KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, COLLEGE OF SCIENCE, FACULTY OF BIOSCIENCES

Co-composting of dewatered sewage sludge (BIOSOLIDS) and sawdust for agricultural use as an organic fertilizer:A case study of the KNUST sewage treatment plant on February, 2009.

BY:

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CO-COMPOSTING OF DEWATERED SEWAGE SLUDGE (BIOSOLIDS) AND SAWDUST FORVAGRICULTURAL USE AS AN ORGANIC FERTILIZER:

A CASE STUDY OF THE KNUST SEWAGE TREATMENT PLANT

BY:

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A thesis submitted to the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, in partial fulfilment of the requirement for the award of the Degree of Master of Science on February, 2009.

FALCULTY OF BIOSCIENCE, COLLEG OF SCIENCES

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DECLARATION

I hereby declare that this submission is my work towards the Msc. Environmental Science and that to the best of my knowledge, it contains no material already published by another person nor materials which has been accepted for the award of any other degree in the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The objective of the study was to determine the best mix ratio of dewatered sewage sludge and sawdust in co-composting, to stabilizing the former and also managing the latter. Three different ratios (1:1, 1:1.5 and 1:2) of the dewatered sewage sludge to sawdust based on their carbon-nitrogen ratio and moisture content were composted for 120 days at the KNUST Sewage Treatment Plant. The compost heaps were turned over every three days for the first month and once a week afterwards to enhance aeration. Temperature was daily monitored at 20 cm and 30 cm depths of the heaps. The rate of decomposition was also assessed weekly by determining the rate of reduction of the compost heaps. Other parameters such as moisture content, dry solids, organic matter, ash, carbon, nitrogen, carbon-nitrogen ratio, phosphorus, potassium, pH, helminth eggs, total and faecal coliforms were determined monthly.

The results showed a significant difference in the monthly levels of all the parameters listed above in each heap. There was no significant difference in the quality of the final compost produced from each heap, in terms of most of the listed parameters. Microbial parameters such as total and fecal Coliforms and helminth eggs decreased appreciably at the end of the composting process. The compost heaps with the ratios 1:1.5 and 1:2 reduced more than the heap with ratio 1:1 of sewage sludge and sawdust. Twenty eight cubic centimeters (28cm) of the different composts produced and dewatered dried sewage sludge were (set up as control) applied on different ten square meter beds to cultivate lettuce. Yield of lettuce, helminth eggs, total and faecal coliform organisms levels were determined upon harvesting. Yield was highest in lettuce cultivated with dewatered dried sewage sludge, followed by the compost with the formulation 1:1, 1:1.5 and lastly 1:2. Helminth eggs, total and faecal coliform levels on lettuce were higher than their levels in their respective compost and the dewatered dried sewage sludge.

There was no significant difference in the quality of compost produced from sludge/sawdust of the various ratios (1:1, 1:1.5 or 1:2).

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1.0 INTRODUCTION

Farmers and gardeners for many centuries have practiced composting in diverse ways. Sewage sludge, vegetable matter, animal manure, refuse, yard trimmings and other such materials, were placed in piles or pits located in some convenient places and allowed to decompose as conditions would permit. The material was used when it was ready for the soil or the farmer was ready to apply it to the land. This process involved little or no control, required long periods for the piles to produce good humus, might or might not conserve maximum nitrogen, and did not provide maximum sanitary safety.

Sewage sludge, also known as biosolids, is nutrient-rich organic matter produced during conventional treatment of sewage. The main available disposal methods that have been widely applied are composting, sanitary land filling and incineration. Landfill has the potential for groundwater contamination through leaching. It is often difficult to find suitable, stable locations for landfills. Incineration can contribute to air pollution and therefore may require expensive treatment techniques to control emissions (Veeken and Hamelers, 1999). Compared to landfill and incineration, land composting is preferable since it produces both a useful and an ecologically compatible product (Hansen and Mancl, 1988).

Sewage sludge is rich in nutrient and trace elements and could be re-used in agriculture as fertilizer and soil conditioner at a minimum cost. High odour emission, high levels of heavy metals and toxic organic compounds and the presence of pathogenic microorganisms demand pretreatment of the sewage sludge before application in agriculture (Veeken and Hamelers, 1999). Over the last twenty years, sewage treatment technology significantly improved the ability to remove toxins and contaminants so that sewage sludge recovered from wastewater treatment plants is relatively clean (Linden *et al*., 1995). Not withstanding this, environmental specialist classified sewage sludge as a hazardous waste because of the high organic compounds concentration, presence of heavy metals and pathogenic microorganisms. It is believed that sewage sludge should be stabilized before disposal and that composting of sewage sludge is an effective and economical method to stabilize the sludge. In the United States, for example, in 1989 out of about 27 kg per person per year of sewage sludge produced, land application of sludge was about 33% of the total sludge produced. This practice includes application to agricultural and reclamation sites as compost.

Composting is a method of solid waste treatment by which the organic component of the solid waste stream is biologically decomposed under controlled conditions to a stable state which can be handled, stored, and/or applied to the land without adversely affecting the environment (Golueke, 1977). The process is used to stabilize wastewater sludge prior to their use as a soil amendment or mulch in landscaping, horticulture, and agriculture. Stabilization of sewage sludge prior to their use serves to destroy pathogens (disease causing organisms), minimize odour, and reduce vector attraction. Sewage sludge, because of its high moisture content, is usually composted with other materials such as sawdust which serve as a bulking agent and also improves porosity of the compost pile.

Co-composting is the term used to describe the digestion of a mixture of organic materials (such as sludge cake and green waste or sawdust) to provide a sustainable and cost effective disposal/re-use process for the co-composted material (Angelidaki and Ahring, 1997).

Compost is one of nature's best mulching and soil amendment materials. It can be used instead of commercial fertilizers. Best of all, compost is cheap because it can be produced at minimum cost. The use of compost improves soil structure, texture, and aeration capacity. It improves soil water-holding capacity (Martin and Gershuny, 1993). Compost loosens clay soils and helps sandy soils retain water by binding soil particles together. Adding compost to soil improves the fertility of the latter and stimulates healthy root development in plants. Nutrients in compost provide food for microorganisms, which keep the soil in balance healthy conditions. Nitrogen, potassium, and phosphorus are produced naturally by the activities of microorganisms. Compost also increases the soil content in compounds of agricultural value (such as Nitrogen, Sulpher, Magnesium and etc.), which are gradually released than in the case of mineral fertilizer and therefore available to crops for a longer period.

Vegetable farmers in Kumasi, especially, those farming around sewage treatment plants apply the dewatered dried sewage sludge directly to the soil for crop cultivation, having experienced the fertilizer value of the sludge. A survey conducted by the author showed that about 52% of vegetable farmers around the KNUST sewage treatment plant apply the sludge directly on their farm lands as a form of fertilizer or soil conditioner.

Problems associated with sewage sludge are the presence of toxic organics, and pathogens, such as bacteria and viruses (Linden *et al.*, 1995), especially when they are applied to grow vegetables that are eaten without cooking (eg. lettuce). Hence the need for this research which is aimed at reducing the level of pathogens that may contaminate vegetable crops for which sewage sludge may be used to grow through composting.

GENERAL OBJECTIVE

The study seeks to assess co-composting of dewatered sewage sludge and sawdust at different ratios to determine which of the combinations best improves nutrient status and reduces pathogen level for agricultural use as organic fertilizer.

Specific Objectives

1. To determine the nitrogen, phosphorus, potassium, organic matter, total coliform, faecal coliform and helminth egg concentrations of each co-compost mixture.
2. To determine the nitrogen, phosphorus, potassium, organic matter, total coliform, faecal coliform and helminth egg concentrations at different stages of composting in each compost type.
3. To quantify the yield of lettuce grown with the various compost types.
4. To determine the presence of total coliforms, faecal coliforms and helminth eggs on lettuce grown on soil to which the compost is applied.

2.0 LITERATURE REVIEW

2.1 Composting

Composting is a managed system that uses microbial activity to decompose 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 an effective available alternative to the handling and the disposal of organic wastes because it leads to stabilization, and utilization of organic waste.

2.2.0 Types of composting

There are three basic types of composting – anaerobic, aerobic, and vermi-composting.

2.2.1 Anaerobic composting

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

2.2.2 Vermi-Composting

Vermi-composting refers to the composting of organic material using red worms. These specialized worms thrive by devouring their weight in organic material daily. The material that passes through the worms' bodies is called "castings" and can contain five times more nitrogen, seven times more phosphorus and eleven times more potassium than ordinary soil. These worms require special care in order to work effectively. They work between temperatures of 16 °C and 25 °C, and are sensitive to light.

2.2.3 Aerobic composting

Aerobic composting is defined as the process in which, under suitable environmental conditions, facultative aerobic organisms, principally, thermophilic, utilize considerable amounts of oxygen in decomposing organic matter to fairly stable humus material (Gotaas, 1976). As the quickest way to produce high quality compost, aerobic composting is the widely accepted means of stabilizing organic wastes and converting them to a usable, and value added compost product. In this process, higher temperatures (above 60 ^{0}C) can be reached and both mesophilic and thermophilic micro-organisms are involved in the composting process. 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).

2.3 Composting processes

There are three general elements of a composting process

1. Pre-processing: this can include grinding or shredding and separation of solid inorganic waste. In case of co-composting, this pre-processing ends with the addition of sludge to other organic waste / material.
2. Composting: this is done by windrows, aerated static pile or in-vessel composting.
3. Post processing: this consists of grinding or sieving, de-stoning and other steps to prepare the compost for utilization and marketing (Epstein, 1997).

Some organic materials like sewage sludge, because of their nature (high moisture content, low carbon-nitrogen ratio, etc.) are usually composted with other organic materials (like sawdust) in co-composting.

2.4 Co-composting

Co-composting is a waste treatment method in which different types of waste are treated (composted) together (Angelidake and Ahring, 1997). Co-composting is an attractive and interesting example of integrated waste management method of resource recovery and waste disposal. Example is the composting of sawdust and sewage sludge, this kind of composting is advantageous because the two waste materials well complement each other. The sewage sludge is high in nitrogen content and moisture and the sawdust is high in organic (carbon) content and has good bulking quality. Further more, both of these waste materials can be converted into a useful product (Obeng and Wright, 1987). Proper mixing of the two ensures an optimum carbon-nitrogen ratio to enhance the biodegradation process.

2.5.0 Factors Affecting Composting

Compost maturity and stability are key factors during application of composting process. For achieving compost maturity, environmental factors such as temperature, moisture content, pH and aeration should be appropriately controlled (Epstein, 1997). Substrate nature parameters such as carbon-nitrogen ratio, particle size, and nutrient content are also important factors affecting compost quality (Golueke, 1977).

2.5.1 Temperature

The composting process can be divided into four major microbiologically important phases based on temperature (Figure 2.1). These phases may have considerable overlap based on temperature gradients and differential temperature effects on microorganisms.

These are

(i) the mesophilic phase; (ii) the thermophilic phase;

(iii) the cooling phase; and (iv) the maturation phase.

The composting process is initiated by the microbiological decomposition of organic material at the mesophilic temperature range. Upon active respiration, the temperature within the pile increases to a level which is prohibitive to mesophiles but suitable for thermophiles. This shift is also associated with a decrease in species diversity. The dominant bacteria of the thermophilic phase are spore formers (Bacillus spp.), thermophilic fungi have also been found (Strom, 1985a,). Since microbial activity in composting is influenced by temperature, several researchers have tried to define the optimal temperature for composting (McKinley and Vestal, 1984)

Generally, an elevated temperature (greater than 60 ^{o}C) is effective in the destruction of pathogens, but lead to increasingly rapid thermal inactivation of mesophilic microorganisms (Jenkins, 1994). 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). Again, in an experimental study of compost made from shredded paper and food scraps, Strom (1985a, 1985b) found that only few bacterial species remained active at temperatures above 60 °C; those that survived were predominantly Bacillus spp. (Table 2.1). Fungi were found only in the narrow temperature interval from 55 °C to 61 °C (Table 2.1).

The elevated temperature range is maintained by periodic turning (manual or mechanical) or the use of controlled air flow (Viel *et al*, 1987). After the rapidly degradable components are consumed, temperatures gradually fall during the "curing"(maturation) stage. At the end of this stage, the material is no longer self-heating, and the finished compost is ready for use.

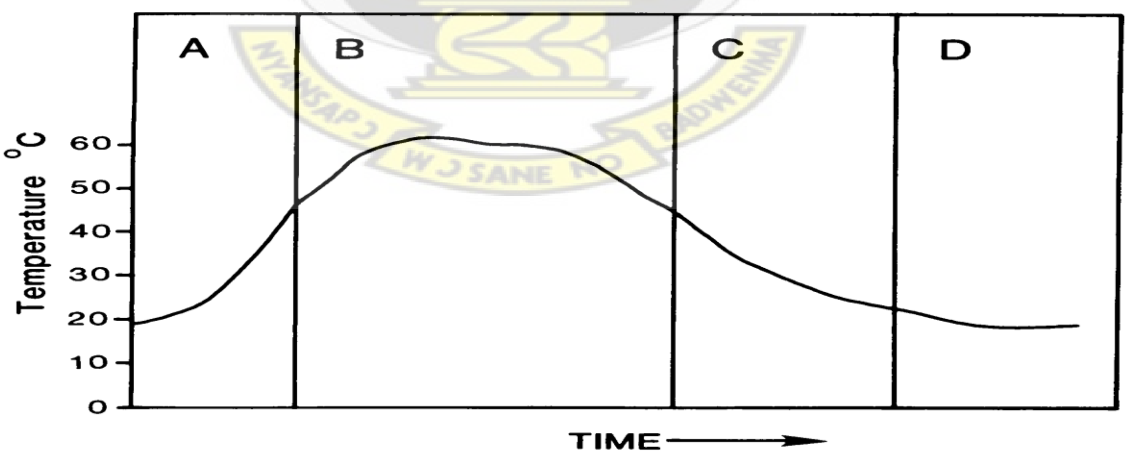


Figure 2.1. Temperature-dependent phases of composting. (A) Mesophilic phase; (B) thermophilic phase; (C) cooling phase; (D) maturation phase.

Source: Snell Environmental Group, Inc., 1982

Table 2. 1 Percentage distribution of microorganisms among groups

Relative distribution of microorganisms from solid waste material during laboratory composting at five different temperature range

Microbial Group	Temperature range				
	(49-55^{0}C)	(50-57^{0}C	(55-61^{0}C)	(60-65^{0}C)	(65-69^{0}C)
Fungi	-	-	17	-	-
Actinomycetes	12	2	+	-	-
Bacillus spp	23	77	78	100	83
Pseudomonas-type	17	21	-	-	-
Arthrobacter-type	47	+	+	-	-

Source: (Strom, 1985a, 1985b)

Symbols: +, present in small numbers: -, not found

2.5.2 Oxygen (Aeration)

Composting is primarily a biological oxidation of organic waste material of recent origin via microbial metabolism to a stabilized organic residue. Most of the organisms that decompose organic matter are aerobic - they need air to survive. The process is associated with the production of heat, microbial biomass, carbon dioxide and water. It is desired that the composting process be based on aerobic decomposition, and thus the availability of oxygen in the compost heap is of prime importance.

Functions of Aeration in composting are

(i) Support of aerobic metabolism

(ii) control of temperature; and

(iii) removal of moisture as well as carbon dioxide and other gases.

Insufficient aeration promotes the formation of anaerobic zones and the generation of foul odour (Brodie *et al*., 2000), whereas excessive aeration limits microbial activity as a result of the reduced moisture and associated cooling. According to De Bertoldi *et al*. (1982), the oxygen content in the circulating air should not fall below 18% in windrows, although there are few experimental data to support this value.

The principal aeration methods providing oxygen during composting are: physical turning of the mass, natural convection, and forced aeration. The optimal turning frequency however varies significantly depending on the type of initial composting material used (Tiquia *et al.*, 1996).

2.5.3 Moisture Content

Moisture content of the composting pile is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (Richard *et al*., 2002). Very low moisture content values would cause early dehydration during composting, which will arrest the biological process, thus giving physically stable but biologically unstable composts (Bertoldi *et al*., 1983). On the other hand, high moisture may create anaerobic conditions through water logging, which will prevent and halt the ongoing composting activities (Tiquia *et al*., 1996,)

Many investigators have conducted experiments and identify that 50–60% moisture content is suitable for efficient composting (Tiquia *et al*., 1998). The moisture content of compost varies depending on the porosity of the reactor feed, free air space, aeration, temperature, and other related physical factors. Moisture in this context is defined as weight loss after the sample has been dried to constant weight at 105 °C for 24 hours. Bacterial metabolic activity is severely inhibited when the moisture content drops below 40 %. If anaerobic composting is practiced, the maximum moisture content is not as important, since oxygen maintenance is not a factor. Also if the composting procedure has initial aerobic conditions to produce high temperatures lasting a few days for the destruction of pathogenic organisms, followed by anaerobic composting, the maximum initial moisture content may be as high as 65% to 85%, depending on the character of the composting materials.

2.5.4 pH

The optimal pH range for most biological reactions in composting is between 5.5 and 8.0 standard pH Units. Bacteria work best at near-neutral pH, whereas fungi favour an acidic pH range. At high pH, ammonia gas may be generated and this may cause adverse odour, microbial population decline, and poor quality compost product. The effects of extreme pH on the composting process are directly related to the effect of pH on microbial activity or, more specifically, on microbial enzymes. The pH-buffering capacity increases as a result of humus formation (Kikuchi, 2004).

2.5.5 Carbon-Nitrogen Ratio (C/N)

The process of decomposition of organic matter is affected by the presence of carbon and nitrogen. The carbon-nitrogen ratio represents the relative proportion of the two elements. The optimal carbon-nitrogen ratios for the microbiological decomposition of organic material in composting processes have been reported to be in the range of 20 to 40 (Rynk *et al*., 1992). In other words, the ingredients placed in the pile should contain 20 to 40 times as much carbon as nitrogen. In general, this range of carbon-nitrogen ratio is similar to that reported for agricultural soils. Night soil for instance, have an elemental carbon-nitrogen ratio of between six-ten (6-10), and raw sawdust have a ratio of 511 as shown in Table 2.2. If the C/N ratio is low, as is the case for night soil, the microbiological degradation leads to excess ammonia formation, which increases the pH and thereby enhances ammonia volatilization. Conversely, if the carbon-nitrogen ratio is too high, the process becomes nitrogen limited. Too much carbon will cause the pile to break down too slowly, while too much nitrogen can cause odour.

The carbon provides energy for the microbes and also combines with nitrogen in building cell protoplasm. Therefore, more carbon is needed then nitrogen. Besides limiting the growth and amount of biomass, nitrogen limitation may lead to extensive organic acid formation from carbonaceous waste, which would tend to lower the pH and thereby retard the microbial activity. The C/N ratio is not constant during composting because of the removal of carbon as carbon dioxide upon microbial respiration.

Table 2.2 Approximate Nitrogen and C/N ratios of some compostable material

Material (dry basis)	**N%**	**(C/N)**
Urine	15-18	0.8
Night soil	5.5-6.5	6-10
Rotted sawdust	0.25	208
Raw sawdust	0.11	511

Source: Gotaas, 1976.

2.5.6 Particle Size

Decomposition occurs primarily on or near the surfaces of particles, where oxygen diffusion into the aqueous films covering the particle is adequate for aerobic metabolism, and the substrate itself is readily accessible to microorganisms and their extracellular enzymes. Small particles have more surface area per unit mass or volume than large particles, so if aeration is adequate, small particles will degrade more quickly.

Particle size also affects the availability of carbon and nitrogen. Large wood chips, for example, provide a good bulking agent that helps to ensure aeration through the pile, but they provide less available carbon per mass than they would in the form of wood shavings or sawdust. The smaller the size of the organic refuse particle, the more quickly it can be consumed by the microbes.

2.6 Organisms in Composting

Compostable materials normally contain a large number of many different types of bacteria, fungi, molds, and other living organisms. Researches by Gotaas (1976) have indicated that no supplementary inoculum is needed in a compost pile. More species of bacteria are involved in aerobic decomposition than in anaerobic putrefaction. Aerobic composting is a dynamic process which combines the activities of a wide succession of mixed bacterial, actinomycetes, fungal, and other biological populations. Since each is suited to a particular environment of relatively limited duration and each is most active in decomposition of some particular type of organic matter, the activities of one group complement those of the other. Soil invertebrates such as termites, worms, ants, etc. also have been reported as colonizing compost pile and contributing to the decomposition process (Anderson, 1988).

Substantial changes occur in microbial populations and species abundance during the various temperature stages in composting (Gupta *et. al,*. 1987). Mesophilic bacteria and fungi are dominant in the initial warming period. Thermophilic bacteria (especially actinomycetes) become dominant during the high temperature phase, and mesophilic bacteria and fungi during the curing phase (Finstein and Mouris, 1975). The resulting compost has a high microbial diversity (Cole, 1994), with microbial populations much higher than fertile, productive soils and many times higher than in highly disturbed or contaminated soils as shown in Table 2.3.

Table 2. 3 Microbial Populations in Soil and Mature Yard Trimmings Compost Per gram of Material

Material	**Bacteria**	**Fungi**
Fertile soil	6 to 46	9 to 46
Recently reclaimed soil	19 to 170	8 to 97
Mixture of silt and clay	19	6
Mature compost	417	155

Source; Cole, 1976 (for reclaimed soil) a, Cole, unpublished data b, Cole, 1994 c, Cole, 1994 d.

2.7 Indicators of Compost Stability and Maturity

The understanding of organic matter transformation throughout the composting process and proper evaluation of compost stability and maturity are essential for successful utilization of composts. Stability refers to the level of biological activity of the compost and is dependent on the degree of degradation achieved during the composting process. Maturity refers to a lack of phytotoxicity when compost is used as a soil conditioner on vegetation (Hue and Liu, 1995). Immature compost, when applied to soils, maintains high decomposition activity, which may retard plant growth due to nitrogen starvation, anaerobic conditions and phytotoxicity of ammonia and some organic acids (Fang and Wong, 1999). Therefore, compost maturity and stability are key factors during application of composting process.

Generally, some of the underlisted parameters are used to determine compost maturity:

- physical parameters: temperature, odour, colour, particle size, water and air retention capacities (Garcia *et al*., 1992),
- chemical parameters: C/N ratio in solid and water phases, cation exchange capacities, elemental concentrations, organic matter level, water-soluble organic matter and humification indexes (Hsu and Lo, 1999),
- spectroscopic analysis: NMR, FTIR and fluorescence (Chen and Inbar, 1993),
- biochemical parameters: total and specific enzyme activity (Grebus *et al*,1994),
- microbiological parameters: oxygen and carbon dioxide (CO_2) respirometery, bioassay responses such as: germination index and plant growth bioassays (Grebus *et al*.,1994).

2.8 Compost Quality

Gotaas (1976) lists ranges of the main constituents in final composts as reported in reviewed publications Table 2.4. The quality varies widely and depends on the initial mixture of material to be composted.

Table 2.4 Ranges of Constituents in Finished Compost

Constituent	**Range (% of dry weight)**
Organic matter	25 – 50
Carbon	8 – 50
Nitrogen (as N)	0.4 – 3.5
Phosphorus (as P_2O_5)	0.3 – 3.5
Potassium (as k_2O)	0.5 – 1.8

Source: Gotaas, 1976.

2.9 Importance of Composting and Compost

The composting process and application of compost to agricultural and mined soils has many advantages discussed below:

2.9.1 Waste management option

Composting is used to stabilize wastewater solids prior to their use as a soil amendment or mulch in landscaping, horticulture, and agriculture, and helping keep organic wastes out of landfills. Stabilization of wastewater solids prior to their use serves to destroy pathogens (disease causing organisms), minimize odour, and reduce vector attraction potential.

2.9.2 Degradation of Pesticides and Heavy Metals

Composting degrades and, in some cases, completely eliminates wood preservatives, pesticides, and both chlorinated and non chlorinated hydrocarbons in contaminated soils. For example, in a survey conducted in Portland, a compost product was tested for 19 pesticides. Only 4 of the 19 pesticides were detected, and they were present at extremely low levels (Gurkewitz, 1989). With the exception of dicamba, MCPA, dichloroprop, and dinoseb, all of the tested pesticides were below the detection level of 0.5 ppm. The composting process has also been shown to bind heavy metals and prevent them from migrating to water sources or being absorbed by plants (Barker and Bryson, 2002).

2.9.3 Improvement of Soil Fertility and Characteristics

Applying compost increases soil fertility by adding nutrients such as nitrogen, phosphorus and potassium, thus substituting mineral fertilizers. It is important to understand that there is no fundamental difference in nutritional quality between organic and inorganic fertilizers. It makes no difference to the roots of plants, if the atoms of potassium it absorbs are from an organic fertilizer such as wood ash or an inorganic one such as muriate of potash. Furthermore, the addition of organic materials improved soil structure, increased water holding capacity and infiltration, increased workability and reduced erosion (Carter and Stewart, 1996).

2.9.4 Disease Control

Mature compost, in many cases, also contains natural organic chemicals and beneficial microorganisms that kill or suppress disease-causing microorganisms (Loper and Lindow, 1993). Several mechanisms of action for this phenomenon have been proposed (Hoitink, 1993), including,

- interspecific competition for nutrients
- production of chemicals with antimicrobial activity
- production of enzymes that destroy the cell walls of pathogens, and
- changes in the environmental conditions of the soil, which inhibit pathogen growth.

2.10 Differences between Organic and Inorganic Fertilizers

It is important to understand that there is no fundamental difference in nutritional quality between organic and inorganic fertilizers to a plant. Depending on the type of fertilizer one chooses, it is important to follow the guidelines regarding timing of application, placement of the fertilizer, and the proper amount of fertilizer to be used. Inorganic fertilizers, although they are immediately available to plants, they have three main disadvantages.

- They are subject to leaching, which occurs when the fertilizers are washed by rain or irrigation water down below the level of the plant roots. Nitrogen is particularly susceptible to leaching.
- A heavy application of chemical fertilizers can "burn" seedlings and young plants. This is actually a process of drying out, or desiccation, due to the presence of chemical salts within the commercial fertilizers.
- Thirdly, the overly heavy applications can build up toxic concentrations of salts in the soil and create chemical imbalances.

Organic fertilizers on the other hand, do more than providing organic nutrients. Other attributes of organic fertilizers are:

- It improves the soil structure and increases its ability to hold both water and nutrients.
- Again, microorganisms in the soil break down the organic material into inorganic soluble forms, a slow release of nutrients is provided over a longer period of time. This is probably a healthier situation for plant growth, in that an over supply of a nutrient such as nitrogen can lead to lush, succulent tissue growth which is more vulnerable to fungal and bacterial entry, more appealing to some insects, and more prone to stress injury from heat, cold, or drought.
- With organic fertilizers, a buildup of toxicity in the soil is unlikely as long as the amount of organic material incorporated into the soil is fully decomposed.
- Organic fertilizers are generally less expensive than the inorganic alternatives, and may be available free of charge or can be prepared at a minimum cost.

The problem with the organic fertilizer is when one just begun to rely on organic material as a nutrient source. The land may experience an initial nutrient deficiency until enough nutrients are released from decomposition, because crops needed initial high nutrients for growth which is not immediately available to the plants. It is important then to apply these organic fertilizers well before periods of rapid plant growth. If organic nutrients have been added to soils continually on an ongoing basis, this may not be a problem, since at a point in time, enough nutrients will be available for plants growth.

2.11 Characteristics of Sewage Sludge

All around the world, people in rural and urban areas have been using human excreta for centuries to fertilize fields and fishponds and to maintain or replenish the soil organic fraction, i.e. the humus layer. Until today, in both agriculture and aquaculture this continues to be common (Timmer and Visker, 1998; Strauss *et al.*, 2000). Reuse practices have led to a strong economic linkage between urban dwellers (food consumers as well as waste producers), and urban farmers (waste recyclers and food producers). Chinese peri-urban vegetable farmers have reported that customers prefer excreta-fertilized vegetables rather than chemically fertilized ones. Thus vegetables grown on excreta-conditioned soils yield higher sales prices.

2.11.1 Nutrient Status of Sewage Sludge

Table 2.6 summarizes the approximate composition of the main nutrients in sewage sludge. Other trace nutrients are calcium, magnesium, sulfur, and sodium, boron, manganese, copper, molybdenum, and zinc (Linden *et al.*, 1995). The substantial nitrogen (N) and phosphorus (P) concentrations in sludge are a useful fertilizer material and its organic constituents give it beneficial soil conditioning properties. Sludge application on land improves the nutrient status, organic matter content, and water-holding capacity of the soil (Pietz *et al.,* 1989*).*

The organic matter in sludge is a key component to its success as an amendment material. In general, it has been shown that the addition of sludge to agricultural land increases crop production. Dowdy *et al.* (1978) reported that the increase of crop yield by sludge application often exceed that of well-managed fertilized controls.

Table 2.5 Approximate Nutrient Composition of Sewage Sludge

Parameter	Percentage (Dry basis)
Organic matter	88-97
Phosphorus	3.0-5.4
Nitrogen	5.0-7.0
Potassium	1.0-2.5
Carbon	40-55
Calcium (as CaO)	4-5

Source: Gotaas, 1976

2.11.2 Pathogens in Sewage Sludge

Sewage sludge contains many different pathogens. The US Environmental Protection Agency classified sewage sludge as Class A or B. B sludges have received treatment to reduce, but not to eliminate pathogens. Class A sludges have been treated with one or more of the following: changes of pH, UV radiation, chemical treatment, drying, storage for a long time, heat, etc. (Feachem *et al*., 1983), with a goal of eliminating pathogens. Table 2.7 and 2.8 list the average number of pathogens expected to be found in a gram of fresh sewage sludge and their survival periods respectively.

Table 2.6 Average Amounts of Selected Pathogens to be expected in a Tropical Sewage Sludge

Pathogen		Average number of organisms per g of sewage sludge
Viruses	Enteroviruses	10^6
Bacteria	Pathogenic E. coli	10^8
	Salmonella spp.	10^6
	Vibrio cholerae	10^6
Protozoa	Entamoeba histloytica	15×10^4
Helminth	Ascaris lumbricoides	10^4
	Hookworm	800
	Schistosomia mansoni	40
	Taenia saginata	10^4
	Trichuris trichiura	2×10^3

Source: Feachem *et al.*, 1983

Table 2.7 Pathogen Survival Periods in Faecal Sludge

Average Survival Time in Wet Faecal Sludge at Ambient Temperature

Organism	In temperate climate (10-15 °C) (Days)	In tropical climate (20-30 °C) (Days)
Viruses	< 100	< 20
Bacteria:		
-Salmonella	< 100	< 30
-Cholera	<30	< 5
-Faecal coliforms	<150	< 50
Protozoa:		
-Amoebic cysts	< 30	< 15
• Helminths:		
-Ascaris eggs	2-3 years	10-12 months
-Tapeworm eggs	12 months	6 months

Sources: Feachem *et al*., 1983 and Strauss, 1985.

2.11.3 Heavy metals and Toxic Organics in Sewage Sludge

Problems associated with sewage sludge are the presence of trace elements, toxic organics, and pathogens, such as bacteria and viruses (Linden *et al*,. 1995). The quality and contaminant status of sewage sludge will depend upon both the source of sludge and the method of treatment. Sludges derived predominantly from residential areas contain fewer heavy metals and other contaminants than those from industrial areas. Pretreatments at wastewater plants can often minimize these contaminants. Over the last twenty years, sewage treatment technology significantly improved the ability to remove toxins and contaminants so that sewage sludge recovered from wastewater treatment plants is relatively clean (Linden *et al*., 1995). Again, focus on the improvement of the composting process to minimize the mobility of heavy metals using various additives is also receiving more attention (Chiang *et al*., 2001).

2.12 Sawdust

Wood residues constitute a significant source of soilless growing media. These materials are generally bi-products of the lumber industry and are 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 media (Wilkerson, 1989). Several sawdust, such as walnut and non-composted redwoods, are known to have direct phytotoxic effects. However, the carbon-nitrogen ratio of sawdust is such that it is not readily decomposed. The high cellulose and lignin content, couple with insufficient nitrogen supply creates depletion problems which can severely restrict plant growth.

2.13 Coliforms as Indicator Organisms in Compost

A good operation of aerobic composting should be able to kill all pathogenic microbes, weeds and seeds especially if the temperature can be maintained between 60 and 70 degrees for 24-hour period.` The presence of coliform bacteria is often used as an indicator of overall sanitary quality of compost. Use of an indicator such as total and faecal coliforms, against actual disease causing organisms is advantageous as the indicators generally occur at higher frequencies than the pathogens and are simple and safer to detect (Hassen *et al*., 2001).

2.14 Helminth Eggs as Indicator Organism in Compost

Sewage sludge contains many different pathogens. It would be impossible to analyze all pathogen species in the resulting compost. It was therefore necessary to observe the concentration of an indicator organism that would allow making predictions about levels of other pathogens. Of the entire pathogen group, helminth eggs are the most resistant. They can survive in the environment for many months, and are very resistant to high temperatures (Feachem *et al*., 1983). It can therefore be assumed, that if all helminth eggs in the compost are dead, all other pathogens have been remove as well.

3.0 MATERIALS AND METHODS

The project work was in two phases;

1. the production of compost from co-composting of dewatered sewage sludge and sawdust, and
2. using the compost produced to cultivate lettuce

Phase One – Production of Compost

3.1 Experimental Set up

The experimental set up was the KNUST sewage treatment plant, where the dewatered sewage sludge was taken from the drying beds. The sawdust was also transported from Anloga woodworks (Kumasi), where the sawdust is readily available. A 5m × 5.5m × 6m shade was provided over a concreted floor to protect the composting process from excessive environmental conditions like rains, sunlight etc. (Fig 3.1).The concrete floor was slightly inclined to allow excess moisture from rains to drain freely from the heap. The structure was constructed such that, the length faces the direction of the air for maximum aeration.

Figure 3.1 The structure and initial state of the compost heaps

3.2 Composting Procedure

Based on a preliminary analysis (Table 3.1) of the characteristics of both the dewatered sewage sludge and sawdust, three (3) different formulations of co-compost heaps were prepared from dewatered sewage sludge and sawdust. The ratios were 1:1, 1:1.5 and 1:2 (v/v) of sewage sludge and sawdust respectively. Replication of each heap ('a' and 'b') was done, which means, every two heaps had the same ratio. The heaps were prepared by measuring a total of 0.4 m^3 of both the dewatered sewage sludge and sawdust in their respective ratios. The mixture was thoroughly mixed up with a shovel to obtain a uniform mixture. The heaps were then heap in a windrow. Manual turning was adopted as it is the commonest and less expensive method of composting sewage sludge.

Table 3.1 Preliminary analysis of dewatered sewage sludge and sawdust

Sample	Moisture (%)	Carbon (%)	Nitrogen (%)	Carbon-Nitrogen Ratio
Sewage sludge	82.1	29.2	3.03	9.57
Sawdust	12.9	60.69	0.53	114.51

3.3 Turning and Watering of the Heap

Using shovel and pitch fork, the heaps were turned every three days for the first 15 days. The frequency was then reduced to once a week when temperature approached the ambient conditions. The turning was done to ensure that the entire compost mass was subjected to the optimum conditions of aeration, temperature and moisture during composting. The high frequency of turning in the early stages was to enable all parts of the windrow to be heated sufficiently for efficient pathogen inactivation, and also to aerate the windrows for the necessary aerobic conditions since consumption of oxygen is greatest during the early stages of composting. Each time the windrows were turned they were watered except when the moisture content was moist enough.

3.4 Temperature Measurement

Temperature of each heap was measured three times a day at 8 am, 12 mid day and 4 pm. This was done by inserting a reotemp (compost thermometer) at 20 cm and 40 cm depth into the heap until a stable reading was reached on the reotemp. This stable reading was read and recorded. The average reading was calculated and recorded. The ambient temperatures were also measured and recorded at the same time.

3.5 Determination of Moisture Content

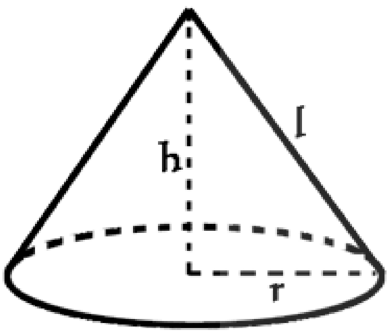
During turning of the heaps, the moisture content was checked by the following manner: A fist full of compost is taken with the hand and squeezed tightly. If moisture but not free water appears between the fingers, the moisture is ideal; if however, water flows out of the tightly clenched fist, it is 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 each composting heap were taken to the laboratory for moisture content determination. Each sample is weighed using mettlar balance (W_1). The samples were then oven-dried at a temperature of 105 ^oC 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:

$$\% \, Moisture = \frac{W_1 - W_2}{W_1} \times 100$$

3.6 Heap Volume Measurement

By using a calibrated rod and a measuring tape**,** the height (h) and the circumference (c) (from which the radius(r) was calculated) of each heap was measured as illustrated in Figure 3.3. Volume of compost heap = $\prod r^2 h/3$, where $r = c/2\prod$



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}).

$$\% \, TS = \frac{M_{after}}{M_{before}} \, x \, 100$$ where M is mass

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 furnance for one hour at the temperature of 600 ^{0}C. The resulting ash weighed using a mettlar balance to obtain the ash contents. Percentage organic matter of each sample was then calculated using the formula:

$$\% \text{ organic matter} = \frac{\text{Weight of oven dried sample} - \text{weight of ash content}}{\text{weight of oven dried sample}} \times 100$$

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 the temperature of 600 ^{0}C. The resulting ash was weighed using a mettlar balance to obtain the ash contents.

$$\% \text{ Ash content} = \frac{\text{Ash content}}{\text{Weight of oven dried sample}} \times 100$$

3.10 Carbon Content

The total organic carbon (TOC) was calculated from organic matter (OM) according to the following equations (Navarro *et al*., 1993):

$$\% \text{ TOC} = 0.51 \times \%\text{OM} + 0.48$$

3.11 Nitrogen Content

One gram (1g) of dry compost sample was weighed out with a mettlar balance into a kjeldahl flask of 300 ml size. 25 ml concentrated sulphuric acid was added with a selenium catalyst tablet (kjeldahl tablet). The flask was then heated in a fume chamber to digest the mixture until clear solution is obtained. The digested sample was then allowed to cool and diluted to 300 ml with distilled water. 50 ml of sodium hydroxide thiosulphate and 10 ml of sodium hydroxide were added to the diluted digest to provide the alkaline condition necessary for the release of organic nitrogen. 200 ml 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 0.02 N sulphuric acid until the indicator turns pale lavender with volume used representing V1. A blank was prepared by heating 25 ml of concentrated sulphuric acid and a tablet of selenium catalyst and treated as a digest to get V0.

The nitrogen of the sample was calculated using the relationship:

$$Nitrogen\left({}^{mg}/_{kg}\right) = \frac{(V1 - V0)}{m} \times 280$$

Where:

V1 is the volume of the sulfuric acid used in the titration of the sample in milliliters (ml),

V0 is the volume of the sulfuric acid used in the titration of the blank test in milliliters (ml)

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

3.12 Phosphorus Content

One gram (1g) of the dry sample was weighed and dissolved in 100 ml of distilled water. The mixture was thoroughly shaken and filtered. A sachet of Phos Ver3 phosphate powder pillow for 10 ml sample was added to 10 ml of the filtrate in a 10 ml cell.

The mixture was swirl immediately to mix and left for 3 min. The mixture turned blue indicating the presence of phosphorus. The content in the cell is placed in the Portable Datalogging Photospectrometer and the phosphorus content determined digitally in milligram per liter (mg/l).

3.13 Potassium Content

One gram (1g) of the dry sample of compost was weighed into a beaker. 25 ml of concentrated nitric acid (HNO_3) was added to it. The mixture was then heated until a clear solution was obtained. The solution was then made up to 100 ml with distilled water. The test solution was then analyzed for the concentration of potassium using Atomic Absorption Spectrophotometry (AAS) with potassium lamp attached to it. With AAS, the sample was aspirated and atomized. The light Beam emitted was directed through the flame into a monochromator and onto a detector that measured the amount of light absorbed by the atomized element in the flame. The concentration of potassium in the sample was then shown in milligram per liter (mg/l).

3.14 Carbon-Nitrogen Ratio determination

This was calculated using the results obtained from carbon and nitrogen content determination. i.e. Carbon Content / Nitrogen content

3.15 Hydrogen Ions Concentration (pH) Determination

One gram (1g) of the compost was weighed into a beaker and suspended in 100ml of distilled water. Using a pH Meter, (WTW 323 model) the probe of the pH Meter was inserted into the solution. The pH of the solution appears digitally and was recorded accordingly.

3.16 Total Coliforms Determination

Total coliforms were estimated using the Most Probable Number method (MPN) according to Standard Methods (Anon, 1992). Ten grams 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^{-10} were prepared by picking one milliliter (1 ml) from the stomacher bag. One millilitre aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 37 ^{0}C for 24 hours. Tubes showing acid and gas production after 24 hours were confirmed by plating on MacConkey No. 3 agar and examined for typical colonies. Counts per 100 ml were calculated from MPN tables and expressed as MPN 100 ml^{-1} (Collins *et al*., 1998).

3.17 Faecal Coliform Determination

Faecal coliforms were estimated following the same procedure for total coliforms in 3.15 above. However, tubes were incubated at 44 ^{o}C for 24 hours. Tubes showing acid and gas production after incubation for 24 hours were confirmed by plating on MacConkey No. 3 agar and examined for typical colonies. Counts per 100 ml were calculated from MPN tables and expressed as MPN 100 ml^{-1} (Collins *et al*., 1998).

3.18 Helminth Egg Level Determination

Ten grams of each compost sample was weighed into a container and diluted with water to 2 litres and allowed to settle overnight. As much supernatant as possible was sucked up using a vacuum pump and the sediment placed into tubes and centrifuged for 3 min at 1500 rmp. The supernatant was poured off and the sediment re-suspended with Zinc Sulphate of 1.3 density and homogenized with a spatula. It was again centrifuged for 3 min at 1500 rpm. The Zinc Sulphate supernatant was poured into a fresh 2 litre bottle and diluted with 1 litre of water. The container was allowed to stand for 3 hours. As much supernatant was sucked up and the sediment re-suspended by shaking and emptied into centrifuge tubes, the bottle was rinsed twice with deionized water and placed into the tubes with the sediment. The tubes were centrifuged for 3 min at 1750 rmp. The sediments were regrouped into one tube and centrifuged again for 3 min at 1750 rpm. The sediment was again re-suspended in about 5 ml acid/alcohol (H_2SO_4+C_2H_5OH) buffer solution and 2 ml ethyl acetate solution. It was shaken and occasionally opened to let out gas. It was then centrifuged for 3 min at 2000 rmp. Much of the supernatant was sucked up leaving less than 1ml of liquid. The deposits were read on a slide using a light microscope. The helminth eggs were identified on the basis of their shape and size and compared with standard eggs on chart (WHO, 1996).

The number of eggs per 10 g was calculated from the equation:

N = (AX)/ (PV)

ere N = Number of eggs per 10 g of sample, V = Original sample mass (L)

A = Number of eggs counted in the slide or mean counts from two or three slides

X = Volume of the final product (ml),

P = Volume of product viewed under the slide (ml),

PHASE TWO

3.19 Cultivation of lettuce

Eight beds of dimension 5 m × 2 m wide each were prepared at the KNUST sewage treatment plant for the cultivation of the lettuce. A volume (0.028) of each compost type was uniformly spread on each of the first six beds. As a control for the experiment, 0.028 m^3 of dried non-composted sewage sludge was spread on the seventh bed. For the eighth bed, no treatment was applied. The arrangement is shown in Figure 3.4. The lettuce was grown for one month before it reached maturation.

← 5 m →

↑ 2 m ↓

1:1, a	1:1.5, a	1:2, a	Dried non-composted sludge
1:1, b	1:1.5, b	1:2, b	No treatment

Figure 3.3 Layout of experimental beds

3.20 Soil and the Treatment Analysis

Samples of soil from the beds before cropping, the different compost types and dried non-composted sewage sludge were taken to the laboratory to determine their moisture, total solids, pH, organic matter, ash content, carbon, nitrogen, phosphorus, potassium, total coliforms, faecal coliforms and helminth eggs using standard methods as described from section 3.5 to 3.17 respectively. The results is shown in Table 3.2

Table 3.2 **Characteristics of the Different Compost, Soil and Dried Non-Composted Sewage Sludge for Cultivation of Lettuce**

Material	pH	MC (%)	TS (%)	OM (%)	Ash (%)	N (%)	C (%)	C/N	P (%	K (%)	TC (MPN)	FC MPN)	HE
1:1,a	6.20	37.0	63.0	60.9	35.1	1.7	31.9	18.9	0.4	0.1	3.2E+03	0.00	10.1
1:1, b	6.24	38.3	61.7	60.5	35.5	1.6	31.3	19.6	0.4	0.2	7.76E+03	0.00	2.8
Mean	6.22	37.7	62.4	60.7	35.3	1.6	31.6	19.3	0.4	0.2	5.48E+03	0.00	6.5
1:1.5,a	5.80	35.7	64.3	62.1	32.9	1.5	32.2	21.5	0.3	0.1	1.03E+02	0.00	6.2
1:1.5,b	6.03	39.1	60.9	61.3	36.2	1.6	31.5	19.2	0.2	0.2	1.32E+02	0.00	3.0
Mean	5.92	37.4	62.9	61.7	34.6	1.6	31.9	20.4	0.3	0.2	1.32E+02	0.00	4.6
1:2,a	5.56	31.8	68.2	62.4	33.6	1.3	32.3	24.8	0.3	0.1	3.2E+02	0.00	2.0
1:2,b	6.19	35.5	64.5	60.1	34.9	1.3	31.1	24.5	0.3	0.2	7.60E+02	0.00	3.2
Mean	5.98	33.7	66.35	61.3	34.3	1.3	31.7	24.7	0.3	0.2	5.42E+02	0.00	2.6
Soil	6.58	4.01	95.9	2.3	97.7	0.4	1.7	3.9	1.5	0.1	1.26E+04	2.00E+02	11.5
Dried Non-composted sludge	6.09	19.5	80.2	40.5	58.5	1.3	21.6	16.9	4.8	0.1	5.30E+03	1.00E+03	11.3

MC ……. Moisture content

TS ……. Total solids

OM ……. Organic matter

ASH ……. Ash content

C ………. Carbon content

N ………. Nitrogen content

C/N ………. Carbon-Nitrogen Ratio

P ………… Phosphorus content

K ……… Potassium content

TC ……….. Total coliforms

FC ………. Faecal coliforms

H E ………. Helminth eggs

3.21 Lettuce Analysis

Samples of the matured lettuce were sent to the laboratory and the following parameters analysed: total coliform, faecal coliform, helminth eggs and average yield of lettuce were determined for each bed.

3.21.1 Total Coliform Determination

As described in section 3.15

3.21.2 Faecal Coliform Determination

As described in section 3.16

3.21.3 Helminth Eggs Determination

100 g of lettuce was weighed and the leaves surfaces washed with about two (2) litters of water under running tap into a bowl. The water was collected into a container and allowed to settle for at least 3 hours. The procedure that follows is the same as helminth eggs determination at section 3.17.

3.21.4 Yield Determination

The average fresh weight of a lettuce from each treatment bed was determined by randomly selecting 20 samples, weighing them with a mettler balance and their mean weight determined. The average dry weight was also determined by drying 100 g of lettuce from each plot in an oven at 105 ^{0}C for 24 hours and their dry weight taken.

3.22 Statistical analysis

All analyses were carried out with two to three replicates per sample, and the mean results per sample used for statistical data treatment.

Graphs and tables have been done with Microsoft excel for the data analysis.

One way ANOVA was also carried out using SPSS Version 13 to compare the differences between the different treatments. Total coliforms, faecal coliforms and helminth eggs count were normalized by log transformation for the ANOVA analysis.

4.0 RESULTS

Figure 4.1 represents the variation in temperature in the different compost heaps and ambient temperature over the 90 days period. The figure indicates that the heap with ratio 1:1 reached its highest mean temperature 50 ^{0}C, 1:1.5 and 1:2 also reached 52 ^{0}C at the same time. These occurred within the first 15 days of composting. The temperatures after the mean highest levels started declining till the 90th day when temperature in 1:1 was 24.7 ^{0}C whilst 1:1.5 and 1:2 was 23.8 ^{0}C.

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 with ratio 1:1, 1:1.5 and 1:2 reduced to 0.1766 m^3, 0.1588 m^3 and 0.1524 m^3 respectively.

The total solids content in all the different heaps kept on increasing from an initial of 34.4% to 62.4% for heap 1:1, 34.6% to 62.8% for heap with ratio 1:1.5 and 35.3% to 66.4 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, it reduced from a mean of 65.7% to 37.7%, 65.5% to 37.4% for 1:1.5 heap and 64.7% to 33.7% for heap with ratio 1:2 (Fig.4.4).

From figure 4.5, the organic matter content decreased over the entire period and for heaps 1:1, 1:1.5 and 1:2, the reduction were from 81.7% to 60.7%, 83.3% to 61.7% and 86.8% to 61.3% respectively. As the organic matter content decreased, the ash content increased from 18.3% to 35.3% for heap 1:1, 16.8% to 34.8% for heap 1:1.5 and 13.2% to 34.3% for heap 1:2 (Fig. 4.6).

The mean carbon content in heap 1:1 declined from 42.2% to 31.6% while that of 1:1.5 and 1:2 declined from 42.9% to 31.9% and 44.5% to 31.5%respectively (Figure 4.7)

The mean nitrogen content also got reduced from 1.83% to 1.64% for heap 1:1, 1.78% to 1.57% for heap 1:1.5 and 1.45% to 1.29% for heap 1:2 (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 23 to 19.3 for heap with ratio 1:1, 24.2 to 20.4 for heap 1:1.5 and 30.7 to 24.7 for the heap with ratio 1:2.

The phosphorus content in all the heaps declined from 1.47% to 0.37%, 1.33% to 0.26% and 1.28% to 0.25% for the heap with ratio 1:1, 1:1.5 and 1:2 respectively (Fig. 4.10). The potassium content also decreased from 0.38% to 0.16% for the 1:1, 0.33% to 0.16% for the 1:1.5 and 0.32% to 0.16% for the 1:2 (Fig. 4.11).

The hydrogen ion concentrations (pH) of the different compost heap are also represented by figure 4.12. The final compost has a mean pH of 6.22, 5.92 and 5.98 for heap with ratio 1:1, 1:1.5 and 1:2 respectively.

The levels of total coliforms, faecal coliforms and helminth eggs are represented by figure 4.13, 4.14 and 4.15 respectively. Their levels got significantly reduced over the four month period. The log of total coliforms reduced from 14.41 to 3.70, 12.50 to 2.08 and 10.35 to 2.20 for heaps 1:1, 1:1.5 and 1:2 respectively.

The log of faecal coliforms also reduced from the initial of 10.37 for 1:1, 10.35 for 1:1.5 and 9.50 for 1:2 to zero at the end of the second month of composting (Figure 14).The number of helminth eggs also reduced from 60.8 to 6.50 for heap with ratio 1:1, 50.9 to 4.60 for the heap with ratio 1:1.5 and 41.9 to 2.60 for the heap with ratio 1:2 (Figure 15).

A one way ANOVA was carried out for all the three different compost types (1:1, 1:1.5 and 1:2) to determine the significance or otherwise of the levels of total solids, moisture content, organic matter, ash, carbon, nitrogen, carbon-nitrogen ratio, phosphorus, potassium, pH, helminth eggs, total and faecal coliforms in the final composts produced. It was realized that, there was no significant difference in the quality of the composts produced for all the parameters listed above as indicated in appendix A ($P > 0.05$), the exceptions being the nitrogen content and carbon-nitrogen ratios which showed very significant difference in the different compost heaps ($P < 0.05$, Appendix D).

Figure 4.16 shows the state of lettuces cultivated with different treatments (the different composts and dried non-composted sewage sludge) as an organic fertilizer.. Table 4.1 represents the results of the analysis of lettuces upon harvesting. Parameters analyzed included, fresh and dried weight of lettuce, total and faecal coliforms and helminth eggs levels.

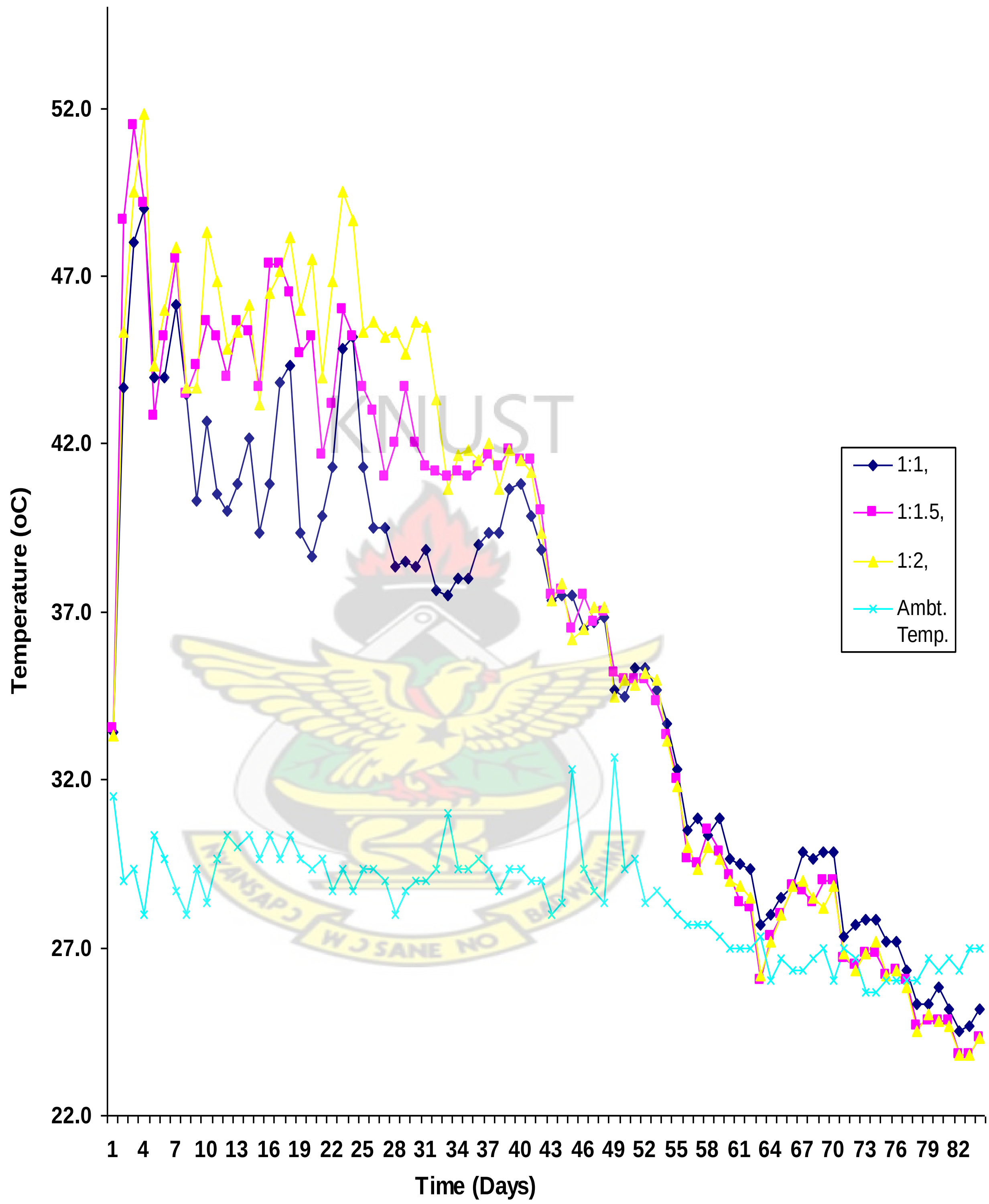


Figure 4.1 Variation in proces temperature (1:1, 1:1.5 and 1:2) and Ambiant Temperature against Time (Days)

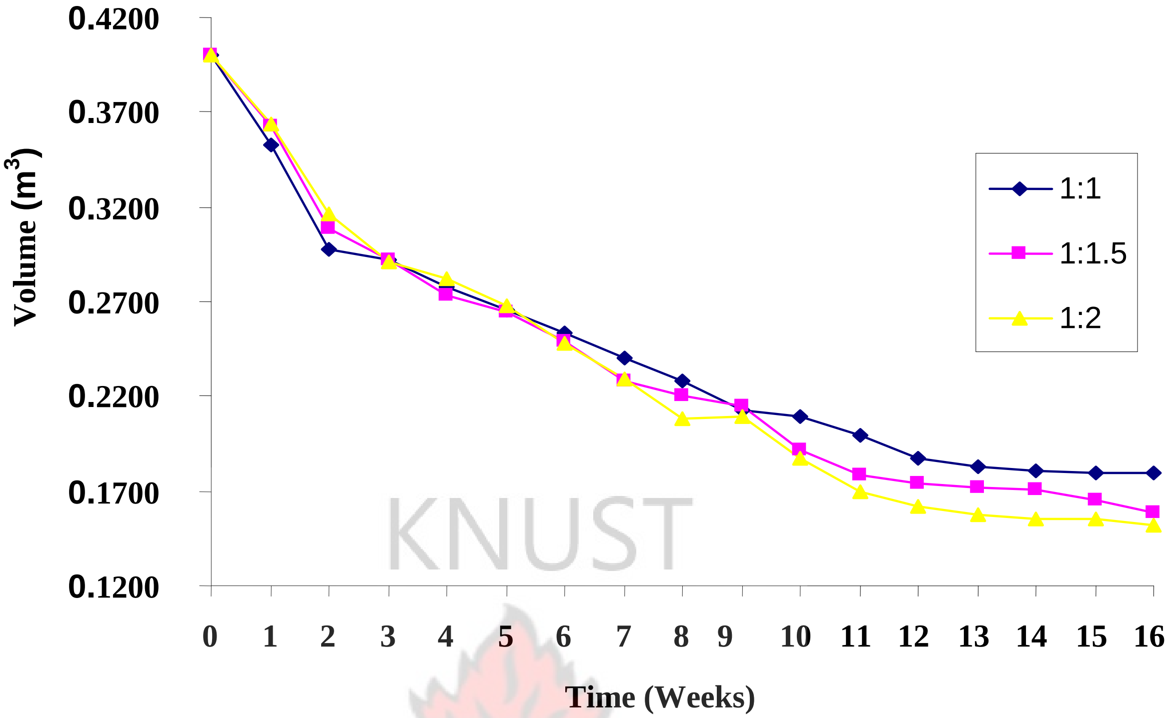


Figure 4.2 Mean Weekly Volumes of the Various Compost Heaps

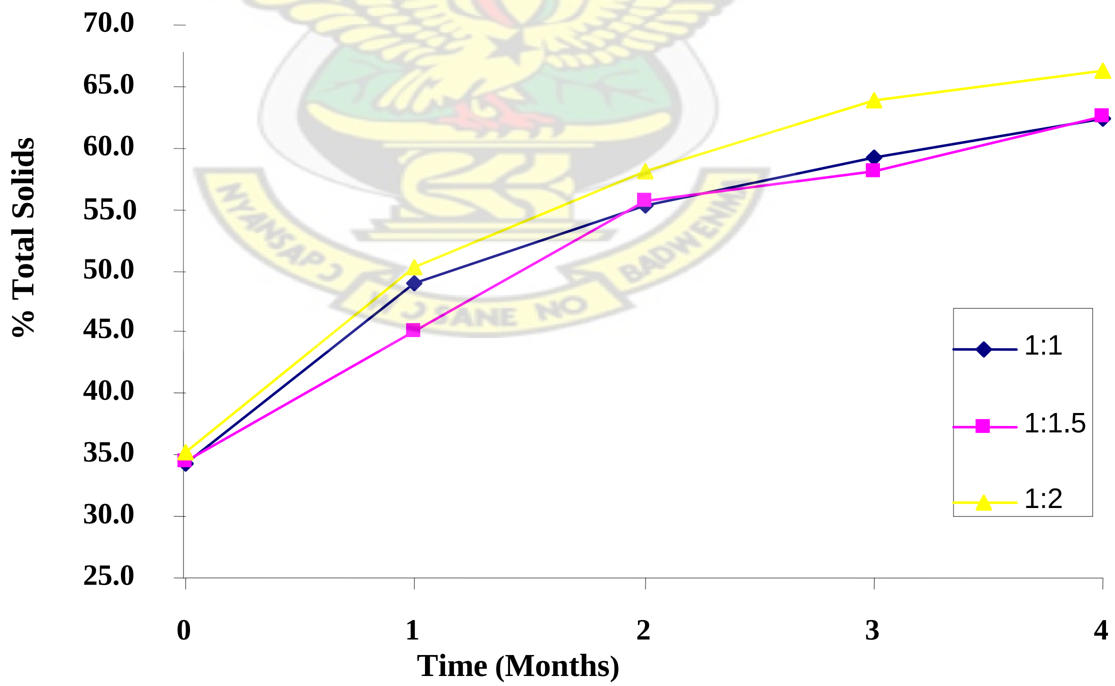


Figure 4.3 Mean Monthly Total Solids (%) in the Various Compost Heaps

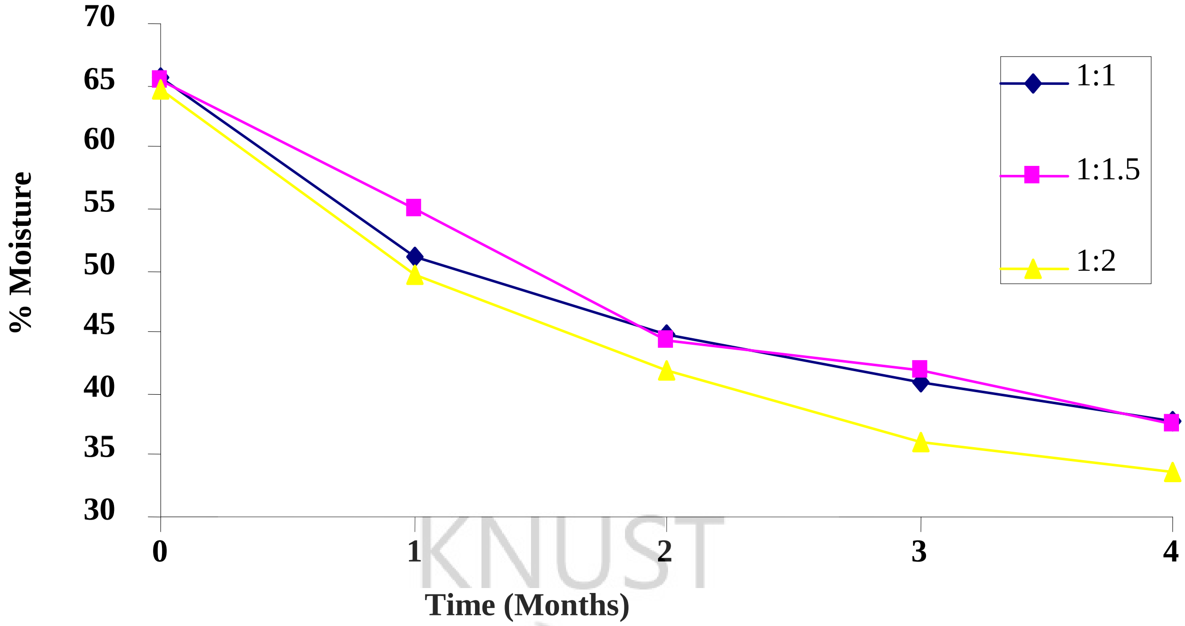


Figure 4.4 Mean Monthly Moisture Content (%) in the Various Compost Heaps

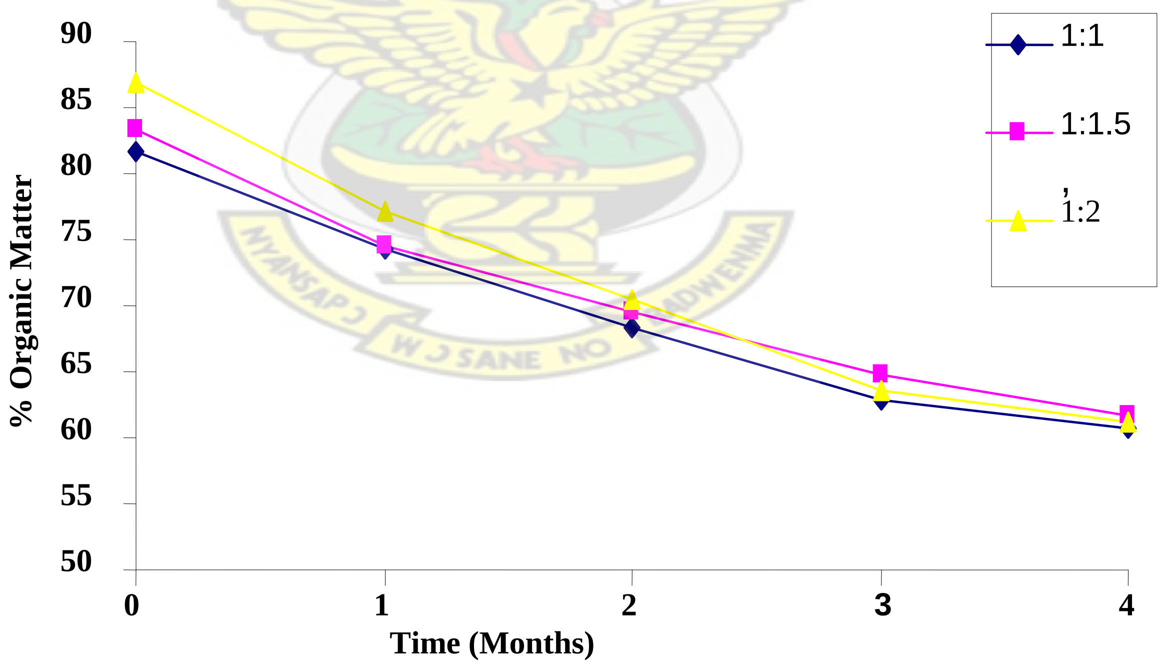


Figure 4.5 Mean Monthly Organic Matter content (%) in the Various Compost Heaps

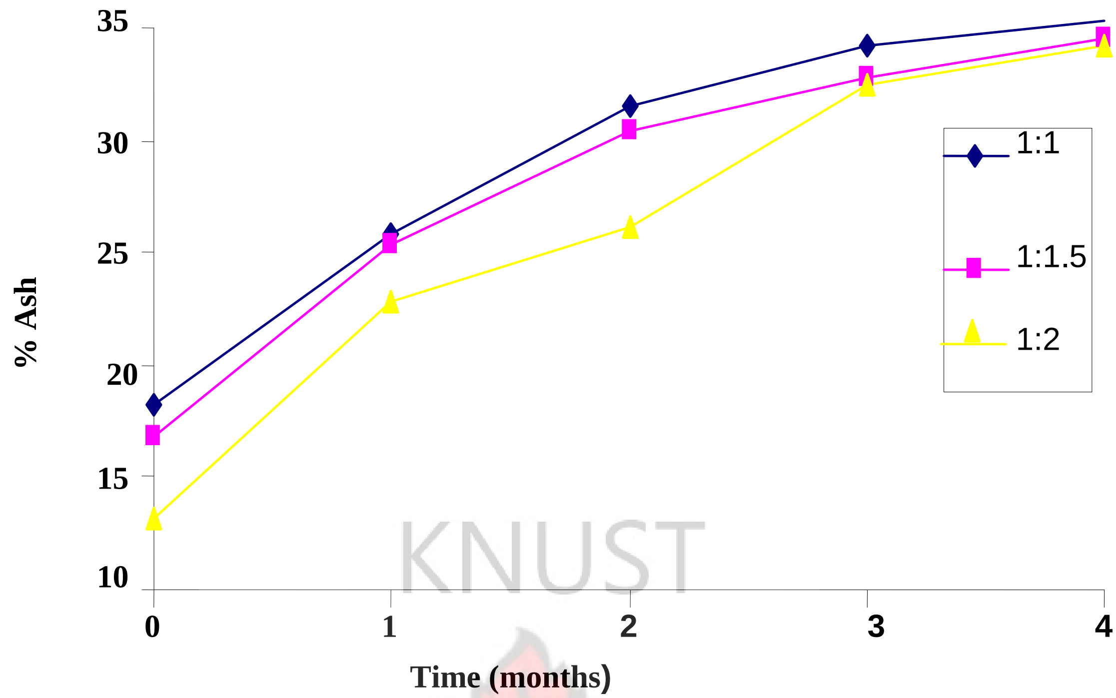


Figure 4.6 Mean Monthly Ash content (%) in the Various Compost Heaps

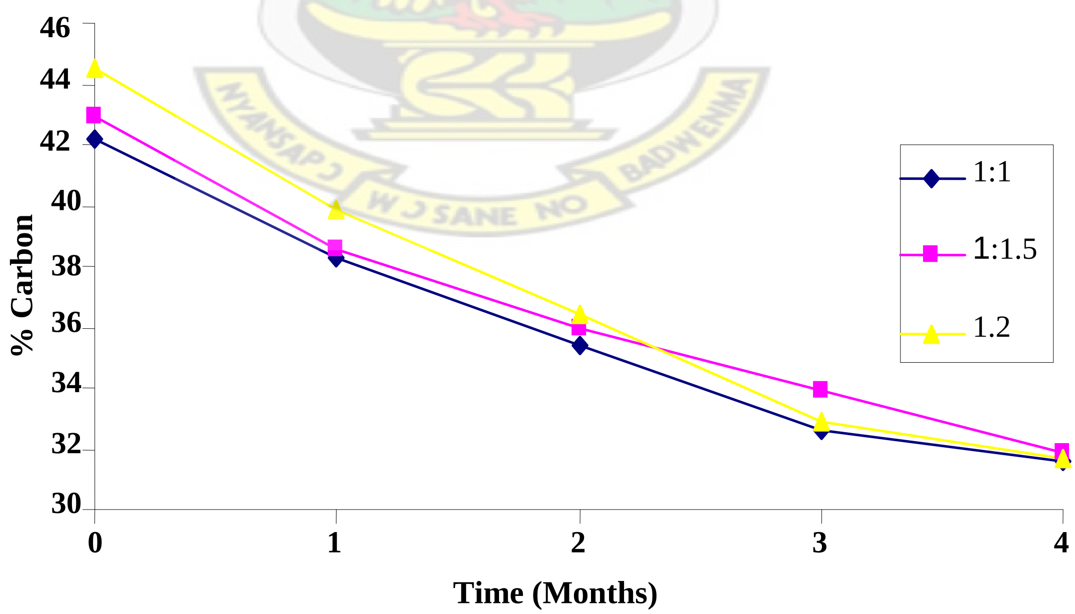


Figure 4.7 Mean Monthly Total Carbon Content (%) in the Various Compost Heaps

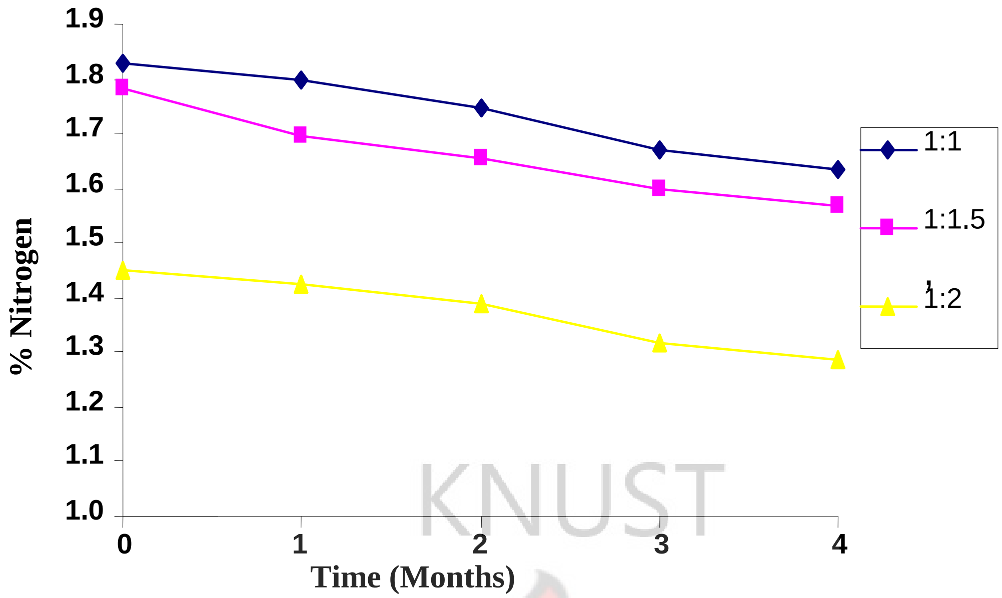


Figure 4.8 **Mean Monthly Nitrogen Content (%) in the Various Compost Heaps**

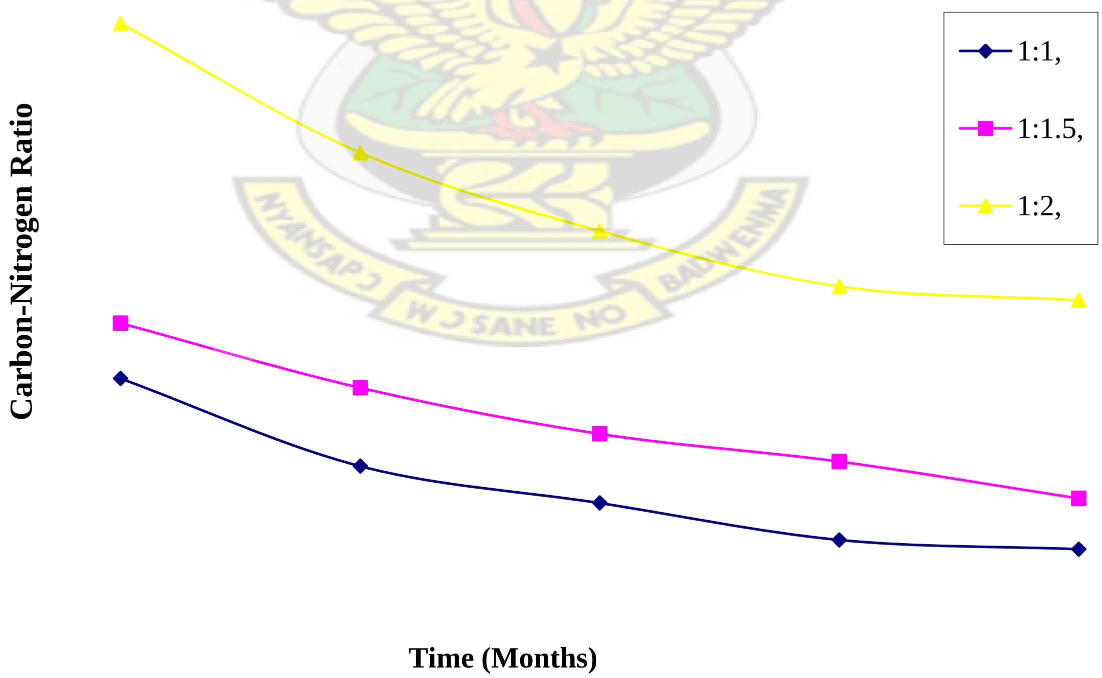


Figure 4.9 Mean Monthly Carbon-Nitrogen Ratio in the Various Compost Heaps

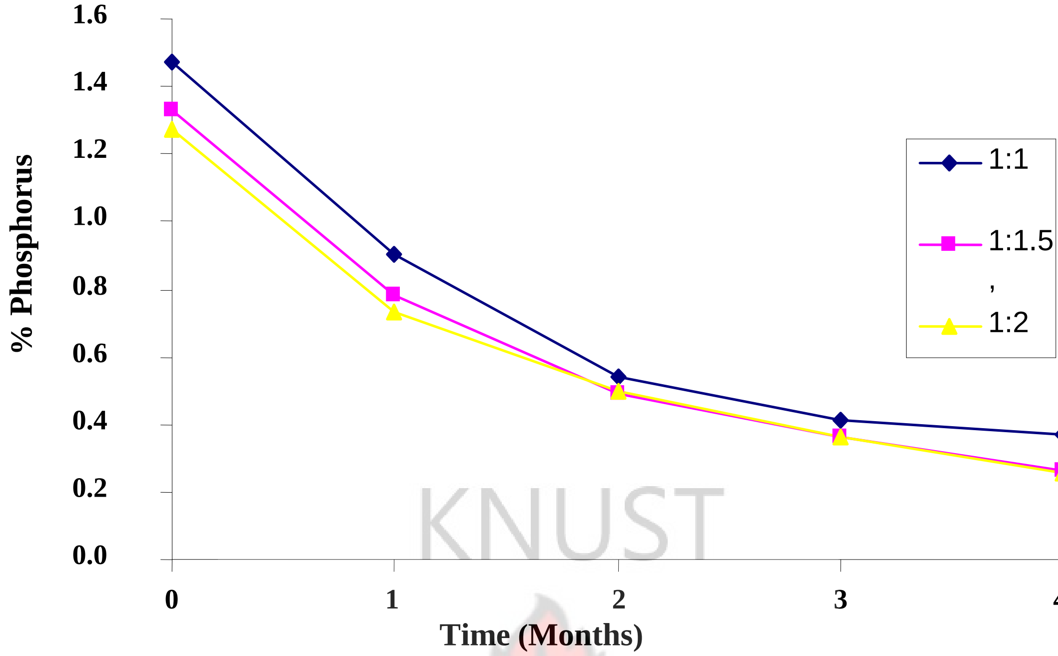


Figure 4.10 Mean Monthly Phosphorus Content (%) in the Various Compost Heaps

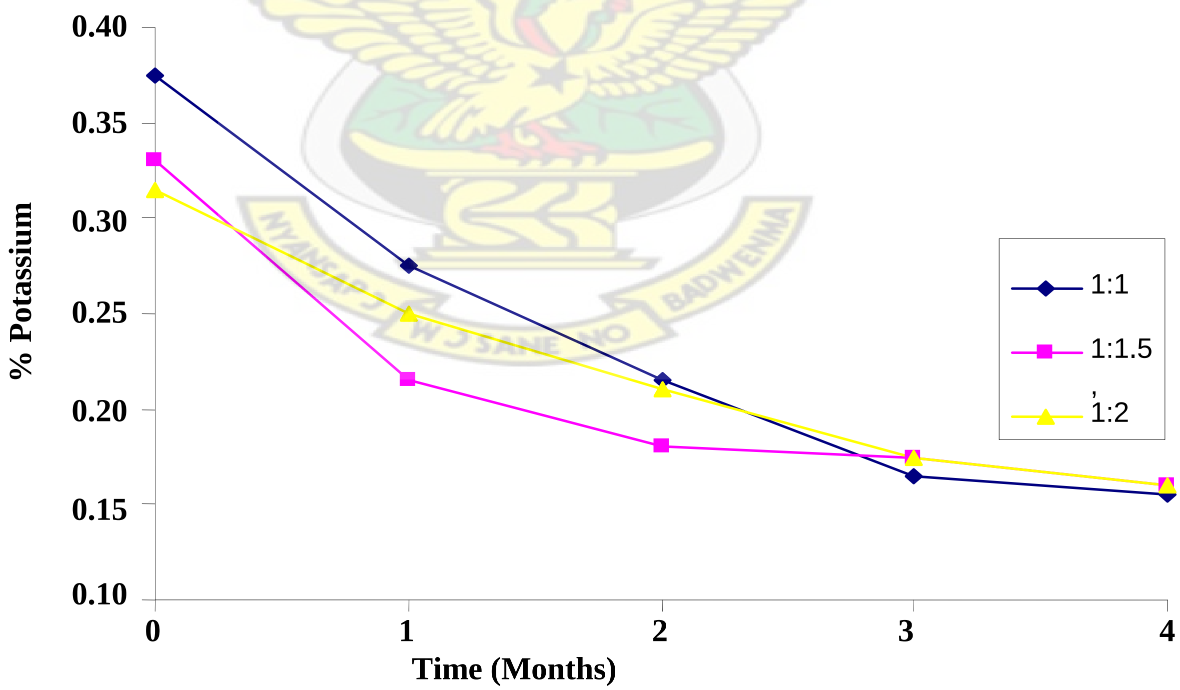


Figure 4:11 Mean Monthly Potassium Content (%) in the Various Compost Heaps

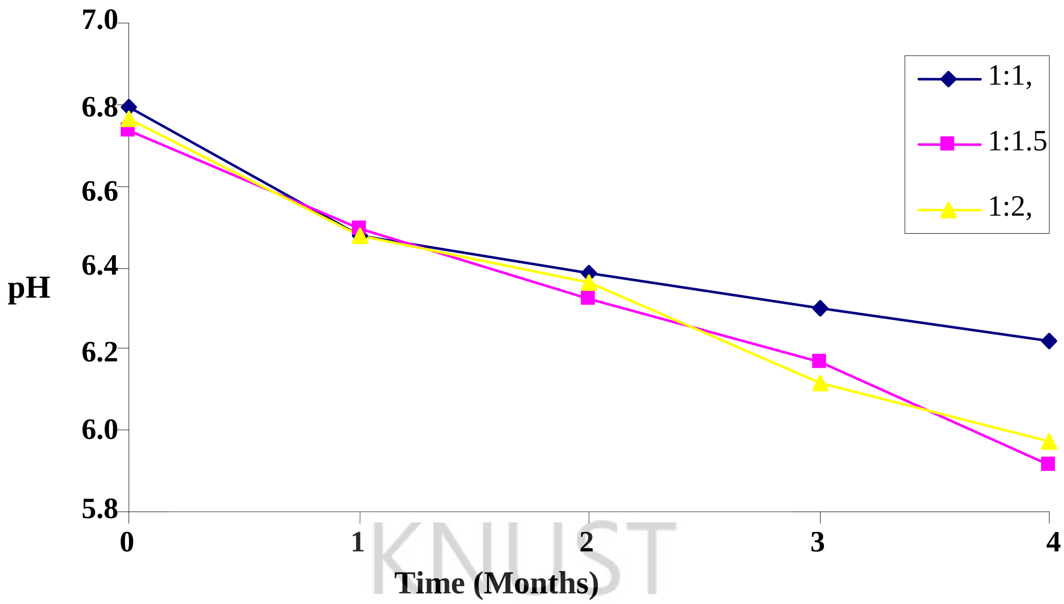


Figure 4.12 Mean Monthly pH of the Various Compost Heaps

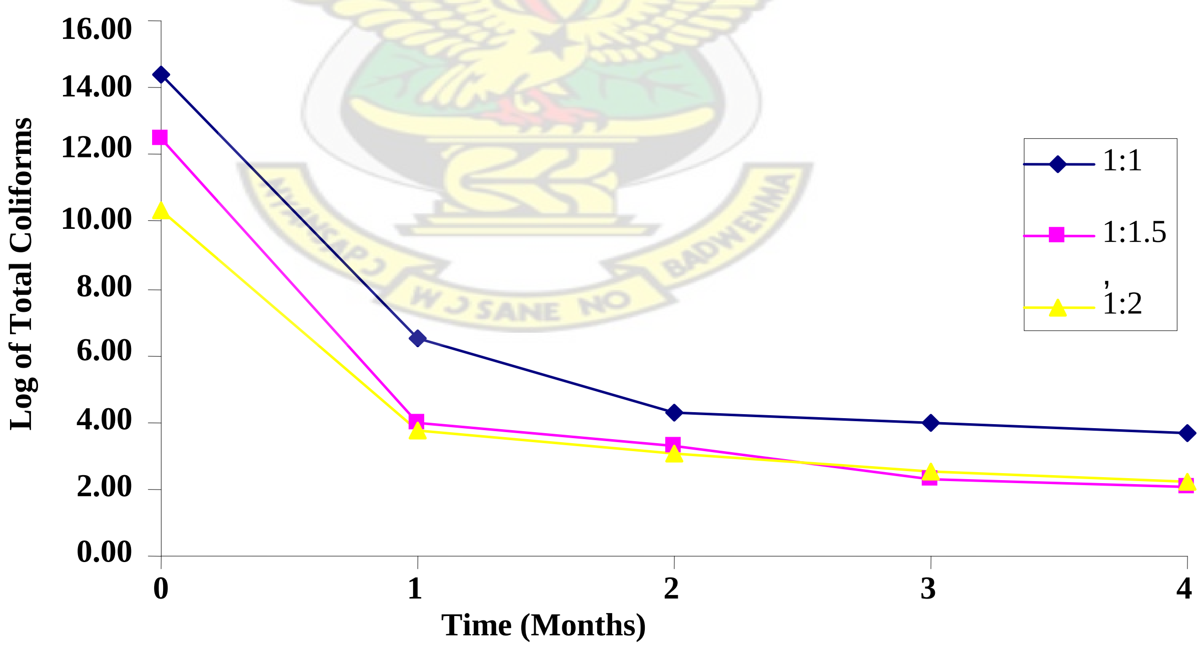


Figure 4.13 Mean Monthly Total Coliforms (log) in 10g of the Various Compost Heaps

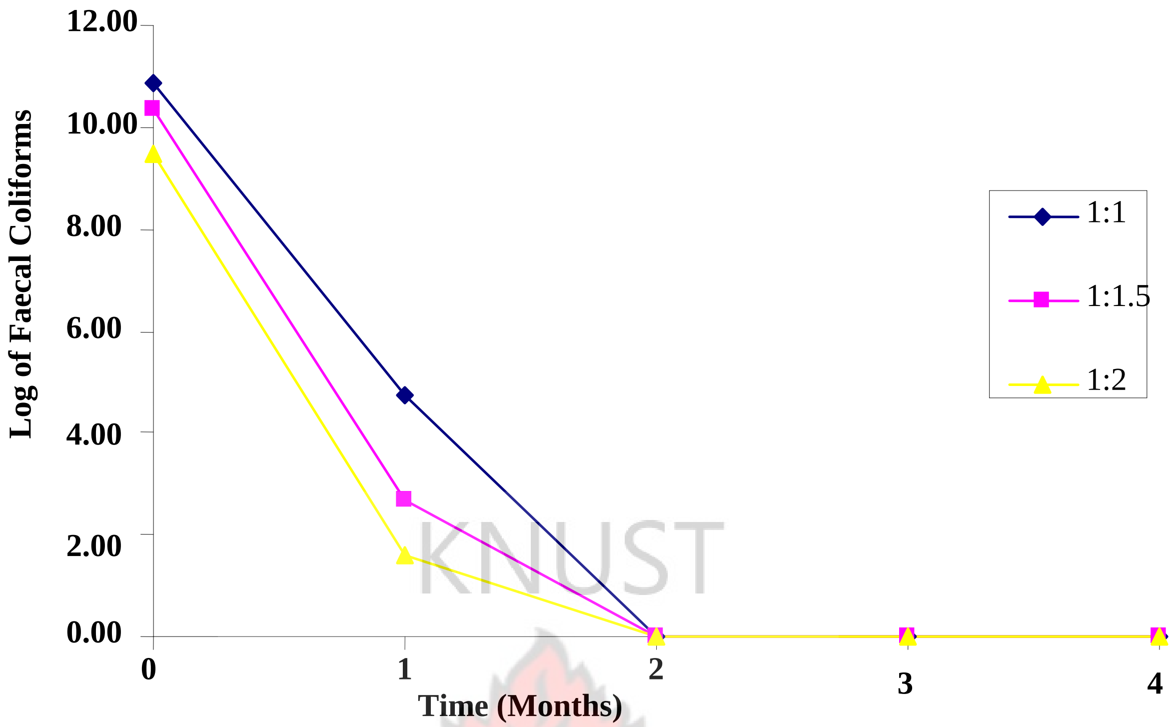


Figure 4.14 Mean Monthly Faecal Coliforms (log) in 10g of the Various Compost Heaps

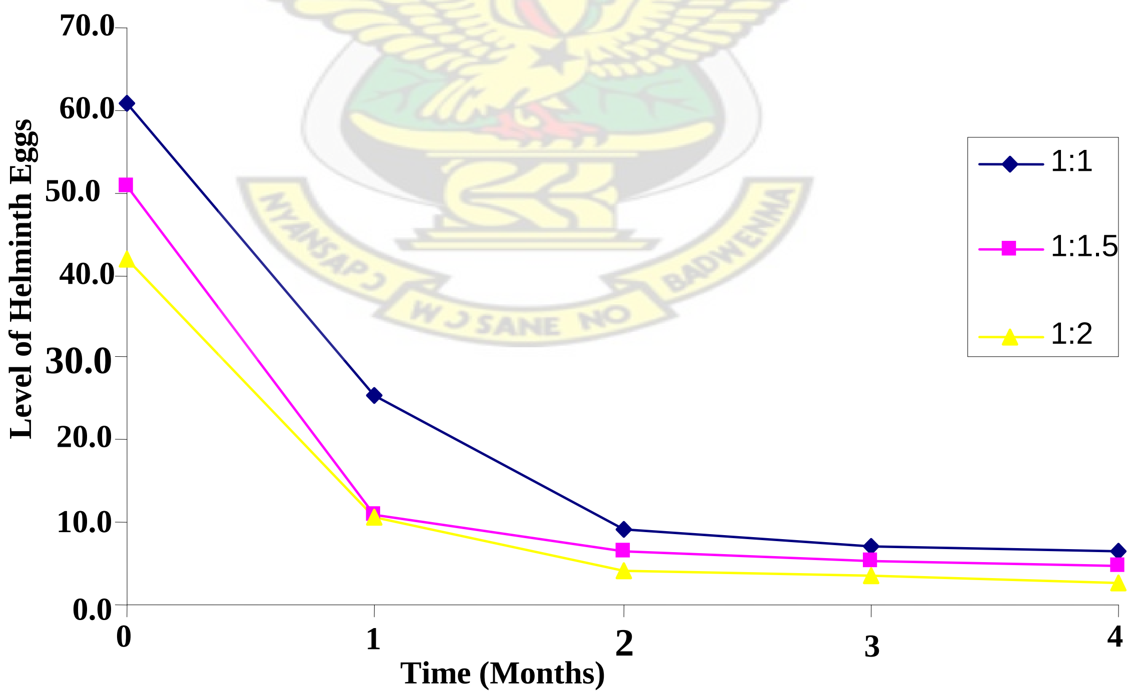


Figure 4.15 Mean Monthly Levels of Helminth Eggs in 10g of the Various Compost Heaps

Figure 4.16 The State of Lettuces Cultivated with Different Treatments

Table 4.1 Results of the 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 / 1g)	Geomean faecal coliforms (MPN / 1g)	Mean Helminth egg per 100g of lettuce
1:1	120.3	9.8	3.90×10^4	$3.9\ 0\times 10^3$	6.5
1:1.5	117.9	7.7	2.38×10^4	2.70×10^3	5.0
1:2	106.5	9.8	8.70×10^3	8.50×10^2	2.6
Non - Composted dried sludge	123.0	9.3	1.23×10^4	8.50×10^2	12.3
No treatment	45.4	6.5	6.39×10^4	$8.4\ 0\times 10^3$	8.0

5.0 DISCUSSION

The level of nutrients in compost largely depends on the type and the extent of decomposition of the organic material. The concentration of these nutrients gives a reliable indication of whether or not the compost has the ability to support crop growth as a substitute to chemical fertilizer.

5.1 Moisture Content and Total Solids of Compost

Water was extensively utilized and there was generally, a gradual reduction in the moisture content in all the various heaps throughout the composting period. The heap with ratio 1:2 was much reduced followed by the 1:1.5 and 1:1. This could be as a result of moisture loss through evaporation, as temperature was highest and sustained in 1:2 followed by 1:1.5 and 1:1. Finstein *et al*. (1986) stated that, during composting of organic matter, heat is built up in the heap which is enough to vaporize moisture from the heaps and as temperature increases, more heat is lost. The mean difference in the moisture content in all the final compost produced was statistically insignificant ($p = 0.755$, Appendix D). However, the monthly reduction in moisture content for each heap group was statistically significant ($P \leq 0.005$). This could be due to water being utilized by the living organisms present in the compost. A study carried out by Richard *et al*. (2002) indicated that, water provides a medium for the transportation of dissolved nutrients required for metabolic and physiological activities of organisms.

Moisture content in the heaps was seen to be inversely proportional to the total solid content of each heap. This implies that, 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 insignificant (p = 0.755, Appendix D) but the monthly increases were very significant ($P \leq 0.005$) as microorganisms and evaporation contributed to moisture lost.

5.2 Organic Matter and Ash Content of Compost

It was observed that, the organic matter content in the various heaps kept on decreasing throughout the composting period. Nevertheless, the rate of reduction slowed as the process progressed (Fig. 4.5). Organic matter is decomposed and transformed to stable humic compounds (Amir *et al*., 2004). The extent of organic matter decomposition at any particular time is related to the temperature at which composting takes place and the chemical composition of the organic substrate undergoing composting (Levi-Minzi *et al.*, 1990). The compost heaps reached their highest temperatures within the first two weeks of composting and maintained temperatures above 45 ^{0}C for almost four weeks. Decomposition was also observed to be highest at those high temperatures. The high temperatures were attained due to the presence of readily degradable carbon compounds (organic matter), most of which initially decompose rapidly. Thereafter, decomposition rate decreases because of the greater resistance of the remaining carbon compounds (lignin and cellulose) to decomposers. Generally, the higher the lignin and polyphenolic content of organic materials, the lower their decomposition rate (Palm and Sanchez, 1991). The rate of organic matter decomposition was found to be almost the same in all the heaps. This implies that, the different ratios of sawdust to sludge was minute and could not exert major difference in their respective final compost. The difference in ash levels in all the compost produced was statistically insignificant. It was detected that, the ash content kept increasing in all the different compost heaps as the process progressed.

The ash content is a measure of non combustible component of organic matter and increases as organic matter decomposed.

5.3 Carbon, Nitrogen and Carbon-Nitrogen ratio

The process of decomposition of organic matter is affected by the presence of carbon and nitrogen. The total organic carbon in all piles gradually decreased over the entire composting period. The gradual decreases in total organic carbon content could be due to the high content of lignin and cellulose usually present in the sawdust. The lignin and cellulose have the ability to affect the degree of organic carbon loss during the decomposition process (Huang *et al.*, 2004). The monthly reduction of organic carbon in all the heaps was statistically significant ($P \leq 0.005$). These decreases in total organic carbon concentration resulted from the oxidation of carbon to carbon dioxide by microorganisms (Tiquia *et al.*, 1996). The carbon provides both an energy source and the basic building block making up about 50 percent of the mass of microbial cells. On the other hand, there is no significant difference ($P > 0.005$) in carbon content of the final composts, as most carbon in the various heaps have been transformed into stable compounds.

From Figure 4.8, nitrogen was lost from all the heaps during the composting process. These losses were not substantial as compared to carbon loss. This reduction could be due to the utilization of inorganic nitrogen by bacteria in the composting process and the conversion of nitrogen into bacterial proteins (Willson, 1989). Again, nitrogen loss could be attributed to organic nitrogen (N) being mineralized by microbial activity during decomposition. The mineralization rate reduced in the process. This is as a result of the rapid conversion of the more labile organic nitrogen, leaving the most resistant organic nitrogen in the organic nitrogen pool which takes a lot of time to mineralized (Iglesias-Jimenez and Alvarez, 1993). In addition, nitrogen could be lost through volatilization of gaseous ammonia during mixing and processing of the compost heaps. For example, nitrogen losses ranging from 9 to 68% have been reported during the composting of cattle manure (Eghball *et al*., 1997). The nitrogen loss is somewhat offset by the loss in mass of the organic materials resulting from oxidation of organic carbon to carbon dioxide and loss of water. There was a significant difference ($P \leq 0.005$) in the nitrogen concentration in the final compost. These differences could be related to the nitrogen content of the respective mixtures before composting. This is because, the highest nitrogen content in the initial compost mixture was found in the 1:1, followed by the 1:1.5 and the 1:2. At the end of composting, the nitrogen content followed the same trend in the composts produced.

There was a general decrease in the carbon-nitrogen ratio in the entire heaps. The heap with the ratio 1:2 was much reduced (30.7 to 24.7), followed by the 1:1.5 (24.2 to 20.4) and 1:1 (23.1 to 19.3) respectively. A significant negative correlation between temperature and carbon-nitrogen ratio was noted during the composting process. This indicates that a large temperature increase is of crucial importance for efficient mineralization, which in turn results in reduced carbon-nitrogen ratio. This explains why carbon- nitrogen ratio got reduced considerably in the 1:2, followed by 1:1.5 and lastly 1:1 as highest temperatures reached and sustained in the heaps followed the same trend.

5.4 Phosphorus and Potassium Content in the Compost

The phosphorus and potassium levels in the compost heaps were low and decreased gradually throughout the composting period (Fig 4.10 and 4. 11). These findings were explained by (Stryer, 1975) that for effective composting, phosphorus is utilized in the energy transfer process of cells and potassium helping to regulate the osmotic pressure of cells. The difference in both phosphorus and potassium content in the final compost produced from the 1:1, 1:1.5 and 1:2 was observed to be statistically insignificant. In China, because of the low level of phosphorus in night soil compost, phosphate fertilizers are added before composting to improve the phosphorus content of the final compost (Chen, 1995).

5.5 PH

The pH typically decreases as organic acids are produced in composting (Chen and Inbar, 1993). The rate of decrease is small and could be due to the high buffer capacity of the sewage sludge components. At the end of the composting, the pH was 6.22, 5.92 and 5.98 in heaps 1:1, 1:1.5 and 1:2, respectively. These values were within the optimum pH range for bacteria and fungi. In comparison, Amir *et al.* (2005) measured a pH of 6.2 in final compost of activated sludge.

5.6 Compost Volume

At the end of the 16 weeks of composting, there was massive reduction in heap volume by about 50 % in all the composting heaps. This is in line with Dao (1999) observation when he composted animal manure and lost volume by more than 50 %. The rate of volume reduction was highest during the first twenty one (21) days of composting. The rate got reducing as the more readily decomposable organic materials got used up and was left with the more resistant organic materials which take a lot of time to decompose. It was observed that the heap with ratio 1:2 significantly reduced in volume, followed by 1:1.5 and 1:1. This could be due to the fact that, more energy was available to microbes involved in the decomposition as a result of more carbon from the sawdust and the high temperature recorded.

5.7 Coliforms in Compost

Microbial parameters such as total and faecal coliforms decreased significantly (P>0.005Appendix A, B and C) at the end of the composting period in all the different composting heaps. After eight weeks of composting, faecal coliform was completely undetectable in all the different compost heaps. On the other hand, total coliforms in the 1:1.5 and the 1:2 had been reduced below the standard of less than 3.00 Log10 MPN g-1 set by the Canadian Council of Ministers (1996) as being A class standard for its application to agricultural lands. The 1:1 compost heap, alternatively, had a total coliform level of $\log_{10}$ 3.7 which is above the class A standard. This could be as a result of comparatively lower temperature attained in the 1:1 compost pile. USEPA (1999) stated that a temperature higher than 40 ^{0}C for 5 days was sufficient to reduce pathogens. In addition, lack of nutrients, caused by high population of indigenous microorganisms in manure compost or the production of compounds detrimental to coliforms may also played a role in the decline of pathogens during composting (Himathongham *et al*., 1999).

5.8 Helminth eggs in Compost

There was an over 90% reduction in the helminth eggs levels in all the different compost heaps over the composting period. The rate of reduction was highest (over 60%) in the first month of composting (Figure 4.15). The reduction persisted as the process progressed. Helminth eggs die-off during the co-composting process was mainly due to the heat that was generated inside the composting heaps. Feachem *et al.* (1983) came out with a theoretical time-temperature relationship leading to the die-off of excreted pathogens. He stated that, if temperature exceeds 45 ^{0}C for at least 5 days or 43 ^{0}C for 8 days, all ascaris eggs should die off. In all the different compost heaps, temperatures attained were above 43 ^{0}C for 25 days and it is expected that all helminth eggs should die-off. Meanwhile, there was no complete die off of helminth eggs in any of the heaps. The heaps, although were turned regularly for all parts to reach the die-off temperature, some parts might not have attained the die-off temperature due to human errors in the turning process. This might have caused some of the pathogens to survive after composting. Maximum reduction in helminth eggs were observed in the heaps with ratio 1:1.5 and 1:2 than the 1:1. This could be due to comparatively higher temperatures recorded and maintained in the 1:1.5 and 1:2 than the 1:1.

5.9 Coliforms and Helminth eggs on lettuce

The finished compost and dried non-composted sewage sludge (control) were applied to soil to cultivate lettuce. The results of helminth eggs, total and faecal coliforms on lettuce were higher than their levels in their respective compost and dried non composted sewage sludge before application to the soil. This observation is believed to be as a result of continuous application of dried non composted sewage sludge on the soil over years, which has the ability to accumulate pathogens in the soil. Soil test before the application of treatments showed that the total coliform, faecal coliform and helminth egg levels in the soil were even higher than their levels in the dried non composted sewage sludge. Gagliardi and Karns (2000) demonstrated that if *Escherichia coli* reached soil, via manure spreading or runoff from a point source, it could survive, replicate, for up to two months, threatening non target environment. During raining and/or irrigation, splashes of soil containing helminth eggs and coliforms can dust the lettuce and increase their levels on the lettuce. The levels of coliforms and helminth eggs on lettuce cultivated with the different compost types were lower than their levels on lettuce of which no treatment was applied. This was explained by Loper and Lindow (1993) and Handelsman and Stabb (1996) that matured compost, in many cases, contain natural organic chemicals and beneficial microorganisms that kill or suppress disease-causing microorganisms in the soil. The level of helminth eggs and coliforms on lettuce cultivated with the 1:1 compost were highest, followed by the 1:1.5 and lastly the 1:2. These levels also conform to their respective concentrations (Appendix E) prior to the application of the different composts to the different beds for lettuce cultivation.

5.10 Yield of Lettuce Grown with the Different Compost

Lettuce cultivated with dried non composted sewage sludge produced the highest yield (fresh weight), but had a higher level of pathogens on the lettuce compared to those cultivated with the various composts.

The lower yields of lettuce harvested from beds fertilized with compost might be due to high temperatures that generated during the composting process. The high temperatures though, led to the inactivation of pathogens, facilitated the loss of some nutrients like nitrogen in the form of ammonia. Among the three different composts applied to the soil, the compost with the ratio 1:1 yielded the highest produce. This could also be attributed to the lowest temperature attained during the compost production.

The results showed that, the higher the heat generated in the composting process, the higher the loss of nutrients from the compost. Another control experiment where no treatment (neither compost nor dried non composted sewage sludge) was applied showed very poor yield. The low levels of nutrients observed during the soil nutrient test (Table 3.2) confirm this. Results of lettuce yield (Table 4.1) and analysis of soil nutrients prior to the cultivation of lettuce showed that the yield of lettuce corresponds to the level of nutrients in the treatment that was applied.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

- The study showed that co-composting of dewatered sewage sludge and sawdust is an effective means of reducing the pathogen in sewage sludge intended for agricultural use as an organic fertilizer and/or soil conditioner.
- The level of nutrients (nitrogen, phosphorus and potassium) in the different compost products was found to be very low.
- Compost obtained cannot be compared with the chemical fertilizers in the market with respect to nutrient value. The chemical fertilizers have been found to contain about 15% each of these nutrients. Such compost cannot therefore serve as an improved alternative to these chemical fertilizers.
- The compost has a better ability of fertilizing and conditioning the soil as compared to the raw sludge (high pathogen content) and raw sawdust (low nitrogen content). Compost has a humus like quality that makes it even more useful, especially in areas where the humus content of soil is being rapidly depleted as a result of excessive cultivation and land erosion (Pagliali *et al*. 1981). That is to say, compost can replace lost humus.
- Application of these composts has relative advantage of being environmentally friendly. The chemical fertilizers pollute aquifers and other subterranean water bodies through leaching and run off of nitrate and cause eutrophication.
- There was no significant difference in the quality of compost produced, whether the compost was from the 1:1, 1:1.5 or 1:2. For that matter, where there is a

scarcity of sawdust, 1:1 should be adopted since it will produce compost of almost the same quality to compost from 1:1.5 or 1:2. On the other hand, where there is abundance of sawdust, then, the 1:2 is recommended for adoption since it will make maximum use of the sawdust but at the same time, produces compost of similar quality as compost from the 1:1 or 1:1.5.

- Composting of dewatered sewage sludge and sawdust has been shown to an economical way of reducing the volume of both the sewage sludge and sawdust. The piles were reduced by more than 50% of their original volume after the 16 weeks of composting. This method of composting can be adopted as a means of disposing the huge volumes of sewage sludge and sawdust produced in the country.

6.2 RECOMMENDATIONS

- The was no significant difference in the quality of compost produced from the three different ratios (1:1, 1:1.5 and 1:2) and therefore, further work should be done to find out the effects of turning on the co-composting process and the resulting compost quality.
- Again, further work should be done to assess the effect of sawdust from different wood species on the composting process and compost quality.

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APPENDICES

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

		Sum of Squares	df	Mean Square	F	Sig.
Moisture Content	Between Groups	980.670	4	245.168	125.985	.000
	Within Groups	9.730	5	1.946		
	Total	990.400	9			
Total Soilds	Between Groups	980.670	4	245.168	125.985	.000
	Within Groups	9.730	5	1.946		
	Total	990.400	9			
Organic Matter	Between Groups	892.666	4	223.167	566.412	.000
	Within Groups	1.970	5	.394		
	Total	894.636	9			
Ash Content	Between Groups	654.774	4	163.694	711.711	.000
	Within Groups	1.150	5	.230		
	Total	655.924	9			
Carbon	Between Groups	228.424	4	57.106	475.883	.000
	Within Groups	.600	5	.120		
	Total	229.024	9			
Nitrogen	Between Groups	.127	4	.032	11.949	.009
	Within Groups	.013	5	.003		
	Total	.140	9			
C-N Ratio	Between Groups	18.716	4	4.679	16.247	.005
	Within Groups	1.440	5	.288		
	Total	20.156	9			
Phosphorus	Between Groups	1.674	4	.418	168.068	.000
	Within Groups	.012	5	.002		
	Total	1.686	9			
Potassium	Between Groups	.066	4	.016	3.832	.087
	Within Groups	.021	5	.004		
	Total	.087	9			
pH	Between Groups	.396	4	.099	18.944	.003
	Within Groups	.026	5	.005		
	Total	.422	9			
Log Total Coliforms	Between Groups	163.233	4	40.808	171.860	.000
	Within Groups	1.187	5	.237		
	Total	164.420	9			
Log Faecal Coliforms	Between Groups	183.625	4	45.906	425.966	.000
	Within Groups	.539	5	.108		
	Total	184.164	9			
Log Helminths eggs	Between Groups	1.784	4	.446	3.163	.119
	Within Groups	.705	5	.141		
	Total	2.489	9			

Appendix B **One Way ANOVA for 1:1.5 Ratio Compost with Composting Period**

		Sum of Squares	df	Mean Square	F	Sig.
Moisture Content	Between Groups	1022.394	4	255.599	28.017	.001
	Within Groups	45.615	5	9.123		
	Total	1068.009	9			
Total Soilds	Between Groups	1022.394	4	255.599	28.017	.001
	Within Groups	45.615	5	9.123		
	Total	1068.009	9			
Organic Matter	Between Groups	579.626	4	144.907	35.223	.001
	Within Groups	20.570	5	4.114		
	Total	600.196	9			
Ash Content	Between Groups	409.576	4	102.394	17.964	.004
	Within Groups	28.500	5	5.700		
	Total	438.076	9			
Carbon	Between Groups	147.146	4	36.787	28.517	.001
	Within Groups	6.450	5	1.290		
	Total	153.596	9			
Nitrogen	Between Groups	.055	4	.014	1.153	.429
	Within Groups	.059	5	.012		
	Total	.114	9			
C-N Ratio	Between Groups	17.814	4	4.454	.986	.491
	Within Groups	22.575	5	4.515		
	Total	40.389	9			
Phosphorus	Between Groups	1.474	4	.369	269.015	.000
	Within Groups	.007	5	.001		
	Total	1.481	9			
Potassium	Between Groups	.038	4	.010	1.275	.390
	Within Groups	.037	5	.007		
	Total	.075	9			
pH	Between Groups	.778	4	.195	18.998	.003
	Within Groups	.051	5	.010		
	Total	.829	9			
Log Total Coliforms	Between Groups	151.717	4	37.929	69.546	.000
	Within Groups	2.727	5	.545		
	Total	154.443	9			
Log Faecal Coliforms	Between Groups	160.538	4	40.135	2879.097	.000
	Within Groups	.070	5	.014		
	Total	160.608	9			
Log Helminths eggs	Between Groups	1.476	4	.369	6.049	.037
	Within Groups	.305	5	.061		
	Total	1.781	9			

Appendix C **One Way ANOVA for 1:2 Ratio Compost with Composting Period**

		Sum of Squares	df	Mean Squares	F	Sig.
Moisture Content	Between Groups	1253.386	4	313.347	50.654	.000
	Within Groups	30.930	5	6.186		
	Total	1284.316	9			
Total Soilds	Between Groups	1253.386	4	313.347	50.654	.000
	Within Groups	30.930	5	6.186		
	Total	1284.316	9			
Organic Matter	Between Groups	869.886	4	217.472	29.203	.001
	Within Groups	37.235	5	7.447		
	Total	907.121	9			
Ash Content	Between Groups	566.346	4	141.587	9.397	.015
	Within Groups	75.335	5	15.067		
	Total	641.681	9			
Carbon	Between Groups	219.216	4	54.804	28.588	.001
	Within Groups	9.585	5	1.917		
	Total	228.801	9			
Nitrogen	Between Groups	.040	4	.010	3.590	.097
	Within Groups	.014	5	.003		
	Total	.054	9			
C-N Ratio	Between Groups	49.794	4	12.449	23.802	.002
	Within Groups	2.615	5	.523		
	Total	52.409	9			
Phosphorus	Between Groups	1.310	4	.327	409.325	.000
	Within Groups	.004	5	.001		
	Total	1.314	9			
Potassium	Between Groups	.033	4	.008	.662	.645
	Within Groups	.063	5	.013		
	Total	.096	9			
pH	Between Groups	.767	4	.192	4.289	.071
	Within Groups	.223	5	.045		
	Total	.990	9			
Log Total Coliforms	Between Groups	90.643	4	22.661	35.969	.001
	Within Groups	3.150	5	.630		
	Total	93.793	9			
Log Faecal Coliforms	Between Groups	136.253	4	34.063	34.115	.001
	Within Groups	4.993	5	.999		
	Total	141.246	9			
Log Helminths eggs	Between Groups	1.724	4	.431	13.469	.007
	Within Groups	.160	5	.032		
	Total	1.884	9			

Appendix D **One Way ANOVA for the Different Compost Ratios**

		Sum of Squares	df	Mean Square	F	P
Moisture Content	Between Groups	70.325	2	35.162	.284	.755
	Within Groups	3342.725	27	123.805		
	Total	3413.050	29			
Total Soilds	Between Groups	70.325	2	35.162	.284	.755
	Within Groups	3342.725	27	123.805		
	Total	3413.050	29			
Organic Matter	Between Groups	8.117	2	4.058	.046	.955
	Within Groups	2401.953	27	88.961		
	Total	2410.070	29			
Ash Content	Between Groups	29.642	2	14.821	.231	.796
	Within Groups	1735.681	27	64.284		
	Total	1765.323	29			
Carbon	Between Groups	1.554	2	.777	.034	.966
	Within Groups	611.421	27	22.645		
	Total	612.975	29			
Nitrogen	Between Groups	.820	2	.410	35.899	.000
	Within Groups	.308	27	.011		
	Total	1.129	29			
C-N Ratio	Between Groups	215.046	2	107.523	25.702	.000
	Within Groups	112.954	27	4.183		
	Total	328.000	29			
Phosphorus	Between Groups	.067	2	.033	.201	.819
	Within Groups	4.481	27	.166		
	Total	4.548	29			
Potassium	Between Groups	.003	2	.002	.164	.850
	Within Groups	.258	27	.010		
	Total	.262	29			
pH	Between Groups	.069	2	.035	.417	.663
	Within Groups	2.242	27	.083		
	Total	2.311	29			
Log Total Coliforms	Between Groups	26.191	2	13.095	.857	.436
	Within Groups	412.656	27	15.284		
	Total	438.847	29			
Log Faecal Coliforms	Between Groups	4.142	2	2.071	.115	.892
	Within Groups	486.018	27	18.001		
	Total	490.160	29			
Log Helminths eggs	Between Groups	.365	2	.182	.800	.460
	Within Groups	6.154	27	.228		
	Total	6.519	29			

Appendix F **Weekly Volume Readings (m^3) of the Different Compost Heaps**

	Heap(ratio)								
Time(week)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000	0.4000
1st	0.3631	0.3432	0.3532	0.3681	0.3567	0.3624	0.3645	0.3619	0.3632
2nd	0.3031	0.2923	0.2977	0.3142	0.3041	0.3092	0.3215	0.3105	0.3160
3rd	0.2988	0.2843	0.2916	0.3010	0.2833	0.2922	0.3021	0.2803	0.2912
4th	0.2843	0.2701	0.2772	0.2800	0.2661	0.2731	0.2901	0.2751	0.2826
5th	0.2702	0.2620	0.2661	0.2691	0.2593	0.2642	0.2866	0.2498	0.2682
6th	0.2618	0.2446	0.2532	0.2500	0.2474	0.2487	0.2676	0.2273	0.2475
7th	0.2447	0.2362	0.2405	0.2392	0.2167	0.2280	0.2522	0.2071	0.2297
8th	0.2355	0.2214	0.2285	0.2341	0.2073	0.2207	0.2343	0.1821	0.2082
9th	0.2161	0.2092	0.2127	0.2295	0.1994	0.2145	0.2379	0.1800	0.2090
10th	0.2145	0.2042	0.2094	0.2056	0.1776	0.1916	0.2115	0.1620	0.1868
11th	0.2072	0.1920	0.1996	0.1976	0.1588	0.1782	0.1986	0.1411	0.1699
12th	0.1935	0.1820	0.1878	0.1908	0.1571	0.1740	0.1844	0.1398	0.1621
13th	0.1876	0.1779	0.1828	0.1880	0.1565	0.1723	0.1796	0.1343	0.1570
14th	0.1842	0.1773	0.1808	0.1864	0.1540	0.1702	0.1785	0.1331	0.1558
15th	0.1833	0.1768	0.1801	0.1854	0.1461	0.1658	0.1780	0.1320	0.1550
16th	0.1826	0.1766	0.1796	0.1745	0.1430	0.1588	0.1728	0.1320	0.1524

Appendix G **Mean Monthly Total Solids Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1,a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	35.7	33.0	34.4	35.0	34.1	34.6	37.4	33.2	35.3
1st	49.9	47.9	48.9	48.6	41.7	45.2	51.0	49.6	50.3
2nd	56.1	54.3	55.2	57.7	53.6	55.7	57.3	58.9	58.1
3rd	60.1	58.3	59.2	60.0	56.2	58.1	66.4	61.3	63.9
4th	63.0	61.7	62.4	64.3	60.9	62.6	68.2	64.5	66.4

Key: 0 …… Initial state, 4th …… Maturation period

Appendix H **Mean Monthly Organic Matter Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	80.8	82.6	81.7	85.4	81.1	83.3	86.2	87.4	86.8
1st	74.2	74.2	74.2	75.8	73.4	74.6	80.8	73.5	77.2
2nd	69.3	67.6	68.5	71.3	67.8	69.6	71.5	69.3	70.4
3rd	62.7	63.2	63.0	65.8	63.8	64.8	65.1	62.0	63.6
4th	60.9	60.5	60.7	62.1	61.3	61.7	62.4	60.1	61.3

Appendix I **Mean Monthly Moisture Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	64.3	67.0	65.7	65.0	65.9	65.5	62.6	66.8	64.7
1st	50.1	52.1	51.1	51.4	58.3	54.9	49.0	50.4	49.7
2nd	43.9	45.7	44.8	42.3	46.4	44.4	42.7	41.1	41.9
3rd	39.9	41.7	40.8	40.0	43.8	41.9	33.6	38.7	36.2
4th	37.0	38.3	37.7	35.7	39.1	37.4	31.8	35.5	33.7

Appendix J **Mean Monthly Ash Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	19.2	17.4	18.6	14.6	18.9	16.8	13.8	12.6	13.2
1st	25.8	25.8	25.8	24.2	26.6	25.4	19.2	26.5	22.9
2nd	30.7	32.4	31.6	28.7	32.2	30.5	21.5	30.7	26.1
3rd	33.3	35.0	34.2	31.2	34.3	32.8	30.9	34.0	32.5
4th	35.1	35.5	35.3	32.9	36.2	34.6	33.6	34.9	34.3

Appendix K **Mean Monthly Carbon Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	41.7	42.6	42.2	44.0	41.8	42.9	44.4	44.6	44.5
1st	38.3	38.3	38.3	39.1	37.9	38.5	41.7	38.0	39.8
2nd	35.8	35.0	35.4	36.8	35.1	36.0	37.0	35.8	36.4
3rd	32.5	32.7	32.6	34.8	33.0	33.9	33.7	32.1	32.9
4th	31.9	31.3	31.6	32.2	31.5	31.9	32.3	31.1	31.7

Appendix L **Mean Monthly Nitrogen Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	1.86	1.80	1.83	1.71	1.85	1.78	1.49	1.41	1.45
1st	1.81	1.79	1.80	1.60	1.79	1.70	1.47	1.38	1.43
2nd	1.78	1.71	1.75	1.57	1.74	1.66	1.44	1.34	1.39
3rd	1.71	1.63	1.67	1.54	1.66	1.60	1.34	1.29	1.32
4th	1.68	1.59	1.64	1.50	1.64	1.57	1.30	1.27	1.29

Appendix M **Mean Monthly Carbon-Nitrogen Ratio of the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:5, b	Mean	1:2, a	1:2, b	Mean
0	22.6	23.5	23.1	25.8	22.6	24.2	29.8	31.6	30.7
1st	21.2	21.4	21.3	24.5	21.2	22.8	28.4	27.5	27.9
2nd	20.1	20.4	20.3	23.5	20.2	21.8	25.7	26.7	26.2
3rd	19.0	20.0	19.5	22.6	19.8	21.2	25.1	24.8	25.0
4th	18.9	19.6	19.3	21.5	19.2	20.4	24.8	24.5	24.7

Appendix N **Mean Monthly Phosphorus Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	1.41	1.53	1.47	1.31	1.35	1.33	1.30	1.25	1.28
1st	0.84	0.96	0.90	0.78	0.78	0.78	0.74	0.72	0.73
2nd	0.56	0.52	0.54	0.50	0.48	0.49	0.53	0.46	0.50
3rd	0.43	0.40	0.42	0.39	0.33	0.36	0.36	0.37	0.37
4th	0.39	0.35	0.37	0.31	0.22	0.26	0.26	0.25	0.25

Appendix O **Mean Monthly Potassium Content (%) in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:1, a	1:1, b	Mean
0	0.31	0.44	0.38	0.25	0.41	0.33	0.23	0.40	0.32
1st	0.23	0.32	0.28	0.17	0.26	0.22	0.18	0.32	0.25
2nd	0.17	0.26	0.22	0.12	0.24	0.18	0.13	0.29	0.21
3rd	0.13	0.20	0.17	0.12	0.23	0.18	0.09	0.26	0.18
4th	0.12	0.19	0.16	0.10	0.22	0.16	0.08	0.24	0.16

Appendix P **Mean Monthly PH in the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:1, a	1:1, b	Mean
0	6.9	6.69	6.8	6.8	6.67	6.74	6.68	6.85	6.77
1st	6.47	6.48	6.48	6.41	6.58	6.5	6.32	6.63	6.48
2nd	6.42	6.35	6.39	6.33	6.32	6.33	6.22	6.51	6.37
3rd	6.32	6.28	6.3	6.14	6.2	6.17	6.0	6.23	6.12
4th	6.2	6.24	6.22	5.8	6.03	5.92	5.76	6.19	5.98

Appendix Q **Log of Mean Monthly Total Coliforms in 10g of the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
1st	13.96	14.86	14.41	11.38	13.62	12.50	11.32	9.37	10.35
2nd	6.10	6.96	6.53	4.03	3.99	4.01	4.27	3.18	3.73
3rd	3.90	4.61	4.26	3.62	2.98	3.30	3.44	2.70	3.07
4th	3.80	4.22	4.01	2.23	2.36	2.30	2.98	2.04	2.51
5th	3.51	3.89	3.70	2.03	2.12	2.08	2.51	1.88	2.20

Appendix R **Log of Mean Monthly Faecal Coliforms in 10g of the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5b	Mean	1:2, a	1:2, b	Mean
0	11.37	10.36	10.87	10.37	10.32	10.35	9.37	9.62	9.50
1st	4.62	4.86	4.74	2.85	2.48	2.67	3.15	0.00	1.58
2nd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3rd	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4th	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix **S** **Mean Monthly Levels of Helminth Eggs in 10g of the Different Compost Heaps**

	Heap(ratio)								
Time(months)	1:1, a	1:1, b	Mean	1:1.5, a	1:1.5, b	Mean	1:2, a	1:2, b	Mean
0	75.0	46.5	60.8	60.0	41.7	50.9	21.3	62.5	41.9
1st	35.8	15.0	25.4	15.0	7.0	11.0	12.0	9.5	10.8
2nd	15.0	3.3	9.2	9.0	4.0	6.5	4.5	4.0	4.3
3rd	11.4	3.0	7.2	7.1	3.5	5.3	3.0	3.8	3.4
4th	10.1	2.8	6.5	6.2	3.0	4.6	2.0	3.2	2.6


Initial state of the compost heaps


Final state of compost