weighed using a mettlar balance to obtain the ash content.

Percentage organic matter of each sample was then calculated using the formulae:

$$Organic\ matter\ (\%) = \frac{(Weight\ of\ oven\ dried\ sample - Weight\ of\ ash\ content) x\ 100}{Weight\ of\ oven\ dried\ sample}$$

## 3.9 ASH CONTENT

A weighed sample of each pile was oven-dried at $105^0$C for 24 hours to obtain a constant weight. The dried samples were then burnt in an ignition furnace for one hour at a temperature of $600^0$C (Greenberg *et al.*, 1992). The resulting ash was weighed using a mettlar balance to obtain the ash contents. Percentage ash content of each sample was then calculated using the formula:

$$Ash\ content\ (\%) = \frac{Ash\ content\ x\ 100}{weight\ of\ oven\ dried\ sample}$$

## 3.10 CARBON CONTENT

The percentage total organic carbon (TOC) was computed from organic matter (OM) using the following equation (Navarro *et al.*, 1993):

TOC (%) = 0.51 x % OM + 0.48

Where TOC = Total Organic Carbon, OM = Organic Matter.

## 3.11 NITROGEN CONTENT

One gram (1g) of dry compost sample was weighed out using a mettlar balance into a kjeldahl flask of 500ml size. 25ml concentrated sulphuric acid was added with selenium catalyst tablets. The flask was then heated in a fume chamber until the mixture became clear.

The digest was then allowed to cool and was diluted to 300ml with distilled water. 50ml of sodium hydrogen thiosulphate and 10ml of sodium hydroxide were added to the diluted digest to provide the alkaline condition necessary for the release of organic nitrogen. 200ml of the mixture was then distilled into a conical flask containing 50ml of boric acid indicator. The solution in the conical flask was then titrated against standard 0.02N sulphuric acid until indicator turns pale lavender with volume $V_1$. A blank was prepared by heating 25ml of concentrated sulphuric acid and selenium catalyst tablet and treated as a digest to get $V_0$ (Greenberg *et al.*, 1992).

The nitrogen of the sample was calculated using the relationship:

$$Nitrogen\ (mg/kg) = \frac{(V_1 - V_0) \times 280}{m}$$

Where:

$V_1$ is the volume, in milliliters (ml), of the sulphuric acid used in the titration of the sample.

$V_0$ is the volume, in milliliters (ml), of the sulphuric acid used in the titration of the blank test.

m is the mass of test sample in gram (g).

### 3.12 CARBON-NITROGEN RATIO DETERMINATION

This was computed using the results obtained from carbon and nitrogen content determination.

$$Carbon - Nitrogen\ Ratio = \frac{\text{Carbon Content}}{\text{Nitrogen Content}}$$

### 3.13 PHOSPHORUS CONTENT

One gram (1g) of the dry sample was weighed out and dissolved in 100ml of distilled water .The mixture was thoroughly mixed up and filtered out. A sachet of Phos Ver3 phosphate powder pillow for 10ml sample was added to 10ml of the filtrate in a 10ml cell. The mixture was swirled immediately to mix and left for 3 minutes. The mixture turns blue indicating the presence of phosphorus (Greenberg *et al.*, 1992). The content in the cell is placed in the Portable data logging spectrophotometer and the phosphorus content determined digitally in milligram per liter (mg/l)

### 3.14 POTASSIUM CONTENT DETERMINATION

Two grams (2g) of sun-dried compost samples were weighed into crucibles. These were then transferred into a muffle furnace set to a temperature of 550 $^{0}$C and left for 2 hours. After 2 hours the crucibles were removed and allowed to cool. Two millilitres (2ml) of distilled water was added to each crucible followed with 5ml of 8N HCL to dissolve the Potassium in the ash. Samples were then evaporated for 20 minutes in a water bath. The solutions were then filtered through Whatman No 40 fitter papers into 100ml volumetric flask. The crucibles were washed with distilled water through the filter to get all the soluble salts washed out of the filter paper. Ten millilitres (10ml) portions are then used for the potassium determination in the flame photometer. However before using the flame photometer it was calibrated using the following standards

| ppm | Emission |
|---|---|
| 0 | 0 |
| 5 | 31 |
| 10 | 56 |
| 15 | 80 |
| 20 | 100 |

A standard curve was then constructed with the potassium readings to obtain actual concentrations in the compost samples in solutions. The following graphical equation was derived;

$$X = \frac{Y}{5.213}$$

X = Concentration of potassium

Y = Emission

The percentage potassium was then derived using the equation;

$$\% K = \frac{Graps\ reading}{wt\ of\ sample}\ x\ 100(X)$$

Wt = 2g

### 3.15 TOTAL COLIFORM DETERMINATION

Total coliforms were estimated using the three tube Most Probable Number (MPN) method according to Standard Methods (Anon, 1994). Ten grams (10 g) of each compost sample was weighed into a stomacher bag and pulsified in 90ml of 0.9 % NaCl MQ-water for 30 sec using a pulsifier (PUL 100E). Serial dilutions of $10^{-1}$ to $10^{-15}$ were prepared by picking 1ml from the stomacher bag. One millilitre (1 ml) aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth with inverted Durham tubes and incubated at 35° C for 24 hours. Tubes showing acid and gas productions after 24 hours were recorded as positives and negatives for tubes with no change. Total coliform were estimated using the MPN table (Anon, 1994).

### 3.16 FAECAL COLIFORM DETERMINATION

Faecal coliforms were estimated using the three tube Most Probable Number (MPN) method according to Standard Methods (Anon, 1994). Ten grams (10 g) of each compost sample was weighed into a stomacher bag and pulsified in 90ml of 0.9 % NaCl MQ-water for 30 sec using a pulsifier (PUL 100E). Serial dilutions of $10^{-1}$ to $10^{-15}$ were prepared by picking 1ml from the stomacher bag. One millilitre aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth with inverted Durham tubes and incubated at 44° C for 24 hours. Tubes showing acid and gas productions after 24 hours were recorded as positives and negatives for tubes with no change. Faecal coliforms were estimated using the MPN table (Anon, 1994).

### 3.17 SALMONELLA DETERMINATION

Salmonella levels were determined using the membrane filtration method. Ten grams (10g) of sample was put into a conical flask. Hundred milliliters (100 ml) of sterilized distilled water was added to the sample. The conical flask was then shaken on a mechanical shaker for an hour to stir for uniformity. This was then allowed to settle. One milliliter (1 ml) was taken and put into 99 ml of sterilized distilled water in a 100 ml bottle. Hundred milliliters (100 ml) was then transferred into the filtration system containing 0.45µm filter membrane. Membranes were then transferred onto Petri dishes containing chromocult coliform Agar. The Petri dishes were incubated at 37°C for 18-24 hours. The appearance of light blue to turquoise colour colonies was indicative of the presence of salmonella. After 24 hours, counting was done with the aid of a magnifying lens.

## PHASE TWO – LETTUCE CULTIVATION

### 3.18 CULTIVATION OF LETTUCE

Randomised Complete Block Design (RCBD) was used in the cultivation of the lettuce. Each block consisted of ten plots of dimension 2 m x 3 m wide. The plots were given treatment with the various composts including dewatered sewage sludge and a control. The plot treatment was replicated three times in RCBD. A quantity of 0.028 $m^3$ from each compost type and sludge was applied per plot on each block. The figure below depicts the arrangements of the plots and the treatment. The lettuce was cultivated according to standard agronomic practice with spacing of 25 cm x 30 cm. The lettuce was grown for five weeks before it reached maturation. Plates 3.2 to 3.7 show lettuce at planting and lettuce at maturity per fertilisation with the compost type.

← 3 m →

2 m

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A<br>S | S/C 1:2 a | S/T 1:1 a | NT | S/C 1:1 b | S/T 1:2 b | S/C 1:2<br>b | S/T 1:1 b | S/C 1:1 a | S/T 1:2 a |
| B<br>S/T 1:1b | S/T 1:1 a | S | S/C 1:2 b | S/T 1:2 a | S/T 1:2 b | S/C 1:1 b | NT | S/C 1:2 a | S/T 1:1 a |
| C<br>S/T 1:2 a | S/C 1:2 a | S/C 1:1 b | S/C 1:1 a | S/T 1:1 b | S | S/C 1:2 b | S/T 1:2 b | NT | S/T 1:1 a |

**Figure 3.3: Layout of experimental plots**

<u>Key</u>

A – 1st block of bed

B – 2nd block of bed

C – 3rd block of bed

S/C – Sludge/Cedrela ratio

S/T – Sludge/Teak ratio

NT – No Treatment

Plate 3.2 Lettuce at transplanting


Plate 3.3 Lettuce on plot fertilised with sludge after five weeks


**Plate 3.4 Lettuce on plot fertilised with Sludge/Cedrela 1:1 a compost after five weeks**


**Plate 3.5 Lettuce on plot fertilised with Sludge/Cedrela 1:1 b compost after five weeks**

**Plate 3.6 Lettuce on plot fertilised with Sludge/Teak 1:1 b compost after five weeks**

**Plate 3.7 Lettuce on plot fertilised with Sludge/Teak 1:2 a compost after five weeks**


**Plate 3.8 Lettuce after five weeks on control plot (No Treatment)**

### 3.19 SOIL AND THE TREATMENT ANALYSIS

Samples of soil from the beds, the different compost types and dried uncomposted sewage sludge were taken to the laboratory and tested. The tests determined moisture, total solids, pH, organic matter, ash, carbon, nitrogen, phosphorus, potassium, total coliforms, faecal coliforms and salmonella content of the samples using standard methods as described at sections 3.5 to 3.17.

### 3.20 LETTUCE ANALYSIS

Total coliforms, faecal coliforms, salmonella and average yield of lettuce were determined for each plot. Lettuce samples were analysed for coliforms levels. Ten grams of lettuce from each category/plot was aseptically cut and placed in a stomacher bag and pulsified in 0.9 Sodium Chloride MQ – water for 30 seconds using a pulsifier (Microgen Bioproducts Ltd, Survey, UK, Serial No. 230 03071)

### 3.20.1 Total Coliform, Faecal Coliform and Salmonella Levels on Lettuce

Methodologies used were the same as Total coliform, Faecal coliform and Salmonella levels determination in sections 3.15, 3.16 and 3.17.

### 3.20.2 Yield Determination

Five (5) samples of lettuce were taken from each treatment plot at random. The lettuce batches were weighed with a metler balance and their mean weight determined. The average dry weight was also determined to assess the biomass of lettuce. This was done by drying 100 g of lettuce from each plot in an oven at 105 $^0$C for 24 hours and their dry weight taken.

# CHAPTER FOUR

# RESULTS

## 4.1 INTRODUCTION

Results from nutrients and pathogen levels determination of composts from the ratios of dewatered sewage sludge and sawdust from teak and cedrela are presented in Figure 4.3 to 4.15. Total solids, moisture content, organic matter, ash, carbon, nitrogen, phosphorous, potassium, total coliforms, faecal coliform, salmonella and carbon-nitrogen ratio levels were used as indices of compost quality.

## 4.2 TEMPERATURE

Figure 4.1 represents variation in temperature in the different compost heaps and ambient temperature over the 95-day period. The figure indicates that the heap with ratio 1:1 sludge/cedrela mixture reached its highest temperature 49.10 °C, 1:2 sludge/cedrela reached 49.75 °C, 1:1 sludge/teak reached 49.5 °C and 1:2 sludge/teak reached 49.92 °C. These occurred within the first 10 days of composting. The temperatures after the highest levels started declining till the 95$^{th}$ day when the temperature in 1:1 sludge/cedrela was 26.65 °C, 1:2 sludge/cedrela was 27 °C, 1:1 sludge/teak was 26.8 °C and 1:2 sludge/teak was 26.5 °C.

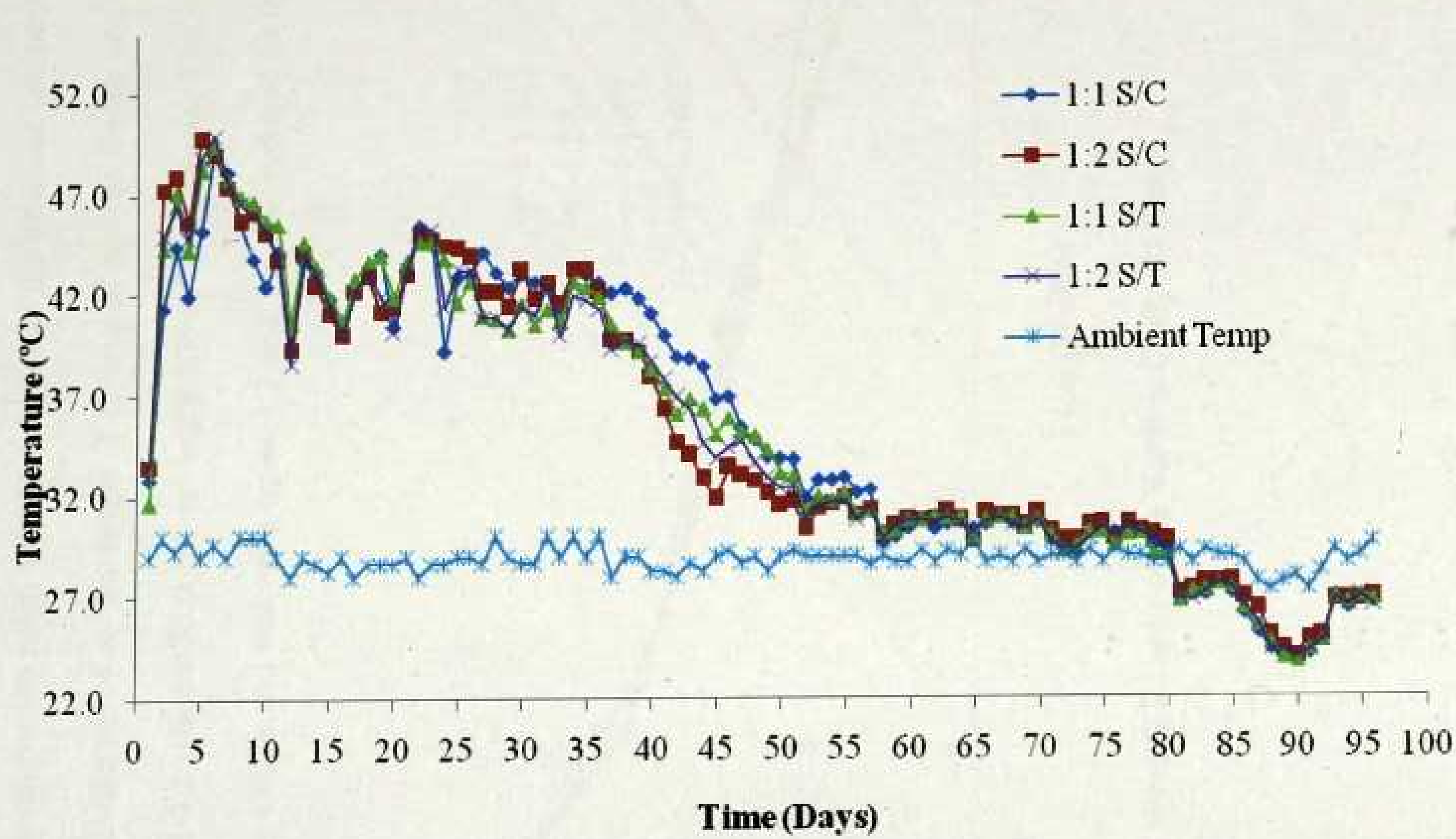


**Figure 4.1 Variation in process temperature (1:1 S/C, 1:2 S/C, 1:1 S/T and 1:2 S/T) and Ambient Temperature against Time (Days)**

### 4.3 VOLUME

Figure 4.2 also represents the mean weekly volumes of the different compost heaps. From an initial volume of 0.4 $m^3$ the heaps of dewatered sewage sludge and cedrela with ratio 1:1 and 1:2 reduced to 0.207 $m^3$ and 0.206 $m^3$ respectively. The heaps of dewatered sewage sludge and teak with ratios 1:1 and 1:2 also reduced to 0.21 and 0.22 respectively.

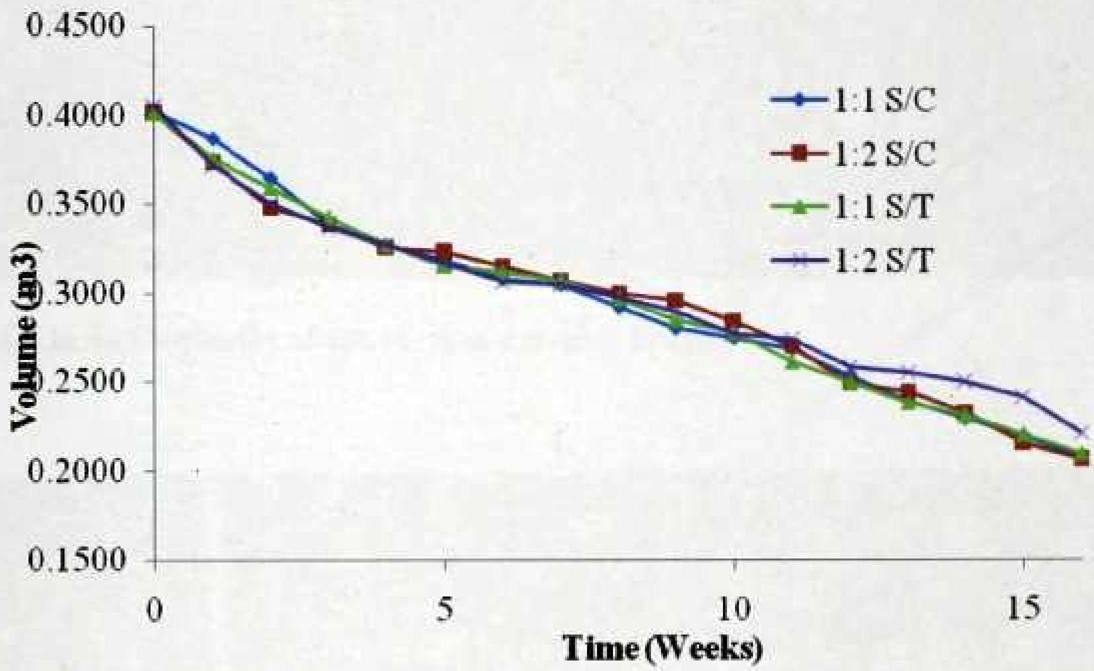


**Figure 4.2 Mean Weekly Volume of the Various Compost Heaps**

**Plate 4.1 Initial Volumes of the various compost heaps**

**Plate 4.2 Final volumes of the various compost heaps**

## 4.4 TOTAL SOLIDS AND MOISTURE CONTENT

The total solids content in all the different heaps of dewatered sewage sludge and cedrela kept on increasing from an initial of 35.60% to 62.75% for heap 1:1 and 35.44% to 63.80% for the 1:2 ratio heap. Also that of dewatered sewage sludge and teak kept increasing from an initial of 35.24% to 79.10% for heap 1:1 and 32.57% to 74.44% for the 1:2 ratio heap (Fig. 4.3). As the total solids increased, the moisture content decreased and for heap with ratio 1:1 sludge and cedrela, it reduced from a mean of 66.40% to 37.26% and 64.56 % to 36.21 % for heap with ratio 1:2 sludge and cedrela (Fig. 4.4). For sludge and teak, moisture content decreased and for heap with ratio 1:1, it reduced from a mean of 64.76% to 20.91% and 67.43% to 25.57% for heap with ratio 1:2 respectively.

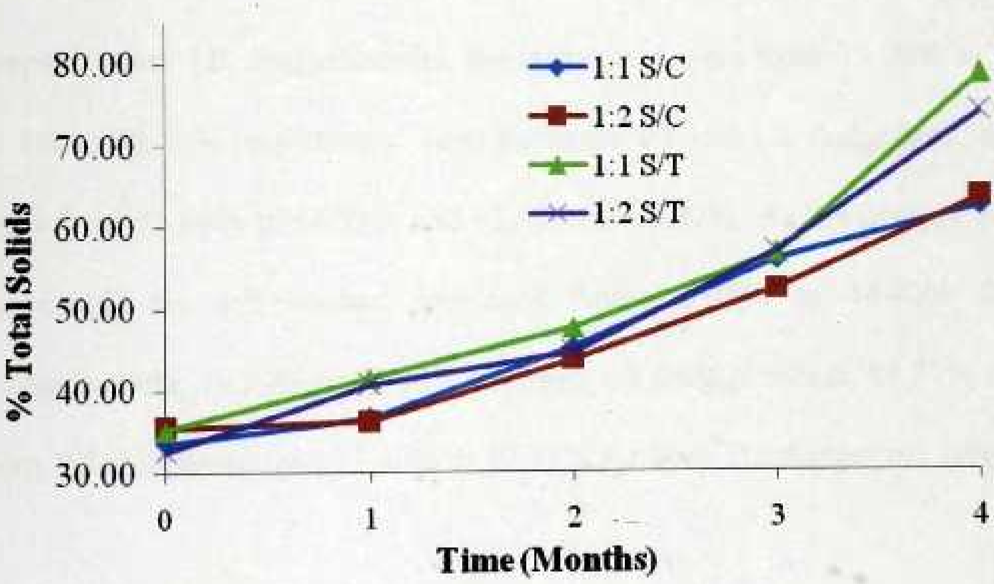


**Figure 4.3 Mean Monthly Total Solids (%) in the Various Compost Heaps**

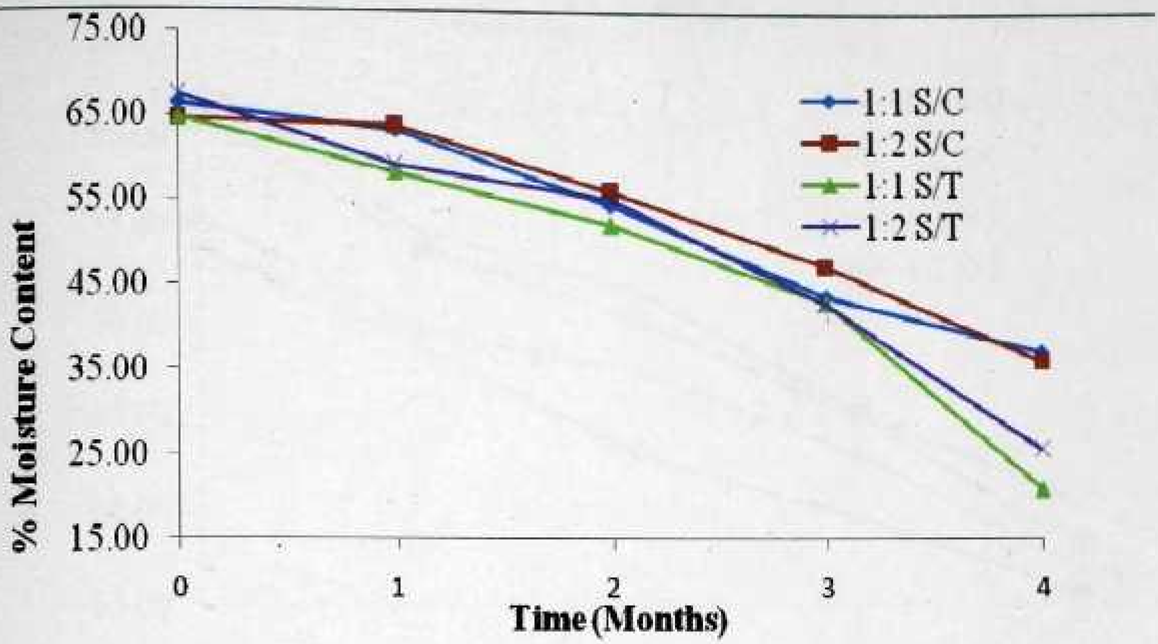


**Figure 4.4 Mean Monthly Moisture Content (%) in the various Compost Heaps**

## 4.5 ORGANIC MATTER AND ASH CONTENT

From figure 4.5, the organic matter content decreased over the entire period and for heaps 1:1 and 1:2 sludge/cedrela, the reductions were from 73.99% to 55.61 % and 81.1% to 58.20% respectively. Also for heaps 1:1 and 1:2 sludge/teak, the reductions were from 75.69% to 56.91% and 82.90% to 60.47%. As the organic matter content decreased, the ash content increased from 26.01% to 44.40% for heap 1:1 sludge/cedrela, 18.90% to 41.80% for heap 1:2 sludge/cedrela, 24.31% to 43.09% for heap 1:2 sludge/teak and 17.10% to 39.53% for heap 1:2 sludge/teak (Fig. 4.6).

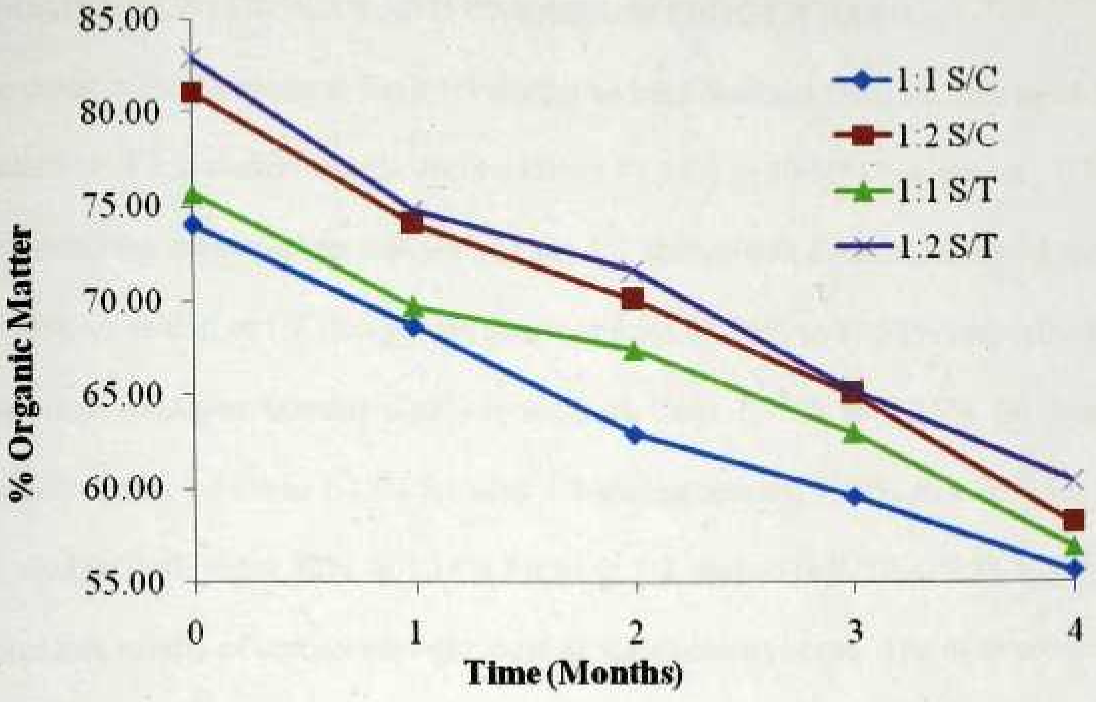


**Figure 4.5 Mean Monthly Organic Matter Content (%) in the various Compost Heaps**

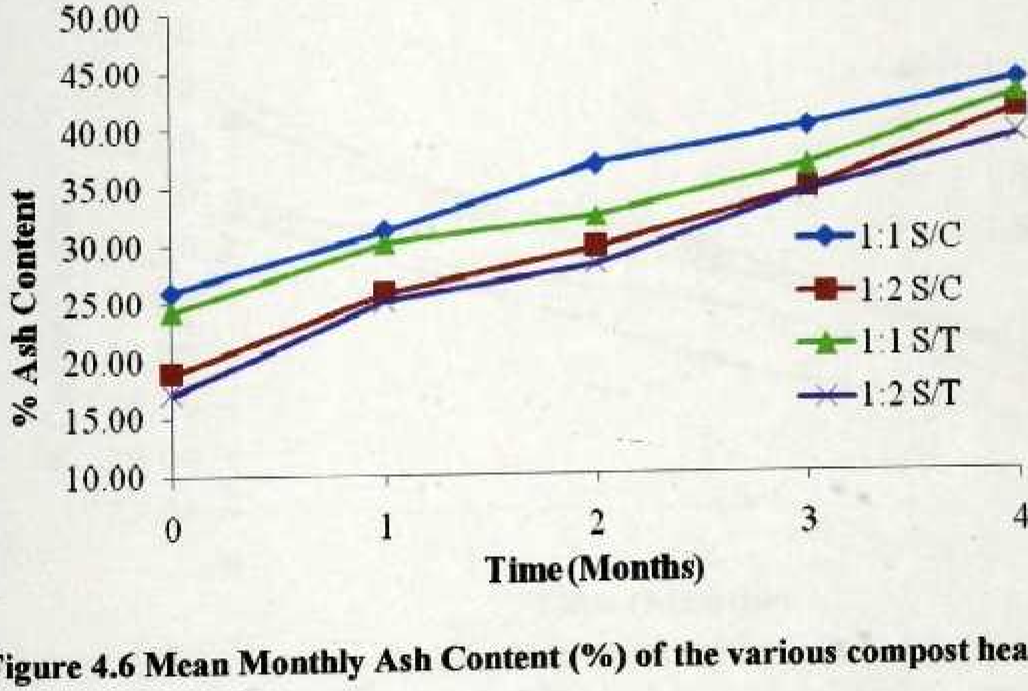


**Figure 4.6 Mean Monthly Ash Content (%) of the various compost heaps**

## 4.6 CARBON, NITROGEN AND CARBON/NITROGEN RATIO

The mean carbon content in heap 1:1 sludge/cedrela declined from 38.22% to 28.84% while that of 1:2 sludge/cedrela declined from 41.84% to 30.16% respectively (Figure 4.7). Also the mean carbon content in heap 1:1 sludge/teak declined from 39.08% to 29.50% while that of 1:2 sludge/teak declined from 42.76% to 31.32% respectively.

The mean nitrogen content also got reduced from 1.55% to 1.35% for heapl:1 sludge/cedrela, 1.34% to 1.15% for heap 1:2 sludge/cedrela, 1.58% to 1.36% for heap 1:1 sludge/Teak and 1.38% to 1.14% for heap 1:2 sludge/Teak (Fig. 4.8). Figure 4.9 represents results of carbon-nitrogen ratio in the different heaps. The carbon-nitrogen ratio declined from the initial of 24.73 to 21.36 for heap with ratio 1:1 sludge/cedrela, 31.20 to 26.34 for the heap with ratio 1:2 sludge/cedrela, 24.75 to 21.75 for the heap with ratio 1:1 sludge/Teak and 31.04 to 27.38 for the heap with ratio 1:2 sludge/Teak.

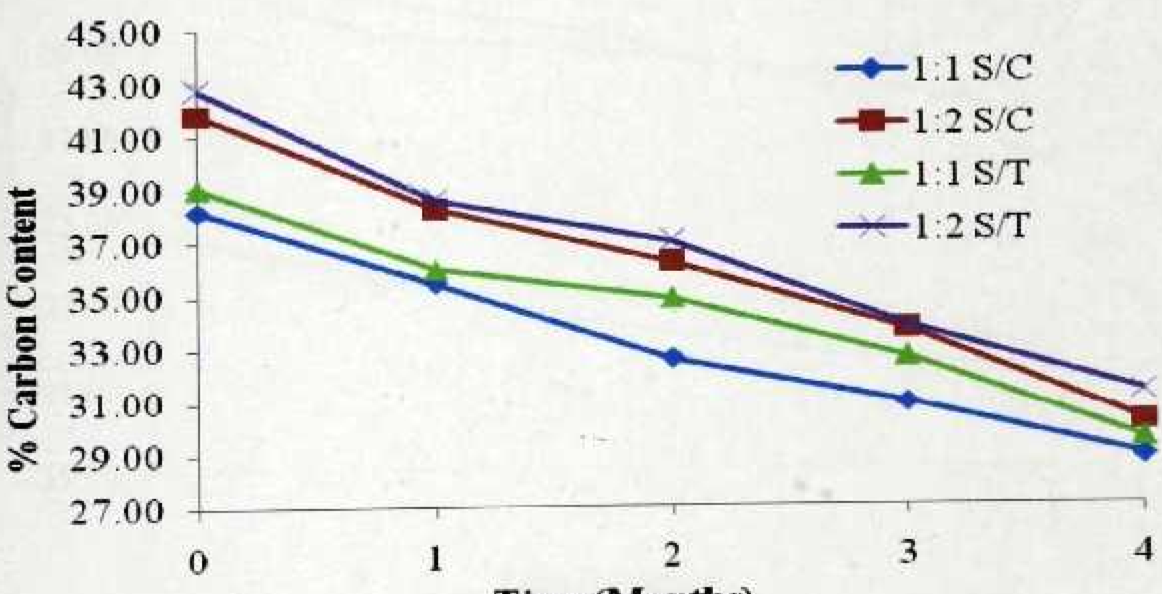


**Figure 4.7 Mean Monthly Carbon Content (%) of the various compost heaps**

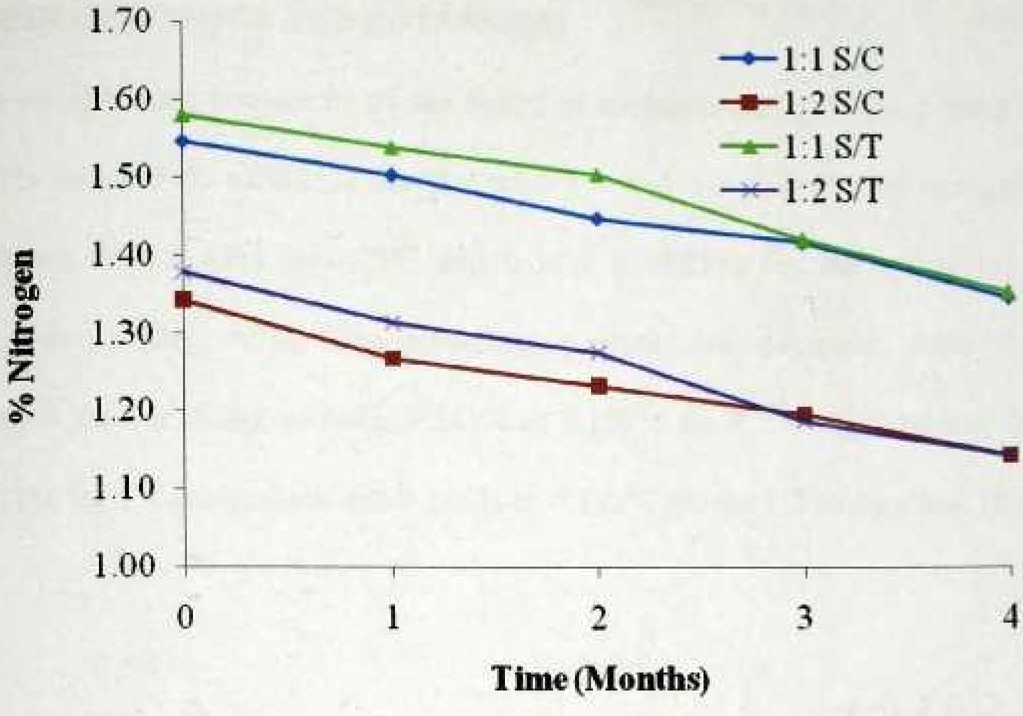


**Figure 4.8 Mean Monthly Nitrogen Content (%) in the Various Compost Heaps**

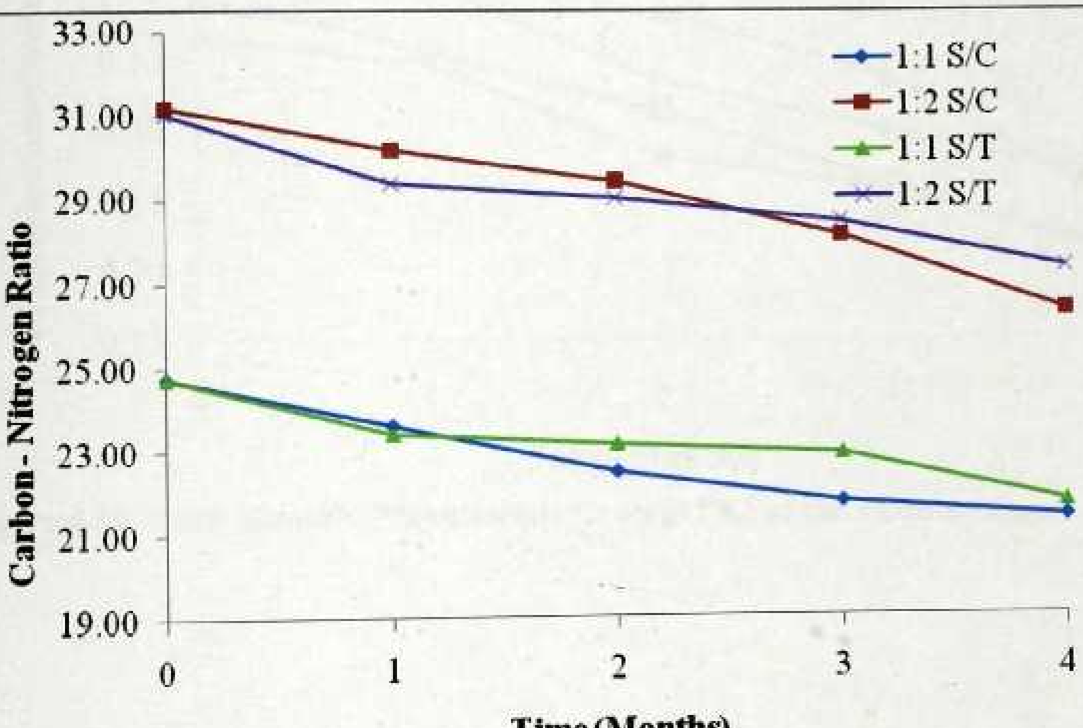


**Figure 4.9 Mean Monthly Carbon – Nitrogen Ratio in the Various Compost Heaps**

## 4.7 PHOSPHOROUS AND POTASSIUM

The phosphorous content in all the heaps of sludge/cedrela declined from 0.43% to 0.21% and 0.39% to 0.21% for the ratio 1:1 and 1:2 and that of sludge/teak also declined from 0.42% to 0.25% and 0.36% to 0.21% for the ratios 1:1 and 1:2 respectively (Fig. 4.10). The potassium content also decreased from 0.231% to 0.153% for 1:1 sludge/cedrela, 0.241% to 0.167% for 1:2 sludge/cedrela, 0.225% to 0.151% for 1:1 sludge/teak and 0.216% to 0.152% for the 1:2 sludge/teak (Fig. 4.11).

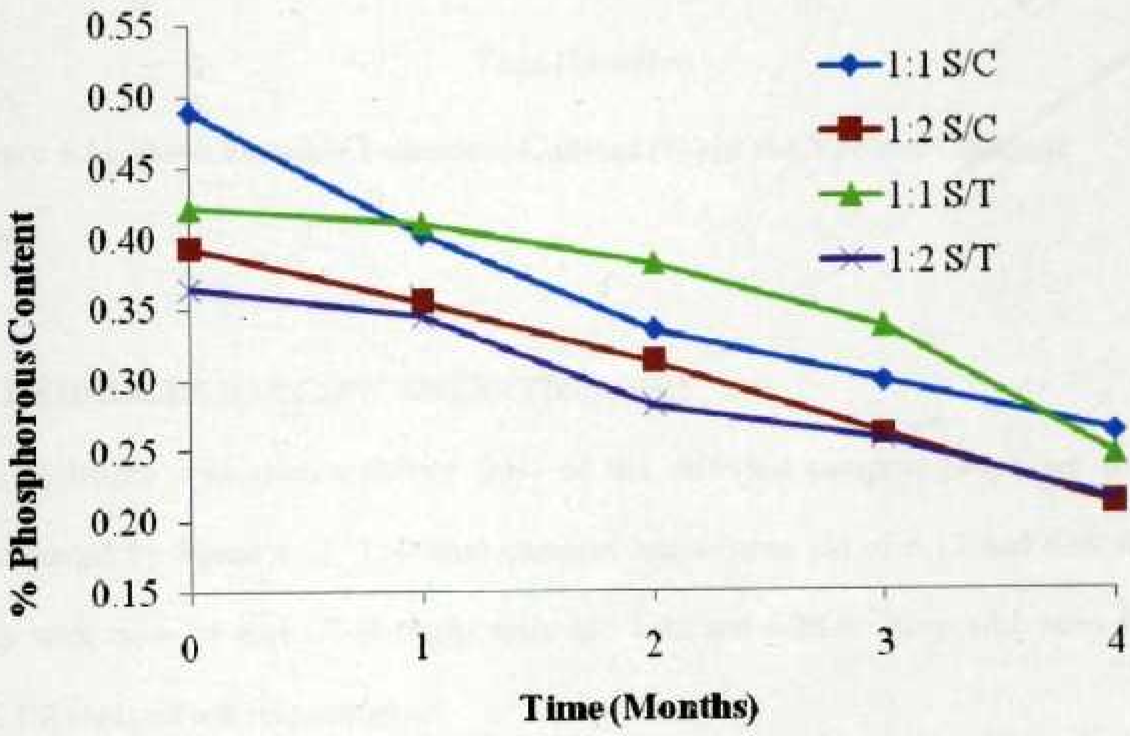


**Figure 4.10 Mean Monthly Phosphorous Content (%) of the various heaps**

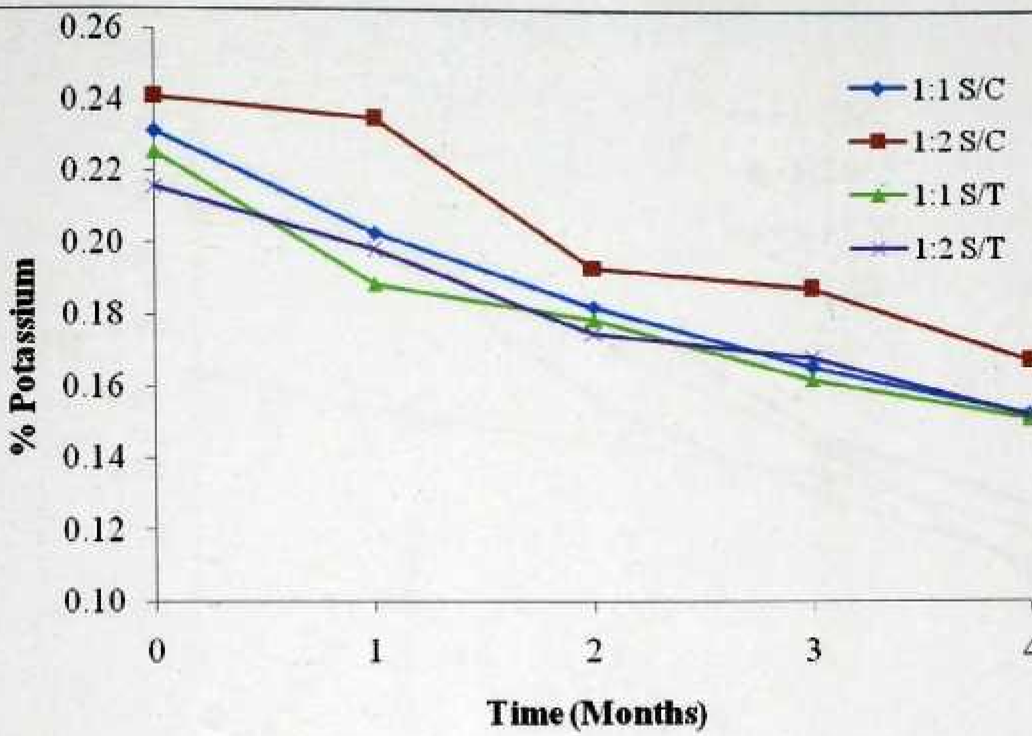


**Figure 4.11 Mean Monthly Potassium Content (%) in the Various Compost Heaps**

## 4.8 HYDROGEN ION CONCENTRATION (PH)

The hydrogen ions concentrations (pH) of the different compost heaps are also represented by figure 4.12. The final compost has a mean pH of 6.13 and 6.09 for heap with ratio 1:1 and 1:2 sludge/cedrela and 6.22 and 6.29 for heap with ratio 1:1 and 1:2 sludge/Teak respectively.

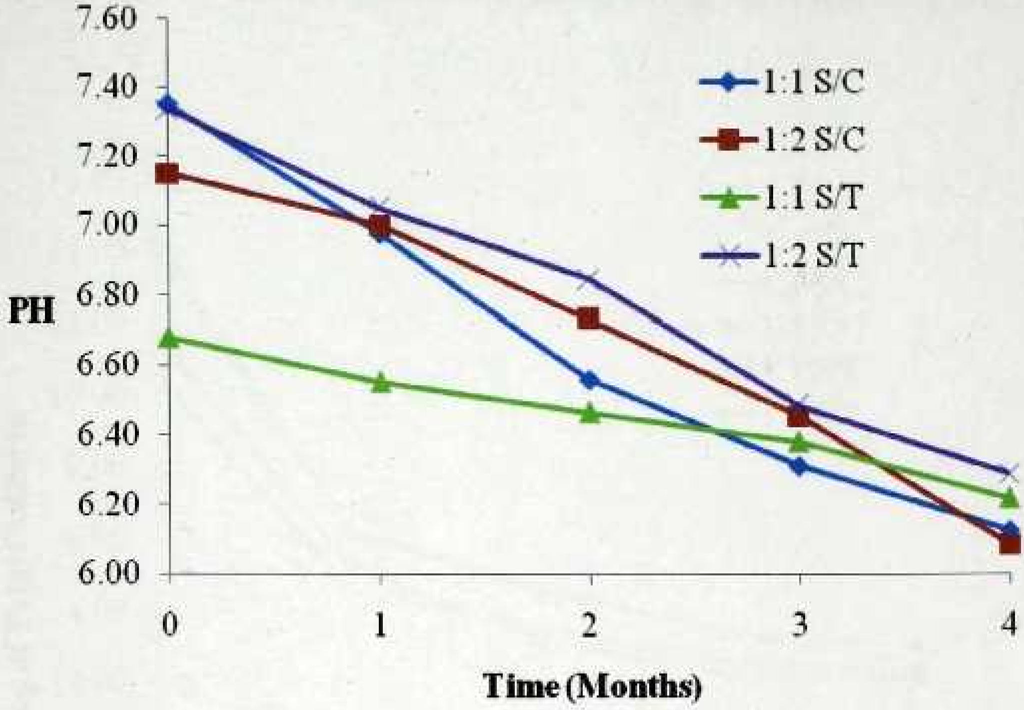


**Figure 4.12 Mean Monthly pH of the Various Compost Heaps**

## 4.9 TOTAL COLIFORMS, FAECAL COLIFORMS AND SALMONELLA

The levels of total coliforms, faecal coliforms and salmonella are represented by figure 4.13, 4.14 and 4.15 respectively. Their levels significantly reduced over the four month period. The log of total coliforms reduced from 14.01 to 2.92, and 11.64 to 2.06 for heaps 1:1 and 1:2 of sludge and cedrela. Also the log of total coliforms sludge and teak heaps reduced from 14.47 to 2.50 and 10.63 to 2.27 respectively.

The log of faecal coliforms reduced from the initial of 11.77 for 1.1 sludge/cedrela and 9.94 for 1:2 sludge/cedrela to 1.13 and 1.06 at the end of the composting process. Also that of sludge and teak heaps reduced from the initial of 11.48 for 1:1 and 9.37 for 1:2 to 0.82 and 0.98 at the end of the composting process. The log of samonella reduced from the initial of 11.21 for 1.1 sludge/cedrela and 9.36 for 1:2 sludge/cedrela to 0.65 and 0.39 whilst that of sludge and teak heaps reduced from the initial of 10.87

for 1:1 and 8.84 for 1:2 to 0.39 and 0.30 at the end of the composting process (Fig. 15).

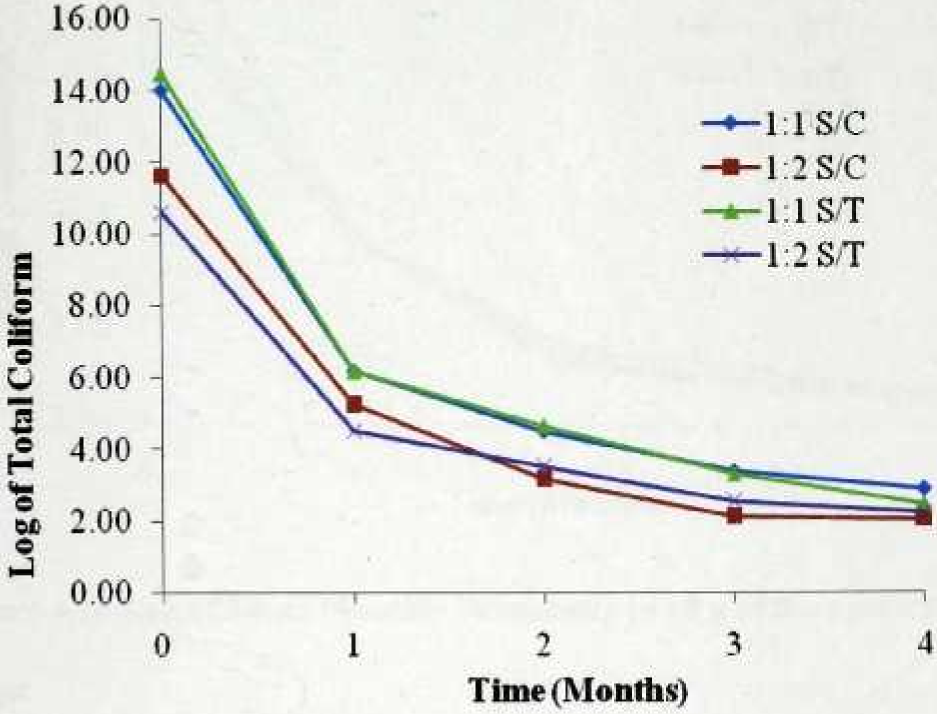


**Figure 4.13 Log of Mean Monthly Total Coliform in 10 g of the various compost heaps**

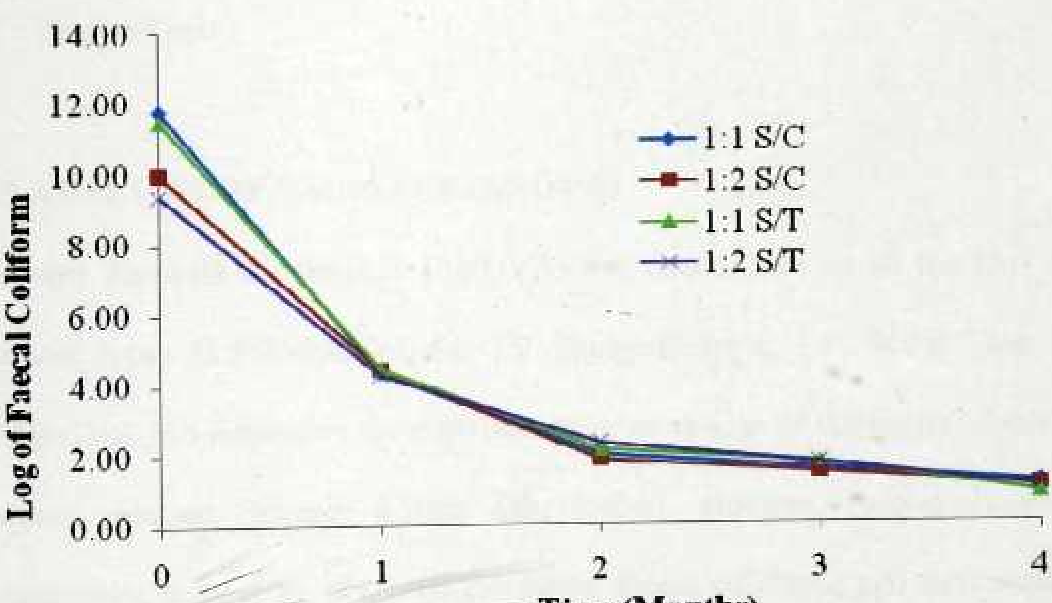


**Figure 4.14 Log of Mean Monthly Faecal Coliform in 10 g of the various compost heaps**

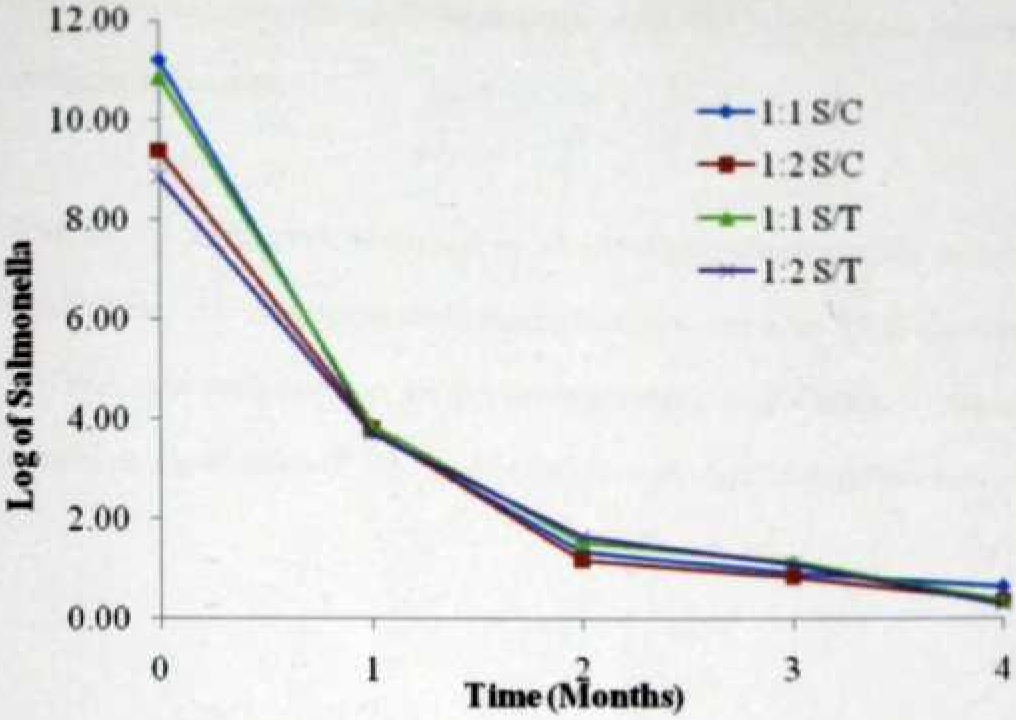


**Figure 4.15 Log of Mean Monthly Salmonella in 10 g of the various compost heaps**

**Key**

S/C : Sludge/Cedrela

S/T : Sludge/Teak

## 4.10 ANALYSIS OF VARIANCE (ANOVA)

One way Analysis of Variance (ANOVA) was carried out for all the four different compost types (1:1Sludge/Cedrela, 1:2 Sludge/Cedrela, 1:1 Sludge/Teak and 1:2 Sludge/Teak,) to determine the significance or otherwise of the levels of total solids, moisture content, organic matter, ash, carbon, nitrogen, carbon-nitrogen ratio, phosphorous, potassium, pH, total coliforms, faecal coliforms and salmonella in the final composts produced. There was significant difference in the level of the parameters in the ratio 1:1 sludge/Cedrela ($P < 0.05$) with the exception of potassium which showed no significant difference ($P > 0.05$). The trend was the same for the 1:2 sludge cedrela heaps.

With the 1:1 sludge/teak, phosphorous showed no significance while the rest showed significance. All parameters showed significance in the heap 1:2 sludge/Teak. When ANOVA was performed on all the compost heaps, only Carbon – Nitrogen Ratio showed no significance ($P > 0.05$). The rest showed significant difference

**Table 4.1: Analysis of Lettuce Grown with Different Organic Fertilizer**

| Treatment | Mean fresh weight per lettuce (g) | Mean dried weight per 100g of Lettuce | Geomean total coliforms (MPN/100g) | Geomean faecal coliforms (MPN/1g) | Geomean Salmonella (MPN/1g) |
|---|---|---|---|---|---|
| 1:1, S/C | 81.13 | 7.63 | 32750 | 450 | 40 |
| 1:2, S/C | 81.55 | 7.20 | 24525 | 260 | 25 |
| 1:1, S/T | 74.18 | 6.95 | 41000 | 420 | 56 |
| 1:2, S/T | 72.50 | 6.90 | 29500 | 290 | 30 |
| Uncomposted Dried Sludge | 87.10 | 8.17 | 33500 | 950 | 120 |
| No Treatment | 10.84 | 5.23 | 21500 | 130 | 22 |

**Table 4.2 Values of parameters measured on the various ratio mixes of Sawdust and dewatered sewage sludge at the end of the composting process**

| Parameters | Ratio of raw materials and parameters | | | |
|---|---|---|---|---|
| | 1:1 S/C | 1:2 S/C | 1:1 S/T | 1:2 S/T |
| pH | 6.13 | 6.09 | 6.22 | 6.29 |
| Moisture Content (%) | 37.26 | 36.21 | 20.91 | 25.57 |
| Total Solids (%) | 62.75 | 63.80 | 79.10 | 74.44 |
| Organic Matter (%) | 55.61 | 58.20 | 56.91 | 60.47 |
| Ash Content (%) | 44.40 | 41.80 | 43.09 | 39.53 |
| Nitrogen (%) | 1.35 | 1.15 | 1.36 | 1.14 |
| Carbon (%) | 28.84 | 30.16 | 29.50 | 31.32 |
| Carbon/Nitrogen Ratio | 21.36 | 26.34 | 21.75 | 27.38 |
| Phosphorous (%) | 0.26 | 0.21 | 0.25 | 0.21 |
| Potassium (%) | 0.15 | 0.17 | 0.15 | 0.15 |
| Total Coliforms (MPN) | 840 | 115 | 320 | 190 |
| Feacal Coliform (MPN) | 14 | 11.5 | 12 | 10.5 |
| Salmonella | 4.5 | 3 | 3 | 2 |

# CHAPTER FIVE

# DISCUSSION

## 5.1 TEMPERATURE

The different compost heaps showed a temperature-time relationship typical for composting of organic materials. The relationships were similar to those reported by Eghball *et al* (1997) for open-windrow composting of feed lot manure in Nebraska. The main mode of pathogen destruction was based on the temperature-time relationship (Epstein 1997). The temperature-time relationship for all the heaps showed the three distinct stages of composting. There was an initial rise in temperature from 29°C to about 35°C (Mesophilic stage) which was experienced in all the heaps. This was followed by a temperature rise to above 45 °C in both the sludge/cedrela and sludge/teak heaps. The 1:1 Sludge/cedrela reached a high of 49.10 °C while 1:2 sludge/cedrela reached 49.75 °C. Also 1:1 sludge/Teak reached a high of 49.5 °C while 1:2 sludge/Teak reached 49.92 °C. Regular turning and watering of heaps resulted in slight temperature falls. The turning provided the opportunity for most of the ammonia and phenols to be released into the air and bacterial population can resume growth (Liao *et al.*, 1994). The secondary peaks in temperature after, was as a result of the recommencement of the activities of microbes. The depletion of food sources after the highest temperatures had been attained led to the decrease in microbial activities, resulting in temperature fall in a second mesophilic phase. The fall in temperature continued until it went below the ambient temperature of 30°C.

## 5.2 COMPOST VOLUME

The volumes of the heaps kept decreasing throughout the composting period (Fig. 4.2). The reduction was great such that at the end of the process about 50% of the various heaps was left. This was in accordance with Dao (1999) observation when he composted manure and lost volume by more than 50%. During the first thirty (30) days, the rate of volume reduction was highest. As the more decomposable organic materials were used up, the rate kept reducing as the heaps were left with the more resistant organic materials which take a lot of time to decompose.

For the sludge/cedrela heaps, it was discovered that the heap with ratio 1:2 significantly reduced in volume, than that of 1:1 ratio. However, for the sludge/teak heaps, it was observed that the heap with ratio 1:1 significantly reduced in volume, than that of 1:2 sludge/teak. This could be due to the fact that the final reduction in moisture content of the ratio 1:1 was higher than that of 1:2 (Figure 4.4). That is at the end of the period, sludge/teak 1:2 had higher final moisture content (25.57%) than the 1:1 sludge/teak (20.91%).

## 5.3 MOISTURE CONTENT AND TOTAL SOLIDS OF COMPOST

There was a gradual reduction in the moisture content in all the various compost heaps throughout the composting period. A study done by Finstein *et al* (1986) found that, heat is generated in the heap during composting of organic matter. This heat according to Finstein *et al* (1986) is enough to vapourise moisture from the heaps and as temperature increases, more heat is lost. For sludge/Cedrela, the heap with ratio 1:2 was much reduced followed by 1:1. This could be attributed to moisture loss through evaporation, as temperature was slightly highest in 1:2 followed by 1:1. However, for sludge/Teak heaps, the heap with 1:1 was much reduced followed by 1:2. The mean difference in the moisture content in all the final compost produced was statistically significant ($p \leq 0.05$, Appendix E). The monthly reduction in moisture content for each heap group was also statistically significant ($P \leq 0.05$). This could be due to water being utilized by the living organisms present in the compost. Richard *et al* (2002) indicated that, water provides a medium for the transportation of dissolved nutrients required for metabolic and physiological activities of organisms.

The amounts of moisture in the heaps were seen to be inversely proportional to the total solid contents of the heaps. That is, the total solid content increased with the loss of moisture from the heaps. The mean total solid content in the final composts produced was statistically highly significant ($p = 0.000$, Appendix E). The monthly increases were also very significant. Micro-organisms and evaporation contributed to moisture lost.

## 5.4 ORGANIC MATTER AND ASH CONTENT OF COMPOST

It was realised throughout the composting period that, the organic matter content in the various heaps kept on decreasing (Fig. 4.5). This was as a result of the decomposition and transformation of the organic matter into stable humic compounds (Amir *et al.*, 2004). This according to Epstein (1997), improve soil physical properties, increase soil buffer capacity, add plant nutrients to the soil, increase soil water holding capacity and support and enhance microbial population. At any particular period, the magnitude of organic matter decomposition is associated with the temperature at which decomposition takes place and the chemical composition of the organic substrate undergoing composting (Levi-Minzi *et al.*, 1990).

Within ten (10) days of composting, the various heaps reached their highest temperatures. For sludge/cedrela 1:1 and 1:2 heaps the highest temperatures reached were 49.1°C and 49.8°C on the sixth and fifth days respectively. Sludge/teak 1:1 and 1:2 heaps on the other hand reached their highest temperatures of 49.5°C and 49.9°C on the sixth day. The temperatures fluctuated above 40°C for about forty-days. The decomposition of organic matter was also found to be highest at those temperatures. After the highest temperatures had been reached, the decomposition rates started decreasing. The reduction was as a result of the opposition of the remaining carbon compounds to the microorganisms. Palm and Sanchez (1991) stated that, the higher the lignin and poly-phenolic content of organic materials, the lower the decomposition rate. Organic matter decomposition rate was found to be almost the same in all the heaps, denoting that the different ratios of sawdust to sludge were low. It could not show any significant difference in their respective final compost. The ash content was seen to increase in all the different compost heaps during the entire composting period (Fig. 4.6). The difference in ash levels in all the compost produced was statistically significant.

## 5.5 CARBON, NITROGEN AND CARBON-NITROGEN RATIO

Throughout the entire composting period, the total organic carbon content decreased gradually (Figure 4.7). The presence of carbon and Nitrogen affected the process of organic matter decomposition. High content of lignin and cellulose present in the sawdust caused the gradual decrease in the total organic carbon content. According to Huang *et al*, 2004, lignin and cellulose have the ability to influence the degree of organic carbon loss during the decomposition process. The monthly decrease of organic carbon in all the heaps was statistically highly significant ($p \leq 0.005$). These decreases in organic carbon concentration were as a result of the oxidation of carbon to carbon dioxide by microorganisms (Tiquia *et al*., 1996). The microbial cells get energy from carbon.

The levels of Nitrogen in all the heaps gradually reduced during the composting process (Figure 4.8). This could be due to the fact that the bacteria in the heaps utilised inorganic nitrogen in the composting process. Nitrogen is used for protein synthesis (Willson, 1989). The nitrogen levels in the 1:1 ratios of both the sludge/cedrela and sludge/teak heaps were higher than their corresponding 1:2 ratios. This could be due to the fact that the sludge content in the 1:1 ratios was higher and as nitrogen is higher in sludge (Gotaas, 1956), hence that outcome. It could also be due to the conversion of nitrogen to organic nitrogen (N) being mineralised by microbial activity during the decomposition process. There was rapid conversion of the more reactive organic nitrogen which resulted in the reduction in the rate of mineralisation process. This left the most resistant organic nitrogen in the nitrogen pool which takes a lot of time to mineralise (Iglesias-Jimenez and Alvarez, 1993). The volatilisation of gaseous ammonia during the mixing and turning of the compost heaps could have additionally led to loss of nitrogen. Eghball *et al* (1997), reported that 9 to 68% of nitrogen was lost during the composting of cattle manure.

There was a significant difference ($P \leq 0.005$) in the nitrogen concentration in the respective mixtures before composting. The content of nitrogen in the 1:1 ratio was higher than that in the 1:2 ratio in both the sludge/cedrela and sludge/teak composts. This was realised both at the beginning and end of the composting period. This could be due to the fact that the content of sludge in the 1:1 ratio is higher than that of the

1:2 ratio as C/N in sludge is lower than that of sawdust. That is the nitrogen content of sludge is higher than that of sawdust.

In general, there was a decrease in the carbon-nitrogen ratio in all the heaps. In the Sludge/Cedrela heaps, the heap with the ratio 1:2 was significantly reduced (31.20 to 26.34) followed by the 1:1 (24.73 to 21.36). For Sludge/Teak heaps, the heap with ratio 1:2 was much reduced (31.04 to 27.38) followed by the 1:1 ratio (24.75 to 21.75). There was a negative correlation between temperature and carbon-nitrogen ratio during composting. This shows that for mineralization to be effective, large temperature increase is essential. This will in turn lead to reduced carbon-nitrogen ratio, depicting why carbon-nitrogen ratio got reduced considerably in the 1:2, followed by 1:1 in all the various compost heaps.

## 5.6 PHOSPHOROUS AND POTASSIUM CONTENTS IN THE COMPOSTS

Throughout the composting period, the phosphorous and potassium levels in the heaps were low and kept decreasing (Fig 4.10 and 4.11). The initial levels of phosphorous in the 1:1 ratios for both sludge/cedrela and sludge/teak mixes were higher than that of the level in the 1:2 ratios. Stryer (1975) stated that for efficient composting, phosphorous is utilised in the energy transfer process of cells and potassium helping to regulate the osmotic pressure of cells. For both phosphorous and potassium, the differences were statistically significant. An FAO report (1975) in China states that due to the low level of phosphorous in night soil compost, phosphate fertilizers are added before composting. This is done to improve the phosphorous content of the finished compost.

## 5.7 HYDROGEN ION CONCENTRATION (pH)

In general, the pH decreases as organic acids are produced in composting (Chen and Inbar, 1993). PH is relevant because microbial activities depend on it and it is an important parameter that can control nitrogen losses from ammonia volatilisation (Qiao and Ho, 1997). Due to the high buffer capacity of the sewage sludge components, the rate of decrease is small. At the end of the composting process, the pH was 6.13 and 6.09 for 1:1 and 1:2 sludge/Cedrela heaps and 6.22 and 6.29 for 1:1 and 1:2 sludge/Teak heaps. These pH values were within the optimum pH range for bacteria and fungi activities, Amir *et. al.* (2005) measured a pH of 6.2 in the final compost of activated sludge.

## 5.8 COLIFORMS IN COMPOST

Microbial parameters such as total coliforms, faecal coliforms and salmonella decreased significantly at the end of the composting process. Of all the three microbial parameters that were measured, salmonella was the most reduced with total coliforms been the least reduced. The coliforms were all reduced below the standard of less than 3.00 Log 10 MPN/g set by the Canadian Council of Ministers (1996) as a result of the high temperatures reached. This is the A class standard for the application of compost to agricultural lands.

The total coliform, faecal coliform and salmonella of all the two ratios for both sludge/cedrela and sludge/teak, the 1:2 ratio had the least levels of coliforms at the end of the process. These trends could be due to the temperature differences of the two ratios as 1:2 had the highest recorded temperature. The only exception occurred in the faecal coliforms of sludge/teak where the 1:1 ratio had the least levels of faecal coliforms compared with the 1:2 ratio. USEPA (1999) stated that a temperature higher than 40 °C for 5 days was sufficient enough to reduce pathogens. The lack of nutrients which is normally caused by high population of indigenous microorganisms in manure composts can lead to the reduction of coliforms. Also the production of compounds detrimental to coliforms might have also played a role in the decline of pathogens during composting (Himathongham *et al*., 1999)

## 5.9 COLIFORMS ON LETTUCE

The various composts and dried non-composted sewage sludge were used to cultivate lettuce on various beds. Though the land was virgin, it was close to an already cultivated land. The results depicted levels of total coliforms and faecal coliforms that were higher than their levels in the composts that were applied. This realisation is believed to be as a result of the continous use of contaminated water for watering the lettuce. The water therefore could have contributed to the high levels of the coliforms on the lettuce. The high levels could also be due to splashes of rain from the already cultivated site which could contaminate the lettuce. Gagliardi and Kans (2000) showed that, when *E-coli* reached soil through manure contamination or surface run-off from a point source, it could survive, replicate for up to two months. This then threatens non-target environments.

Of all the treatments that were applied, the non-composted sewage sludge exhibited higher levels of faecal coliforms and salmonella. The bed to which no treatment was applied showed low levels of both faecal coliforms and salmonella concentration compared with the other bed that was cultivated with finished composts and dried non-composted sewage sludge. This was explained by Handelsman and Stabb (1996) when they found that mature compost contain natural organic chemicals and beneficial microorganisms that destroy or inhibit disease causing organisms.

## 5.10 YIELD OF LETTUCE GROWN WITH THE DIFFERENT COMPOST

The yield (fresh weight) of lettuce cultivated with dried non-composted sewage sludge was highest compared with the various composts. This could be due to the high temperatures attained in the various heaps during the composting process. These temperatures resulted in the inactivation of pathogens, hence the loss of some nutrients. The nutrients are lost as they are utilised by the micro-organisms for their metabolic and physiological activities. Nitrogen was utilised for the synthesis of protein (Obeng and Wright, 1987) and Carbon was oxidised to Carbon dioxide (Tiquia *et al*., 1996).

The mean dry weights of lettuce fertilised with 1:1 composts were heavier compared to those fertilised with 1:2 composts. For sludge/cedrela, the mean dry weights of lettuce fertilised with 1:1 and 1:2 composts were 7.63 g and 7.20 g while that of cedrela/teak composts were 6.95 g and 6.90 g for 1:1 and 1:2 composts. These could be attributed to the temperature differences between the 1:1 and the 1:2 heaps. The 1:2 heaps achieved higher temperatures (49.75 °C and 49.92 °C) than their corresponding 1:1 heaps (49.10 °C and 49.10 °C). Though the temperature differences between the 1:1 and the 1:2 ratios were small, it could be deduced that the higher the heat produced in the process, the higher the loss of nutrients from the compost. On the other hand the lettuce from the dried non-composted sewage sludge had the highest level of pathogens on them. The control experiment where no treatment was applied showed abysmal yield. Confirming this is the low levels of nutrients seen during the soil nutrient test. The lettuce yield and soil nutrient status test before the cultivation showed that the yields in lettuces were as a result of the treatments that were applied to the soils.

## CHAPTER SIX

# CONCLUSION AND RECOMMENDATION

### 6.1 CONCLUSION

- Composting is an effective means of reducing concentrations of pathogens in sewage sludge and sawdust. The temperatures achieved reduced both pathogens and beneficial microbes in compost.
- The study established that there was no significant difference in the quality of compost produced from the different ratios of sludge/cedrela and sludge/teak mixes.
- The corresponding ratios of the two compost types showed no significant difference.
- It is seen that whether hard wood or soft wood, the compost quality has insignificant difference.
- Nitrogen, phosphorous and potassium levels in the various composts were found to be very low.
- The study established that the reduction of pathogens in sewage sludge is very potent when it is co-composted with sawdust.
- Sewage sludge application in lettuce cultivation resulted in high yield (87.1 g fresh weight and 8.17 g dry weight).
- The levels of pathogens infection on lettuce fertilised with sewage sludge were high when compared with their corresponding levels on lettuce fertilised with composts from the sludge/cedrela and sludge/teak mixes.

- Co-composting of dewatered sewage sludge and sawdust from two wood species for Agricultural use as an organic fertilizer can help prevent or curtail the occurrence of diseases caused by the pathogens otherwise present in sun dried sewage sludge.
- From observations of the final volumes of the various compost heaps, it can be concluded that co-composting of sawdust with sludge helped to reduce the initial volumes of 0.4 $m^3$ of the two raw materials input.

## 6.2 RECOMMENDATIONS

- At the end of the research there was no significant difference in the quality of compost produced with the two different ratios of sludge/cedrela sawdust and sludge/teak sawdust. It is therefore recommended that further work be done using different ratios alongside 1:1 and 1:2 ratios for observation and comparison.
- Natural water devoid of coliform organisms should be used to water vegetables grown with compost to establish whether there would be coliforms re-infection.

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**Appendix A: One Way ANOVA for 1:1 Sludge Cedrela Compost with Composting Period**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| MC | Between Groups | 1242.99 | 4 | 310.748 | 42.902 | 0 |
| | Within Groups | 36.216 | 5 | 7.243 | | |
| | Total | 1279.21 | 9 | | | |
| TS | Between Groups | 1242.99 | 4 | 310.748 | 42.902 | 0 |
| | Within Groups | 36.216 | 5 | 7.243 | | |
| | Total | 1279.21 | 9 | | | |
| OM | Between Groups | 424.009 | 4 | 106.002 | 36.624 | 0.001 |
| | Within Groups | 14.472 | 5 | 2.894 | | |
| | Total | 438.48 | 9 | | | |
| Ash | Between Groups | 424.009 | 4 | 106.002 | 36.624 | 0.001 |
| | Within Groups | 14.472 | 5 | 2.894 | | |
| | Total | 438.48 | 9 | | | |
| C | Between Groups | 110.285 | 4 | 27.571 | 36.624 | 0.001 |
| | Within Groups | 3.764 | 5 | 0.753 | | |
| | Total | 114.049 | 9 | | | |
| N | Between Groups | 0.046 | 4 | 0.011 | 60.473 | 0 |
| | Within Groups | 0.001 | 5 | 0 | | |
| | Total | 0.047 | 9 | | | |
| CN | Between Groups | 15.297 | 4 | 3.824 | 13.651 | 0.007 |
| | Within Groups | 1.401 | 5 | 0.28 | | |
| | Total | 16.698 | 9 | | | |
| P | Between Groups | 0.064 | 4 | 0.016 | 9.347 | 0.015 |
| | Within Groups | 0.009 | 5 | 0.002 | | |
| | Total | 0.073 | 9 | | | |
| K | Between Groups | 0.008 | 4 | 0.002 | 4.945 | 0.055 |
| | Within Groups | 0.002 | 5 | 0 | | |
| | Total | 0.01 | 9 | | | |
| pH | Between Groups | 1.985 | 4 | 0.496 | 16.909 | 0.004 |
| | Within Groups | 0.147 | 5 | 0.029 | | |
| | Total | 2.132 | 9 | | | |
| TC | Between Groups | 164.13 | 4 | 41.032 | 188.821 | 0 |
| | Within Groups | 1.087 | 5 | 0.217 | | |
| | Total | 165.216 | 9 | | | |
| FC | Between Groups | 157.814 | 4 | 39.454 | 85.482 | 0 |
| | Within Groups | 2.308 | 5 | 0.462 | | |
| | Total | 160.122 | 9 | | | |
| Sal | Between Groups | 157.436 | 4 | 39.359 | 83.55 | 0 |
| | Within Groups | 2.355 | 5 | 0.471 | | |
| | Total | 159.792 | 9 | | | |

**Appendix B: One Way ANOVA for 1:2 Sludge Cedrela Ratio Compost with Composting Period**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| MC | Between Groups | 1142.185 | 4 | 285.546 | 47.575 | 0 |
| | Within Groups | 30.01 | 5 | 6.002 | | |
| | Total | 1172.195 | 9 | | | |
| TS | Between Groups | 1142.207 | 4 | 285.552 | 47.576 | 0 |
| | Within Groups | 30.01 | 5 | 6.002 | | |
| | Total | 1172.217 | 9 | | | |
| OM | Between Groups | 605.512 | 4 | 151.378 | 336.03 | 0 |
| | Within Groups | 2.252 | 5 | 0.45 | | |
| | Total | 607.764 | 9 | | | |
| Ash | Between Groups | 605.535 | 4 | 151.384 | 336.091 | 0 |
| | Within Groups | 2.252 | 5 | 0.45 | | |
| | Total | 607.787 | 9 | | | |
| C | Between Groups | 157.477 | 4 | 39.369 | 339.83 | 0 |
| | Within Groups | 0.579 | 5 | 0.116 | | |
| | Total | 158.057 | 9 | | | |
| N | Between Groups | 0.043 | 4 | 0.011 | 19.629 | 0.003 |
| | Within Groups | 0.003 | 5 | 0.001 | | |
| | Total | 0.046 | 9 | | | |
| CN | Between Groups | 28.534 | 4 | 7.133 | 18.183 | 0.004 |
| | Within Groups | 1.962 | 5 | 0.392 | | |
| | Total | 30.495 | 9 | | | |
| P | Between Groups | 0.042 | 4 | 0.011 | 9.463 | 0.015 |
| | Within Groups | 0.006 | 5 | 0.001 | | |
| | Total | 0.048 | 9 | | | |
| K | Between Groups | 0.008 | 4 | 0.002 | 1.203 | 0.412 |
| | Within Groups | 0.008 | 5 | 0.002 | | |
| | Total | 0.016 | 9 | | | |
| pH | Between Groups | 1.464 | 4 | 0.366 | 8.082 | 0.021 |
| | Within Groups | 0.227 | 5 | 0.045 | | |
| | Total | 1.691 | 9 | | | |
| TC | Between Groups | 128.336 | 4 | 32.084 | 9.28E+03 | 0 |
| | Within Groups | 0.017 | 5 | 0.003 | | |
| | Total | 128.354 | 9 | | | |
| FC | Between Groups | 110.614 | 4 | 27.653 | 84.156 | 0 |
| | Within Groups | 1.643 | 5 | 0.329 | | |
| | Total | 112.257 | 9 | | | |
| Sal | Between Groups | 111.956 | 4 | 27.989 | 69.767 | 0 |
| | Within Groups | 2.006 | 5 | 0.401 | | |
| | Total | 113.962 | 9 | | | |

## Appendix C: One Way ANOVA for 1:1 Sludge Teak with Composting Period

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| MC | Between Groups | 2331.344 | 4 | 582.836 | 80.036 | 0 |
| | Within Groups | 36.411 | 5 | 7.282 | | |
| | Total | 2367.755 | 9 | | | |
| TS | Between Groups | 2331.412 | 4 | 582.853 | 80.038 | 0 |
| | Within Groups | 36.411 | 5 | 7.282 | | |
| | Total | 2367.823 | 9 | | | |
| OM | Between Groups | 398.908 | 4 | 99.727 | 20.616 | 0.003 |
| | Within Groups | 24.187 | 5 | 4.837 | | |
| | Total | 423.095 | 9 | | | |
| Ash | Between Groups | 398.923 | 4 | 99.731 | 20.616 | 0.003 |
| | Within Groups | 24.187 | 5 | 4.837 | | |
| | Total | 423.11 | 9 | | | |
| C | Between Groups | 103.75 | 4 | 25.938 | 20.59 | 0.003 |
| | Within Groups | 6.299 | 5 | 1.26 | | |
| | Total | 110.049 | 9 | | | |
| N | Between Groups | 0.065 | 4 | 0.016 | 56.443 | 0 |
| | Within Groups | 0.001 | 5 | 0 | | |
| | Total | 0.066 | 9 | | | |
| CN | Between Groups | 9.258 | 4 | 2.315 | 7.07 | 0.027 |
| | Within Groups | 1.637 | 5 | 0.327 | | |
| | Total | 10.895 | 9 | | | |
| P | Between Groups | 0.041 | 4 | 0.01 | 1.829 | 0.261 |
| | Within Groups | 0.028 | 5 | 0.006 | | |
| | Total | 0.068 | 9 | | | |
| K | Between Groups | 0.007 | 4 | 0.002 | 23.48 | 0.002 |
| | Within Groups | 0 | 5 | 0 | | |
| | Total | 0.007 | 9 | | | |
| pH | Between Groups | 0.241 | 4 | 0.06 | 28.208 | 0.001 |
| | Within Groups | 0.011 | 5 | 0.002 | | |
| | Total | 0.252 | 9 | | | |
| TC | Between Groups | 185.003 | 4 | 46.251 | 79.873 | 0 |
| | Within Groups | 2.895 | 5 | 0.579 | | |
| | Total | 187.898 | 9 | | | |
| FC | Between Groups | 149.852 | 4 | 37.463 | 184.284 | 0 |
| | Within Groups | 1.016 | 5 | 0.203 | | |
| | Total | 150.869 | 9 | | | |
| Sal | Between Groups | 146.591 | 4 | 36.648 | 214.367 | 0 |
| | Within Groups | 0.855 | 5 | 0.171 | | |
| | Total | 147.446 | 9 | | | |

**Appendix D: One Way ANOVA for 1:2 Sludge Teak with Composting Period**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| MC | Between Groups | 2129.061 | 4 | 532.265 | 78.285 | 0 |
| | Within Groups | 33.996 | 5 | 6.799 | | |
| | Total | 2163.057 | 9 | | | |
| TS | Between Groups | 2129.061 | 4 | 532.265 | 78.285 | 0 |
| | Within Groups | 33.996 | 5 | 6.799 | | |
| | Total | 2163.057 | 9 | | | |
| OM | Between Groups | 598.553 | 4 | 149.638 | 69.258 | 0 |
| | Within Groups | 10.803 | 5 | 2.161 | | |
| | Total | 609.356 | 9 | | | |
| Ash | Between Groups | 598.553 | 4 | 149.638 | 69.258 | 0 |
| | Within Groups | 10.803 | 5 | 2.161 | | |
| | Total | 609.356 | 9 | | | |
| C | Between Groups | 155.684 | 4 | 38.921 | 69.258 | 0 |
| | Within Groups | 2.81 | 5 | 0.562 | | |
| | Total | 158.494 | 9 | | | |
| N | Between Groups | 0.071 | 4 | 0.018 | 77.164 | 0 |
| | Within Groups | 0.001 | 5 | 0 | | |
| | Total | 0.073 | 9 | | | |
| CN | Between Groups | 14.409 | 4 | 3.602 | 18.796 | 0.003 |
| | Within Groups | 0.958 | 5 | 0.192 | | |
| | Total | 15.367 | 9 | | | |
| P | Between Groups | 0.031 | 4 | 0.008 | 93.203 | 0 |
| | Within Groups | 0 | 5 | 0 | | |
| | Total | 0.031 | 9 | | | |
| K | Between Groups | 0.005 | 4 | 0.001 | 13.887 | 0.006 |
| | Within Groups | 0 | 5 | 0 | | |
| | Total | 0.006 | 9 | | | |
| pH | Between Groups | 1.421 | 4 | 0.355 | 27.683 | 0.001 |
| | Within Groups | 0.064 | 5 | 0.013 | | |
| | Total | 1.485 | 9 | | | |
| TC | Between Groups | 93.916 | 4 | 23.479 | 52.75 | 0 |
| | Within Groups | 2.225 | 5 | 0.445 | | |
| | Total | 96.141 | 9 | | | |
| FC | Between Groups | 91.961 | 4 | 22.99 | 367.78 | 0 |
| | Within Groups | 0.313 | 5 | 0.063 | | |
| | Total | 92.273 | 9 | | | |
| Sal | Between Groups | 94.368 | 4 | 23.592 | 262.56 | 0 |
| | Within Groups | 0.449 | 5 | 0.09 | | |
| | Total | 94.817 | 9 | | | |

**Appendix E: One Way ANOVA for the Different Compost Ratios**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| MC | Between Groups | 6575.084 | 4 | 1643.771 | 91.911 | |
| | Within Groups | 625.955 | 35 | 17.884 | | |
| | Total | 7201.039 | 39 | | | 0 |
| TS | Between Groups | 6575.084 | 4 | 1643.771 | 91.911 | |
| | Within Groups | 625.955 | 35 | 17.884 | | |
| | Total | 7201.039 | 39 | | | 0 |
| OM | Between Groups | 1994.87 | 4 | 498.718 | 46.59 | |
| | Within Groups | 374.651 | 35 | 10.704 | | |
| | Total | 2369.521 | 39 | | | 0 |
| Ash | Between Groups | 1994.87 | 4 | 498.718 | 46.59 | |
| | Within Groups | 374.651 | 35 | 10.704 | | |
| | Total | 2369.521 | 39 | | | 0 |
| C | Between Groups | 518.866 | 4 | 129.716 | 46.59 | |
| | Within Groups | 97.447 | 35 | 2.784 | | |
| | Total | 616.312 | 39 | | | 0 |
| N | Between Groups | 0.219 | 4 | 0.055 | 3.85 | |
| | Within Groups | 0.499 | 35 | 0.014 | | |
| | Total | 0.718 | 39 | | | 0.011 |
| CN | Between Groups | 62.597 | 4 | 15.649 | 1.44 | |
| | Within Groups | 380.484 | 35 | 10.871 | | |
| | Total | 443.081 | 39 | | | 0.242 |
| P | Between Groups | 0.167 | 4 | 0.042 | 16.44 | |
| | Within Groups | 0.089 | 35 | 0.003 | | |
| | Total | 0.256 | 39 | | | 0 |
| K | Between Groups | 0.027 | 4 | 0.007 | 14.811 | |
| | Within Groups | 0.016 | 35 | 0 | | |
| | Total | 0.042 | 39 | | | 0 |
| pH | Between Groups | 4.546 | 4 | 1.137 | 24.506 | |
| | Within Groups | 1.623 | 35 | 0.046 | | |
| | Total | 6.17 | 39 | | | 0 |
| TC | Between Groups | 561.617 | 4 | 140.404 | 132.823 | |
| | Within Groups | 36.998 | 35 | 1.057 | | |
| | Total | 598.615 | 39 | | | 0 |
| FC | Between Groups | 503.237 | 4 | 125.809 | 315.599 | |
| | Within Groups | 13.952 | 35 | 0.399 | | |
| | Total | 517.19 | 39 | | | 0 |
| Sal | Between Groups | 504.014 | 4 | 126.004 | 312.852 | |
| | Within Groups | 14.097 | 35 | 0.403 | | |
| | Total | 518.111 | 39 | | | 0 |

**Appendix F: Weekly Volume Readings ($m^3$) of the Difference Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 0.4000 | 0.4000 | 0.4000 | 0.4000 | 0.400 | 0.4000 | 0.4000 | 0.4000 | 0.4000 | 0.4000 | 0.4000 | 0.4000 |
| 1 | 0.3870 | 0.3870 | 0.3870 | 0.3718 | 0.3750 | 0.3734 | 0.3758 | 0.3756 | 0.3757 | 0.3747 | 0.3685 | 0.3716 |
| 2 | 0.3539 | 0.3756 | 0.3647 | 0.3475 | 0.3495 | 0.3485 | 0.3489 | 0.3697 | 0.3593 | 0.3547 | 0.3466 | 0.3506 |
| 3 | 0.3294 | 0.3473 | 0.3384 | 0.3384 | 0.3390 | 0.3387 | 0.3331 | 0.3515 | 0.3423 | 0.3370 | 0.3376 | 0.3373 |
| 4 | 0.3199 | 0.3355 | 0.3277 | 0.3240 | 0.3287 | 0.3263 | 0.3205 | 0.3346 | 0.3276 | 0.3349 | 0.3208 | 0.3278 |
| 5 | 0.3053 | 0.3321 | 0.3187 | 0.3226 | 0.3246 | 0.3236 | 0.3093 | 0.3222 | 0.3158 | 0.3311 | 0.3040 | 0.3176 |
| 6 | 0.2964 | 0.3209 | 0.3086 | 0.3213 | 0.3111 | 0.3162 | 0.3038 | 0.3209 | 0.3123 | 0.3173 | 0.2975 | 0.3074 |
| 7 | 0.2951 | 0.3165 | 0.3058 | 0.3067 | 0.3098 | 0.3082 | 0.2957 | 0.3196 | 0.3077 | 0.3146 | 0.2962 | 0.3054 |
| 8 | 0.2835 | 0.3022 | 0.2928 | 0.2983 | 0.3040 | 0.3012 | 0.2806 | 0.3144 | 0.2975 | 0.3106 | 0.2856 | 0.2981 |
| 9 | 0.2746 | 0.2876 | 0.2811 | 0.2957 | 0.2988 | 0.2973 | 0.2769 | 0.2943 | 0.2856 | 0.3027 | 0.2789 | 0.2908 |
| 10 | 0.2722 | 0.2795 | 0.2758 | 0.2823 | 0.2886 | 0.2854 | 0.2679 | 0.2893 | 0.2786 | 0.2876 | 0.2691 | 0.2784 |
| 11 | 0.2656 | 0.2739 | 0.2697 | 0.2603 | 0.2819 | 0.2711 | 0.2603 | 0.2639 | 0.2621 | 0.2814 | 0.2691 | 0.2753 |
| 12 | 0.2579 | 0.2488 | 0.2533 | 0.2421 | 0.2574 | 0.2498 | 0.2557 | 0.2450 | 0.2503 | 0.2639 | 0.2545 | 0.2592 |
| 13 | 0.2480 | 0.2309 | 0.2395 | 0.2360 | 0.2540 | 0.2450 | 0.2460 | 0.2312 | 0.2386 | 0.2603 | 0.2522 | 0.2563 |
| 14 | 0.2360 | 0.2238 | 0.2299 | 0.2284 | 0.2381 | 0.2333 | 0.2410 | 0.2219 | 0.2314 | 0.2568 | 0.2437 | 0.2503 |
| 15 | 0.2218 | 0.2179 | 0.2198 | 0.2173 | 0.2138 | 0.2156 | 0.2228 | 0.2179 | 0.2203 | 0.2505 | 0.2338 | 0.2422 |
| 16 | 0.2079 | 0.2060 | 0.2070 | 0.2030 | 0.2090 | 0.2060 | 0.2156 | 0.2041 | 0.2099 | 0.2341 | 0.2086 | 0.2214 |

**Appendix G: Mean Monthly Total Solids Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 31.59 | 35.61 | 33.60 | 35.596 | 35.29 | 35.44 | 37.03 | 33.452 | 35.24 | 31.25 | 33.89 | 32.57 |
| 1 | 36.63 | 36.63 | 36.63 | 35.29 | 37.1 | 36.20 | 44.55 | 38.61 | 41.58 | 39.60 | 42.00 | 40.80 |
| 2 | 47.57 | 43.14 | 45.36 | 45.54 | 42.16 | 43.85 | 49.02 | 46.53 | 47.78 | 45.71 | 43.69 | 44.70 |
| 3 | 56.86 | 55.45 | 56.16 | 54.9 | 50.2 | 52.55 | 57.43 | 56.44 | 56.94 | 56.86 | 57.43 | 57.15 |
| 4 | 59.8 | 65.69 | 62.75 | 61.39 | 66.2 | 63.80 | 81.19 | 77 | 79.10 | 78.00 | 70.87 | 74.44 |

**Appendix H: Mean Monthly Organic Matter Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 74.82 | 73.16 | 73.99 | 81.38 | 80.82 | 81.10 | 75.31 | 76.06 | 75.69 | 83.20 | 82.60 | 82.90 |
| 1 | 69.57 | 67.80 | 68.69 | 74.86 | 73.44 | 74.15 | 67.85 | 71.67 | 69.76 | 76.50 | 73.23 | 74.87 |
| 2 | 62.27 | 63.70 | 62.99 | 70.74 | 69.67 | 70.21 | 64.78 | 70.23 | 67.51 | 71.79 | 71.71 | 71.75 |
| 3 | 58.02 | 61.29 | 59.66 | 65.67 | 64.67 | 65.17 | 62.21 | 64.01 | 63.11 | 66.83 | 63.97 | 65.40 |
| 4 | 54.00 | 57.21 | 55.61 | 58.30 | 58.10 | 58.20 | 57.17 | 56.65 | 56.91 | 61.24 | 59.70 | 60.47 |

## Appendix I: Mean Monthly Moisture Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 68.41 | 64.39 | 66.40 | 64.40 | 64.71 | 64.56 | 62.97 | 66.55 | 64.76 | 68.75 | 66.11 | 67.43 |
| 1 | 63.37 | 63.37 | 63.37 | 64.71 | 62.90 | 63.81 | 55.45 | 61.39 | 58.42 | 60.40 | 58.00 | 59.20 |
| 2 | 52.43 | 56.86 | 54.65 | 54.46 | 57.84 | 56.15 | 50.98 | 53.47 | 52.23 | 54.29 | 56.31 | 55.30 |
| 3 | 43.14 | 44.55 | 43.85 | 45.10 | 49.80 | 47.45 | 42.57 | 43.56 | 43.07 | 43.14 | 42.57 | 42.86 |
| 4 | 40.20 | 34.31 | 37.26 | 38.61 | 33.80 | 36.21 | 18.81 | 23.00 | 20.91 | 22.00 | 29.13 | 25.57 |

**Appendix J: Mean Monthly Ash Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 25.18 | 26.84 | 26.01 | 18.62 | 19.18 | 18.90 | 24.69 | 23.94 | 24.31 | 16.80 | 17.40 | 17.10 |
| 1 | 30.43 | 32.20 | 31.32 | 25.14 | 26.56 | 25.85 | 32.15 | 28.33 | 30.24 | 23.50 | 26.77 | 25.14 |
| 2 | 37.73 | 36.30 | 37.02 | 29.26 | 30.33 | 29.80 | 35.22 | 29.77 | 32.50 | 28.21 | 28.29 | 28.25 |
| 3 | 41.98 | 38.71 | 40.35 | 34.33 | 35.33 | 34.83 | 37.79 | 35.99 | 36.89 | 33.17 | 36.03 | 34.60 |
| 4 | 46.00 | 42.79 | 44.40 | 41.70 | 41.90 | 41.80 | 42.83 | 43.35 | 43.09 | 38.76 | 40.30 | 39.53 |

**Appendix K: Mean Monthly Carbon Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 38.64 | 37.79 | 38.22 | 41.98 | 41.70 | 41.84 | 38.89 | 39.27 | 39.08 | 42.91 | 42.61 | 42.76 |
| 1 | 35.96 | 35.06 | 35.51 | 38.66 | 37.93 | 38.30 | 35.08 | 37.03 | 36.06 | 39.50 | 37.83 | 38.66 |
| 2 | 32.24 | 32.97 | 32.60 | 36.56 | 36.01 | 36.28 | 33.52 | 36.30 | 34.91 | 37.09 | 37.05 | 37.07 |
| 3 | 30.07 | 31.74 | 30.90 | 33.97 | 33.46 | 33.72 | 32.21 | 33.13 | 32.67 | 34.56 | 33.10 | 33.83 |
| 4 | 28.02 | 29.66 | 28.84 | 30.21 | 30.11 | 30.16 | 29.64 | 29.37 | 29.50 | 31.71 | 30.93 | 31.32 |

**Appendix L: Mean Monthly Nitrogen Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 1.56 | 1.53 | 1.55 | 1.36 | 1.32 | 1.34 | 1.56 | 1.60 | 1.58 | 1.37 | 1.38 | 1.38 |
| 1 | 1.50 | 1.51 | 1.50 | 1.25 | 1.29 | 1.27 | 1.53 | 1.55 | 1.54 | 1.32 | 1.31 | 1.31 |
| 2 | 1.45 | 1.45 | 1.45 | 1.22 | 1.24 | 1.23 | 1.49 | 1.53 | 1.51 | 1.27 | 1.29 | 1.28 |
| 3 | 1.42 | 1.42 | 1.42 | 1.21 | 1.18 | 1.20 | 1.43 | 1.43 | 1.43 | 1.20 | 1.18 | 1.19 |
| 4 | 1.34 | 1.36 | 1.35 | 1.16 | 1.13 | 1.15 | 1.35 | 1.36 | 1.36 | 1.16 | 1.13 | 1.14 |

**Appendix M: Mean Monthly Carbon - Nitrogen Ratio of the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 24.78 | 24.67 | 24.73 | 30.79 | 31.62 | 31.20 | 24.89 | 24.61 | 24.75 | 31.28 | 30.80 | 31.04 |
| 1 | 24.05 | 23.19 | 23.62 | 30.89 | 29.52 | 30.20 | 22.91 | 23.92 | 23.41 | 29.88 | 28.93 | 29.41 |
| 2 | 22.27 | 22.69 | 22.48 | 29.88 | 28.97 | 29.42 | 22.50 | 23.79 | 23.14 | 29.24 | 28.83 | 29.04 |
| 3 | 21.18 | 22.31 | 21.75 | 28.02 | 28.25 | 28.14 | 22.60 | 23.24 | 22.92 | 28.84 | 28.08 | 28.46 |
| 4 | 20.98 | 21.75 | 21.36 | 26.00 | 26.68 | 26.34 | 21.91 | 21.58 | 21.75 | 27.29 | 27.48 | 27.38 |

**Appendix N: Mean Monthly Phosphorous Content (%) in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 0.43 | 0.55 | 0.49 | 0.44 | 0.35 | 0.39 | 0.38 | 0.47 | 0.42 | 0.35 | 0.38 | 0.36 |
| 1 | 0.41 | 0.40 | 0.40 | 0.37 | 0.34 | 0.36 | 0.36 | 0.46 | 0.41 | 0.34 | 0.35 | 0.34 |
| 2 | 0.33 | 0.35 | 0.34 | 0.30 | 0.33 | 0.31 | 0.31 | 0.46 | 0.38 | 0.28 | 0.28 | 0.28 |
| 3 | 0.30 | 0.30 | 0.30 | 0.25 | 0.28 | 0.26 | 0.27 | 0.40 | 0.34 | 0.25 | 0.26 | 0.26 |
| 4 | 0.27 | 0.25 | 0.26 | 0.21 | 0.22 | 0.21 | 0.24 | 0.25 | 0.25 | 0.22 | 0.21 | 0.21 |

**Appendix O: Mean Monthly PH in the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 7.50 | 7.20 | 7.35 | 7.05 | 7.25 | 7.15 | 6.67 | 6.69 | 6.68 | 7.31 | 7.36 | 7.34 |
| 1 | 7.06 | 6.90 | 6.98 | 6.81 | 7.20 | 7.01 | 6.51 | 6.60 | 6.56 | 7.02 | 7.09 | 7.06 |
| 2 | 6.62 | 6.51 | 6.57 | 6.68 | 6.80 | 6.74 | 6.45 | 6.49 | 6.47 | 6.98 | 6.73 | 6.86 |
| 3 | 6.23 | 6.40 | 6.32 | 6.42 | 6.50 | 6.46 | 6.42 | 6.35 | 6.39 | 6.60 | 6.38 | 6.49 |
| 4 | 5.94 | 6.31 | 6.13 | 6.33 | 5.84 | 6.09 | 6.26 | 6.18 | 6.22 | 6.34 | 6.24 | 6.29 |

**Appendix P: Log of Mean Monthly Total Coliform in 10 g of the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 14.74 | 13.28 | 14.01 | 11.61 | 11.66 | 11.64 | 15.65 | 13.28 | 14.47 | 11.67 | 9.58 | 10.63 |
| 1 | 6.15 | 6.23 | 6.19 | 5.34 | 5.18 | 5.26 | 6.18 | 6.20 | 6.19 | 4.62 | 4.47 | 4.55 |
| 2 | 4.52 | 4.55 | 4.53 | 3.22 | 3.17 | 3.20 | 4.55 | 4.81 | 4.68 | 3.52 | 3.56 | 3.54 |
| 3 | 3.52 | 3.38 | 3.45 | 2.14 | 2.12 | 2.13 | 3.20 | 3.48 | 3.34 | 2.51 | 2.62 | 2.57 |
| 4 | 2.97 | 2.88 | 2.92 | 2.04 | 2.08 | 2.06 | 2.46 | 2.54 | 2.50 | 2.18 | 2.36 | 2.27 |

**Appendix Q: Log of Mean Monthly Fecal Coliform in 10g of the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 10.71 | 12.82 | 11.77 | 9.04 | 10.85 | 9.94 | 11.00 | 11.95 | 11.48 | 9.26 | 9.48 | 9.37 |
| 1 | 4.34 | 4.30 | 4.32 | 4.30 | 4.48 | 4.39 | 4.36 | 4.49 | 4.43 | 4.45 | 4.08 | 4.26 |
| 2 | 2.08 | 1.79 | 1.94 | 1.79 | 1.78 | 1.79 | 2.10 | 2.08 | 2.09 | 2.41 | 2.13 | 2.27 |
| 3 | 1.58 | 1.48 | 1.53 | 1.41 | 1.41 | 1.41 | 1.81 | 1.66 | 1.73 | 1.45 | 1.90 | 1.67 |
| 4 | 1.26 | 1.00 | 1.13 | 1.08 | 1.04 | 1.06 | 0.30 | 1.34 | 0.82 | 1.18 | 0.78 | 0.98 |

**Appendix R: Log of Mean Monthly Salmonela in 10 g of the Different Compost Heaps of Sludge/Cedrela and Sludge/Teak**

| Time | Sludge/Cedrela Heap (Ratio) | | | | | | Sludge/Teak Heap (Ratio) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (Months) | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean | 1:1, a | 1:1, b | Mean | 1:2, a | 1:2, b | Mean |
| 0 | 10.15 | 12.28 | 11.21 | 8.46 | 10.30 | 9.38 | 10.36 | 11.38 | 10.87 | 8.72 | 8.95 | 8.84 |
| 1 | 3.81 | 3.72 | 3.77 | 3.72 | 3.88 | 3.80 | 3.81 | 3.97 | 3.89 | 3.92 | 3.51 | 3.71 |
| 2 | 1.53 | 1.20 | 1.37 | 1.23 | 1.18 | 1.20 | 1.57 | 1.54 | 1.56 | 1.86 | 1.48 | 1.67 |
| 3 | 1.04 | 0.85 | 0.94 | 0.85 | 0.85 | 0.85 | 1.28 | 1.08 | 1.18 | 0.90 | 1.30 | 1.10 |
| 4 | 0.70 | 0.60 | 0.65 | 0.78 | 0.00 | 0.39 | 0.00 | 0.78 | 0.39 | 0.60 | 0.00 | 0.30 |

**Appendix S: Characteristics of the Different Compost of Sludge/Cedrela, Sludge/Teak and Dried Noncomposted**

**Sewage Sludge Applied on the Soil for the Cultivation of Lettuce**

| Material | pH | MC (%) | TS (%) | OM (%) | Ash (%) | N (%) | C (%) | C/N | P (%) | K (%) | TC (MPN) | FC (MPN) | Sal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sludge/Cedrela 1:1, a | 5.94 | 40.20 | 59.80 | 54.00 | 46.00 | 1.34 | 28.02 | 20.98 | 0.27 | 0.16 | 9.30E+02 | 18 | 5 |
| Sludge/Cedrela 1:1, b | 6.31 | 34.31 | 65.69 | 57.21 | 42.79 | 1.36 | 29.66 | 21.75 | 0.25 | 0.15 | 7.50E+02 | 10 | 4 |
| **Mean** | **6.13** | **37.26** | **62.75** | **55.61** | **44.40** | **1.35** | **28.84** | **21.36** | **0.26** | **0.15** | **8.40E+02** | **14** | **4.5** |
| Sludge/Cedrela 1:2, a | 6.33 | 38.61 | 61.39 | 58.30 | 41.70 | 1.16 | 30.21 | 26.00 | 0.21 | 0.16 | 1.10E+02 | 12 | 6 |
| Sludge/Cedrela 1:2, b | 5.84 | 33.80 | 66.20 | 58.10 | 41.90 | 1.13 | 30.11 | 26.68 | 0.22 | 0.17 | 1.20E+02 | 11 | 0 |
| **Mean** | **6.09** | **36.21** | **63.80** | **58.20** | **41.80** | **1.15** | **30.16** | **26.34** | **0.21** | **0.17** | **1.15E+02** | **11.5** | **3** |
| Sludge/Teak 1:1, a | 6.26 | 18.81 | 81.19 | 57.17 | 42.83 | 1.35 | 29.64 | 21.91 | 0.24 | 0.15 | 2.90E+02 | 2 | 0 |
| Sludge/Teak 1:1, b | 6.18 | 23.00 | 77.00 | 56.65 | 43.35 | 1.36 | 29.37 | 21.58 | 0.25 | 0.15 | 3.50E+02 | 22 | 6 |
| **Mean** | **6.22** | **20.91** | **79.10** | **56.91** | **43.09** | **1.36** | **29.50** | **21.75** | **0.25** | **0.15** | **3.20E+02** | **12** | **3** |
| Sludge/Teak 1:2, a | 6.34 | 22.00 | 78.00 | 61.24 | 38.76 | 1.16 | 31.71 | 27.29 | 0.22 | 0.14 | 1.50E+02 | 15 | 4 |
| Sludge/Teak 1:2, b | 6.24 | 29.13 | 70.87 | 59.70 | 40.30 | 1.13 | 30.93 | 27.48 | 0.21 | 0.16 | 2.30E+02 | 6 | 0 |
| **Mean** | **6.29** | **25.57** | **74.44** | **60.47** | **39.53** | **1.14** | **31.32** | **27.38** | **0.21** | **0.15** | **1.90E+02** | **10.5** | **2** |
| Soil | **6.83** | **12.74** | **87.26** | **2.90** | **97.10** | **0.23** | **1.96** | **8.56** | **0.74** | **0.46** | **1.30E+05** | **45** | **10** |
| Dried Noncomposted sludge | **4.96** | **45.63** | **54.37** | **39.29** | **60.71** | **2.07** | **20.52** | **9.90** | **3.65** | **0.75** | **2.18E+10** | **6.40E+07** | **9.30E+06** |