MANAGING GINNERY TRASH THROUGH COMPOSTING

BY

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DECLARATION

I hereby declare that this thesis is my own work towards the M.Sc degree and that, to the best of my Knowledge. It contains no material previously published by another person or material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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DEDICATION

I dedicate this work first of all, to God Almighty by whose grace I have come this far, and then to my lovely wife, Lena and daughter, Kareen, Vitus-Otto, my ever supportive elder brother and Paschalina my sister.

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ABSTRACT

Cotton ginneries in the Northern, Upper East and West regions generate a lot of trash (waste). One of the problems they face is how to dispose of the trash generated during the ginning process. Disposal methods used are considered environmentally inappropriate. Composting is considered as one possible method of disposal. The goal of the study was to study the feasibility of managing cotton gin trash through windrow composting with dewatered sewage sludge. The study took place at the Kwame Nkrumah University of Science and Technology sewage treatment site. Mixes of dewatered sewage sludge and trash in the ratios 1:1 and 1:2 and a third ratio 1:1 for trash and sandy soil as inoculum were subjected to the windrow (pile) composting method over a 120 day period. pH of the finished compost was between 6.04 and 6.74, organic matter 6.93 % for 1:1 Soil/T and 49.30 % for 1:2 S/T, nitrogen 0.24 % for 1:1 Soil/T and 1.4% for 1:2 S/T, phosphorous 0.05 % for 1:1 Soil/T to 0.17 % for 1:2 S/T, potassium 0.17 % for 1:1 S/T to 0.53 % for 1:1 Soil/T, Nitrogen 0.24 % for1:1 Soil/T to 1.4 % for 1:1S/T. C/N ratio reduced to 16.36 for Soil/T and to 18.13 for 1:2 S/T ratio. Heap volume reduction of 50 % and above was observed. The highest reduction in heap volume took place in the 1:2 S/T ratio which was 60 %. Nutrient concentrations also declined due to their use by the composting organisms for various metabolic and physiological processes. Coliforms and Salmonella concentration showed a decline. By the end of the first thirty (30) days faecal colifom concentrations were mean $\log_{10}$ 3.31 for 1:1 S/T, $\log_{10}$ 3.07 for 1:2 S/T whereas for 1:1 Soil/T. Salmonella was totally eliminated by the end of the first month for 1:1 Soil/T but by the end of the second month for the other ratios. Faecal Coliform and Salmonella concentrations fell below the recommended standard concentrations set by the United States of America Environmental Protection Agency (USEPA). This was due to the high temperatures of between 45 to 57 ^{o}C attained during the composting as pathogen destruction was based on the time-temperature relationship which was typical for the composting of organic matter. Lettuce cultivated with compost from the different ratios including the use of non-composted dewatered sewage sludge produced dry weight of between 7.23-7.80 g and 5.43 g for the control (No treatment). Non-composted dewatered sewage sludge produced the highest mean wet weight of 103.4 g per five (5) plants due to its high nutrient content. The studies revealed that the ratio 1:2 S/T was the best mix ratio. The study also showed that soil could also be used as inoculum with dewatered sewage sludge for the composting of trash. Land application of compost with it's non-detectable concentrations of faecal coliform and Salmonella should minimize environmental risk compared with raw non-composted sewage sludge. Windrow (pile) composting could be used to achieve quick, effective and environmentally safe disposal of gin trash.

Key words: Compost, sewage sludge, gin trash, coliform, nutrient, windrow

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LIST OF ABBREVIATIONS

S/T-- Sludge/Trash ratio

Soil/T--- Soil/Trash ratio

N/T-- No Treatment

S-- Sludge

M C-- Moisture content

T S-- Total solids

O M-- Organic matter

C-- Carbon

N-- Nitrogen

C/N-- Carbon/Nitrogen

P-- Phosphorous

K-- Potassium

pH--- Hydrogen ion concentration

T C-- Total coliform

F C--Faecal coliform

Sal--Salmonella spp

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Cotton has been used for producing clothing for at least 8000 years. Cotton is the most important fibre crop in the world; the lint is used to make processed cotton, which is woven into fabrics, either alone or combined with other fibres. The seeds contain 18-24 % edible oil (used as salad and cooking oil as well as to produce margarine), and the residual cake is rich in proteins and used for cattle food (Eisa et al., 1994). Cotton is one of the World's most important agricultural cash crops. Cotton is harvested in the form of seed cotton and requires ginning to separate the lint from the seed. A necessary situation that occurs in the cotton ginning process is the accumulation of about 90.72 kg of waste per ginned bale (Mayfield and Anthony, 1995).

Crossan and Kennedy, 2008 defined cotton gin trash as a complex mixture of woody fragments of cotton bolls, stalks, knotted cotton fibre residues, mulched leaves, soil and dust particles. The trash comprises about 20-40 % of the harvested cotton by mass separated from the cotton fibre (lint) during the mechanical intensive ginning process.

This waste called gin trash has to be disposed of at some time. Much of the gin thrash was incinerated for years but certain regulations such as the Clean Air Act of 1970 have removed burning as an option. There was a push to stop burning gin trash to improve air quality however it was also a good product that was being wasted. The particulate matter that comes off the gin trash as it burns is so heavy that it causes a great deal of smoke which leads to air quality problems.

Another option in the disposal of gin trash is to spread it directly on fields. Trash has been known to be used for mattress filters in Nigeria. Returning the organic material and nutrients can be beneficial. According to Gillham 1995, these methods have attendant problems. Including Weed seed and diseases, verticulum wilt and other plant pathogens that may be present in the plant residues may be introduced to or increased in fields when spreading raw gin trash. Feeding gin trash to livestock has generated concerns regarding chemical residues. Burning is no longer permitted due to the environmental pollution problems that it represents.

Sewage Sludge is a product of waste water treatment and is rich in nutrient, may contain some trace elements and could be reused as fertilizer. High odour emission, high level of heavy metal and toxic compounds and the presence of pathogenic micro-organisms demand pre-treatment of sewage sludge before application in Agriculture (Tiquia et al., 2002). Sludge characteristics will however depend on the source of the wastewater. Composting is an organized method of producing post manure by decomposition and stabilization of organic waste, Co-composting is a term used to describe the composting of a mixture of materials to provide a sustainable and cost effective disposal/re-use method for the co-composted material Ahring et al., (1992).

1.2 PROBLEM STATEMENT

Cotton production, takes place mainly in the three Northern regions of Ghana, namely in the Upper-West, Upper-East and Northern Regions. Methods adopted so far for the disposal of this trash include burning, spreading it directly on fields or using it as livestock feed (Gilham, 1995).

Stockpiling another disposal method, allows the wind to spread it around the environs creating environmental pollution and nuisance.

Production also involves the use of chemicals such as Polytrin C, Endosulphan, Cypercal among others whose residues can remain in the trash for over a 2-year period, (Crossan and Kennedy, 2008). This will endanger the lives of both livestock and humans as consumers. The widespread stockpiling of gin trash has recently raised concern with respect to the potential of residues leaching into the environment.

All the major Cotton Producing Companies have ginneries, namely Ghana Cotton Company Ltd (three ginneries). Plantation Development Limited in Wa, Nulux Plantations Limited based in Tamale and International Cotton farms also in Tamale. The ginning process results in 30-40 % of trash material with 64 % of the trash composed of burs and 15 % fine trash which include sand (Baker et al., 1994).

Since according to Gillham, (1995), these methods have attendant problems, an effective method of handling gin trash and reducing problems associated with it, is mainly to compost it. With moisture, approximately 70 %, the heat generated in the composting process can be sufficient to kill weed seeds and disease organisms. Gin trash once composted, becomes a rich, humus material, and the high nitrogen level in the trash (approximately 3 %) allows it to compost readily, (Crossan and Kennedy, 2008).

Sewage Sludge a product of waste water treatment is rich in nutrient, may contain some trace elements and could be reused as fertilizer. Conspicuously absent in literature is the composting of sludge and cotton trash hence the need for the current research to put both waste to good use.

1.3 JUSTIFICATION

Compost application to soil has several benefits. Numerous investigations revealed that compost produced from a variety of organic materials such as sewage sludge, animal manure and yard waste, can improve the physical, chemical and biological properties of soil Shiralipour et al., (1992) Composting is a successful strategy for the sustainable recycling of organic waste (Fermor, 1993; Tuomela et al., 2000).

Since there are problems associated with current disposal and usage methods for ginnery waste (trash) both by the ginneries and the general public it has become imperative that composting of ginnery trash be undertaken to mitigate these problems.

1.4 GENERAL OBJECTIVE

The general objective of this study therefore is to produce compost from ginnery trash as a means of managing ginnery waste (trash) in the cotton industry in Ghana.

1.5 SPECIFIC OBJECTIVES

The specific objectives are,

1. To determine the most suitable mixing ratio of ginnery trash and sludge so as to establish which has the best nutrient status.
2. To determine and compare the chemical, physical and biological parameters of the different mixtures.
3. To quantify the yield of lettuce that will be grown on each compost type so as to determine their suitability for use as organic fertilizer.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORY OF COMPOSTING

The process of composting organic or green waste is an ancient one. Pre-historic farming people discovered that if they mixed manure from their domesticated animals with straw and others organic waste such as crop residue, the mixture would gradually change into a fertile soil-like material that was good for crops. The Greeks, Romans and the Tribes of Israel were all known to compost their organic waste mixed with animal manure and street sweepings. Composting remained a basic activity in farming until the twentieth century, when various synthetic fertilizers were found to provide many of the nutrients occurring naturally in compost.

The process of composting involved little or no control, required long periods in the piles to provide good humus, might or might not conserve maximum nitrogen and certainly did not provide sanitary treatments. Sir Albert Howard was the first Agricultural scientist to bring a scientific approach to composting almost 75 years ago in India. He in collaboration with others systematized the traditional procedures into a composting method known as the Indore process, named after a city in Southern India. This process involved using only animal manure, but later involved stacking on open ground alternate layer of readily putrescible materials such as night-soil, animal manure, Sewage Sludge and garbage and relatively stable organic matter, such as straw, leaves, municipal refuse, and types of stable Waste (Gotaas, 1976).

The Indian Council of Agricultural Research at Bangalore further improved the method under the name Bangalore Process.

2.2 COMPOSTING

Epstein 1997, in his book, "The Science of Composting", defined composting as the biological decomposition of organic matter under controlled aerobic conditions into humus- like stable product. The term controlled indicated that the process is managed or optimized to achieve the desired objectives. Some of the major objectives are;

1. Decomposition of potentially putrescible organic matter into a stable state and produce a material that may be used for soil improvement or other beneficial uses.
2. Decomposition of Waste into a beneficial product. Composting may be economically favourable as compared to alternative disposable cost and may be more environmentally acceptable than more conventional solid waste management methods.
3. Disinfect pathogen infected organic waste so that they may be beneficially used in a safe manner.
4. Bioremediate or biodegrade hazardous waste by means of the composting process.

Often organic material which may have limited beneficial use in their raw state or have regulatory disposal constraints can be transformed by composting into marketable products. The limits on beneficial reuse of raw organic materials may be regulative or may be due to the potential for the raw materials to be putrescible or pathogenic. Composting can be a solution for each of these (Epstein, 1997). Other waste management options include recycling and land filling. Recently, many countries have made an effort to recycle 15 – 50 % of the wastes they generate (Diaz et al., 2002).

2.3 TYPES OF COMPOSTING

Composting may be divided into two categories by the nature of the decomposition process. Gotass (1976) classified composting into two processes. Aerobic decomposition and stabilization and anaerobic fermentation.

2.3.1 Aerobic composting

Aerobic composting takes place in the presence of ample oxygen. Living organisms which utilize oxygen feed upon the organic matter and develop cell protoplasm from the Nitrogen, Phosphorus, some of the carbon and other required nutrients. Much of the carbon serves as a source of energy for the organisms and is burned up and respired as carbon dioxide (CO_2). Carbon serves both as a source of energy and as an element in cell protoplasm. About two-thirds of the carbon is respired as carbon dioxide while the other third is combined with nitrogen in the living cells. If the excess of carbon over nitrogen in organic materials being decomposed is too high, biological activity diminishes and several cycles of organisms may be required to burn up most of the carbon. When the ratio of available carbon to available nitrogen is low, nitrogen is released as ammonia. Phosphorus, potash and various micro-nutrients are essential for biological growth. A great deal of energy is released in the form of heat in the oxidation of the carbon to CO_2.

If organic materials are in the pile or are otherwise arranged to provide some insulation, the temperature during fermentation will rise to over 70 ^{o}C. If temperature exceeds 65 ^{o}C – 70 ^{o}C biological activities decreased and stabilization slowed down. When temperature exceeds 45 ^{o}C (optimum growth temperature range, 20-45 ^{o}C) thermophilic organisms which grow and thrive in the temperature range 45-65 ^{o}C develop and replace the mesophilic bacteria in fermenting the material (optimum growth temperature range, 50-70 ^{o}C). Oxidation at thermophilic temperatures takes place more rapidly than at mesophilic temperatures and hence a shorter time is required for stabilization. Aerobic composting produces no objectionable odour. Odour presence suggests that the process is not entirely aerobic. Aerobic composting can be accomplished in silo digesters, pits, bins, stacks, or piles if adequate oxygen is provided. Turning the materials at intervals is necessary to maintain aerobic conditions.

2.3.2 Anaerobic Fermentation

In anaerobic composting, decomposition occurs where oxygen (O_2) is absent or in limited supply. Anaerobic micro-organisms in metabolizing nutrients break down the organic compounds by a process of reduction. As in the aerobic process the organisms use nitrogen, phosphorus, and other nutrients in developing cell protoplasm, but reduce the organic nitrogen to organic acids and ammonia. The utilized carbon is released as methane, CH_4.

In anaerobic dissimilation of the glucose molecule, only about 26 kcal of the potential energy per gram-molecule or glucose are released as compared to 484 – 674 cal for aerobic fermentation.

The lack of substantial release of heat is a definite disadvantage in the treatment of night-soil and other contaminated materials, where for public health reasons destruction of pathogens and parasites is necessary. High temperatures do not play a part in the destruction of pathogenic organisms in anaerobic composting. Pathogen disappearance is slow and material must be held for periods of six- months to a year to ensure relatively complete destruction of Ascaris eggs which are the most resistant of the faecal borne disease parasites in wastes (Gotass, 1976).

Under this method of composting, anaerobic micro-organisms dominate and develop intermediate compounds including methane, organic acids, hydrogen sulphide. In the absence of oxygen these compounds accumulate and are not metabolized further. Many of these compounds have strong odour and present phytotoxicity. As anaerobic composting is a low temperature process, it leaves weed seeds and pathogens intact. Moreover, the process usually takes longer than aerobic composting. These drawbacks often offset the merits of this process, viz little work involved and fewer nutrients lost during the process.

While the processes of composting are either aerobic or anaerobic some bacteria are facultative aerobic or facultative anaerobic, i.e. they can grow under aerobic or anaerobic conditions but may grow better under one condition.

2.4 CO-COMPOSTING: A NEW APPROACH TO COMPOSTING

Co-composting is a term used to describe the composting of two or more raw materials together. It is a waste treatment method in which different types of waste are treated together (Ahring et al., 1992, Angelidaki and Ahring 1997). Co-composting is an example of an integrated waste management. It cost less than separate treatment systems, mainly because of the lower cost per volume treated at large treatment plants. Composting of human waste and garbage (organic portion of refuse) is one that is advantageous because the two waste complement each other well. Human waste is high in nitrogen content and moisture and the garbage is high in organic (carbon) content and has good bulking quality.

Shuval et al., (1981) and Obeng and Wright (1987) collated information on historical and actual practices of co-composting "night soil" and (Sewage) sludge.

The concept of co-composting was a natural consequence of composting municipal refuse (Diaz et al., 1993). Co-composting of Potato starch sludge with swine manure has been investigated in Cheju Island in Korea by Yang et al., 1999. Co-composting was found to produce a high quality product that could be used as an organic fertilizer on potato crops.

2.4.1 MATERIALS FOR COMPOSTING

2.4.1.1 Sewage Sludge

Approximately 99 % of the Waste water stream that enters a treatment plant is discharged as rejuvenated water. The remainder is a dilute suspension of solids that has been captured by the treatment process. These wastewater treatment solids are commonly referred to as sewage sludge.

Primary, secondary and tertiary sludge normally are combined, and the resulting mixture, which contains 1 to 4% solids, is called "raw sewage sludge". However because of its pathogen content and its unstable, decomposable nature, raw sewage sludge is a potential health and environmental hazard. Some common treatment levels in sewage sludge are thickening, dewatering anaerobic digestion, aerobic digestion, and alkaline stabilization and composting. Sewage sludge is composed of both inorganic and organic materials, large concentration of some plant nutrients, much smaller concentration of numerous trace elements, organic chemicals and some pathogens. The composition of sewage sludge varies depending on the wastewater composition and the treatment process employed.

Land application of raw or treated sludge can reduce significantly the sludge disposal cost component of sewage treatment as well as providing a large part of the nitrogen and phosphorus requirement of many crops. Sewage sludge may contain potentially toxic elements, traces of many pollutants, some of which could be phytotoxic and some toxic to humans and/or animals. Sewage sludge also contains pathogenic bacteria, viruses and protozoa along with other parasitic helminthes which can give rise to potential hazards to the health of humans, animals and plants Dean and Suess (1985).

A WHO (1981) Report on the risk to health of microbes in sewages sludge applied to land identified Salmonellae and Taenia as giving rise to greatest concern. The numbers of pathogenic and parasitic organisms in sludge can be significantly reduced before application to the land. By employing the appropriate sludge treatment processes. The potential and health risk of compost is further reduced by the effect of climate, soil micro-organisms after the sludge is applied to the soil. Apart from the possible presence of toxic elements and pathogens, sewage sludge also contains useful concentration of nitrogen, phosphorus and organic matter. The organic matter in sludge can improve the water retaining capacity and structure of some soils especially when applied in the form of dewatered sludge cake. Other options for dealing with sewage sludge are by use of land filling and incineration.

2.4.1.2 Cotton Gin Waste (Trash)

Ginnery trash management is one of the biggest problems faced by the cotton ginning industry. Cotton gin trash (GGT) is a waste product of the cotton industry that basically is a mixture of stems, leaves, cotton lint and a few cotton seeds that have escaped the ginning process. The general make up of cotton gin waste consist of sticks, leaves, burs, soil particles other plant materials, mote and cotton lint. Ginning one bale (22.7 kg) of spindles harvested seed cotton lint contributes between 37 and 147 kg of waste (Thomason, 1990).

Generally cotton gin trash comprises about 30 – 40 % of the harvested cotton by weight, separated from the cotton fibre (lint) during intensive ginning process. In Ghana production takes place in the three Northern regions. The major producer of cotton is the Ghana cotton company limited. Similar companies such as Nulux Plantations, Plantation Development Company are also into cotton production but are however inconsistent.

Data obtained from the major producer Ghana Cotton Company Limited, (G.C.C.L) show that in the past cropping years the following amount of trash/ waste was produced;

2003/ 2005	=	310 tonnes
2004/ 2005	=	1,137 tonnes
2005/ 2006	=	1772 tonnes
2006/ 2007	=	708 tonnes
2007/ 2008	=	583 tonnes (Projected)

Source (Annual Report G.C.C.L 2007).

The availability of cotton gin trash is not in question for the production of compost. Cohen and Lansford (1992) determined that most cotton gin trash was disposed of by spreading on the land, composting, feeding to livestock, landfill disposal, incineration, conversion to energy, making pellets for fuel in heat store building materials, and insulation. Incineration is rapidly been phased out due to regulations such as the 1970 clean Air Act. Inspite of these disposal methods, most of the waste generated by the ginnery is thrown back onto the field, where it becomes a soil additive.

Avant (1982) reported that cotton gin trash has immediate potential as a boiler or combustion unit fuel for regional processing industries. Le Pori et al., (1982) studied the combustion and gasification of cotton gin trash and concluded that cotton gin trash has the potential of supplying all the energy needed for a gin in stripper harvesting areas. Beck and Clements (1982), showed that ethanol production form cotton gin residue is both technically and economically feasible, and that 37.8 gallons of ethanol can be produced per ton of gin trash. Composting of gin trash offers the potential to reduce the negative attributes of "raw gin trash" if the material is composted properly. The resulting compost is valuable as a soil additive because it contains substantial nutrients.

2.5 THE COMPOSTING PROCESS

This process is divided into two; the active stage and the curing stage. The aerobic composting process starts with the formation of the pile. The material being composted decomposes as a result of the activity of the bacteria, fungi, actinomycetes and protozoa present in the waste material and of those that are from the atmosphere. The efficiency of the process depends to a large extent on temperature since microbial succession occurs with the temperature changes brought about by microbial activity. Table 2.1 shows typical numbers of some organisms present in various stages of composting.

Table 2.1: Microfloral Population during Aerobic composting

	Numbers per gram wet compost			
	Mesophilic initial temperature – 40 ºC	**Thermophilic 40 – 70 ºC**	**Mesophilic 70 ºC – initial temperatures**	**Numbers of microorganisms identified (species)**
Bacteria				
Mesophilic	10^8	10^6	10^{11}	6
Thermopilic	10^4	10^9	10^7	1
Actinomycetes				
Thermophilic	10^4	10^8	10^5	14
Fungi[1]				
Mesophilic	106	10^3	10^5	18
Thermophilic	10^3	10^7	10^6	16

Source: adapted from Poincelot (1974).

In many cases, the temperature rises rapidly to 70 ^oC – 80 ^oC within the first couple of days. First mesophilic organisms multiply rapidly on the readily available sugars and amino-acids. They generate heat by their own metabolism and raise the temperature to a point where their own activities become suppressed and their population declines. Then a few thermophilic fungi and thermophilic bacteria continue the process raising the temperature to 65 ^oC or higher. This peak heating phase is important for the quality of compost as the heat kills pathogens and weed seeds (FAO, 1980).

The active composting stage is followed by a cooling stage, as the pile temperature decreases gradually. The start of this phase is identified when turning no longer reheats the pile. At this stage, another group of thermophilic fungi starts to grow. These fungi bring about a major phase of decomposition of plant cell-wall materials such as cellulose and mini-cellulose (FAO, 1980). Curing of the compost provides a safety net against the risk of using immature compost. At this point mesophilic organisms (mainly fungi and actinomycetes) once again increase. As the process approaches completion, the temperature eventually returns to its ambient value. Typical minimal, optimal and maximal temperature ranges for mesophils and thermophils, are as shown in table 2.2 below (Obeng and Wright 1987)

Table 2.2: Maximum, Optimum, and Minimum Temperature Ranges for Mesophils and Thermophils (^{o}C)

	Minimum	Optimum	Maximum
Mesophilic	10-25	25-35	35-45
Thermopilic	25-45	50-55	75-80

Source: Glathe and Farkasdi (1966).

By the time composting is completed, the pile becomes more uniform and less active biologically although mesophilic organisms recolonize the compost. The material turns dark brown to black in colour. The particles reduce in size and become consistent and soil-like in texture. In the process, the amount of humus increases, the ratio of carbon to nitrogen (C: N) decreases, pH, becomes neutral.

2.6 ORGANISMS INVOLVED IN COMPOSTING

Compostable waste materials (refuse, night, soil, manure, sewage sludge, and miscellaneous vegetable matter) normally contain a large number of many different types of bacteria, fungi, moulds and other living organisms.

Extensive studies of the microbiology of aerobic composting of manure and other organic matter have shown that a variety of specific organisms perform specific functions and that no single organism, no matter how active, can compare with a mixed population in producing rapid and satisfactory decomposition. During decomposition marked changes take place in the type and numbers of the microbiological population. Temperature changes and the availability of food probably exert the greatest influence in determining the species of organisms comprising the population at any given time. (FAO, 1980). In aerobic composting the facultative and obligate representative of bacteria actinomycetes and fungi are the most active. Mesophilic bacteria are characteristically predominant at the start of the process soon giving way to thermophilic bacteria which inhabit all parts of the stack where the temperature is satisfactory. Thermophilic fungi usually appear after 5-10 days actinomycetes become conspicuous when short duration rapid composting is practiced.

The thermophilic actinomycetes and fungi have been found to grow in the temperature range between about 45 ^{o}C and 60 ^{o}C Inspite of being confined primarily to the outer layers and becoming active only during the maturation part of the composting period, fungi and actinomycetes play an important role in the decomposition of cellulose, lignins and other more resistant materials. Considerable cellulose and lignin decomposition by actinomycetes and fungi can occur near the end of the composting period, when the temperatures have begun to drop and the environment in a larger part of the pile is satisfactory for their growth. Hence in the interest of their activity, turning is necessary for providing sufficient aerobic conditions and controlling flies. Among the actinomycetes, Streptomyces and Micromonosporo are common in compost, Micromonospora being the most prevalent. Fungi in compost include Thermomyces sp, Penicillium duponti, and Aspergillus fumigatus.

2.7 METHODS OF COMPOSTING

2.7.1 Small Scale Composting

The methods employed in composting depends on whether it is being done on a small scale or a large scale and whether, anaerobic or aerobic, fast or slow composting. Composting of organic substances are usually carried out in windrows, aerated static piles, in vessel reactors and tumbling cylinders, (Deport et al., 1995; Dincer et al., 1996).

2.7.1.1 THE BANGOLORE METHOD OF INDIA (ANAEROBIC)

This method of composting was developed at Bangalore in India in 1939 (FAO, 1980). It is recommended where night soil and refuse are used for preparing the compost. It consists of the digging of Trenches or pits about 1m deep. Trenches should have sloping sides and a floor with a 90 cm slope to prevent water logging.

2.7.1.2 THE COIMBATORE METHOD OF INDIA

This method involve digging a pit 360 cm long × 90 cm deep in shaded area (length can vary according to the volume of waste materials available). Farm waste such as straw, vegetable refuse, weeds and leaves are spread to a thickness of 15-20 cm. Wet animal dung is spread over this layer to a thicker of 5 cm water is sprinkled to moisten the materials (50-60 % of mass). This procedure is repeated until the whole mass reaches a height of 60 cm above ground, it is then plastered with mud and anaerobic decomposition commences. Compost is ready for use after four months. Mud plaster is removed and the entire mass is turned. Aerobic decomposition commences at this stage.

Other traditional methods are the Indian Indore heap method (FAO, 1980). Chinese rural composting–pit method (FAO, 1980). Ecuador in farm composting methods, Berkley rapid composting method which corrects some of the problems associated with the earlier methods of composting, (Aerobic high temperature composting with inoculum called the effective micro-organisms based quick composting method has been used in Myanmar This employs the use of effective micro-organism such as photosynthetic bacteria, lactobacillus, streptomyces, actinomycetes yeast and others that are commonly available from microbe banks or from the environment.

2.7.2 Windrow Composting

A windrow is simply an elongated pile of material with a more or less triangular cross section. As Illustrated in Figure 1, a windrow should measure about 3 metres (10 feet) wide and 1.5 metres (5 feet) high; its length will vary depending upon the amount of materials used. Aeration occurs naturally. As hot air rises, fresh air is drawn into the pile. Materials can be added as they become available, or stockpiled until sufficient amounts are available to make a good sized pile or windrow. There are two types of windrow composting.

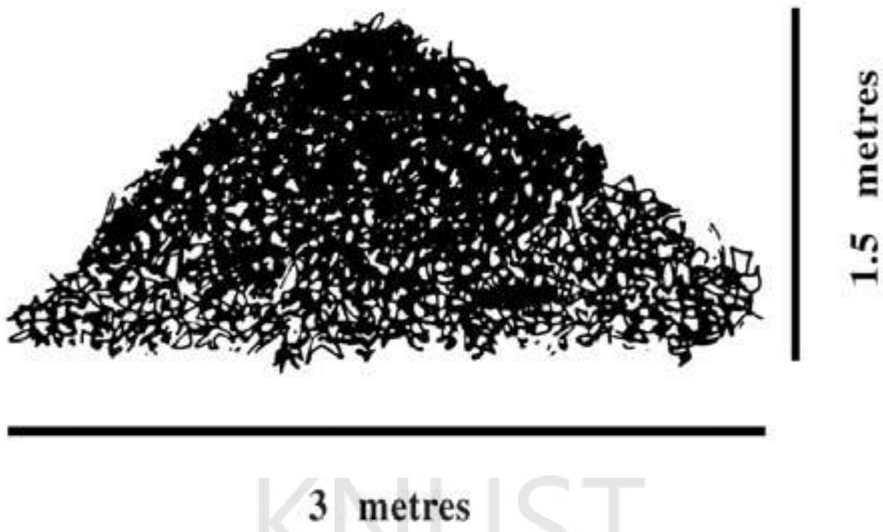


Figure 2.1: The Width and Height of a Pile

2.7.2.1 TURNED WINDROW METHOD

Windrow composting consist of placing the mixture of materials in long narrow piles called windrows that are agitated or turned on a regular basis (NRAES 1992). Typically, the wind-rows are from 90 cm high for dense materials such as manure to 360 cm high for light voluminous materials such as leaves. They vary in width from 300-600 cm equipment used for turning determines the size, shape and spacing of the wind-rows. Windrows aerate primarily by natural or passive air movement Windrows should be turned frequently at first and then at longer intervals by the end of the first month. A recommended turning frequency is;

1st week	-	3 turning
2nd week	-	2 turning
3rd week	-	2 turning
4th and 5th week	-	1 turning each week
6th and above	-	1 tuning every 2 week if heating still occurs

In windrow composting thermophilic range lies between 45 ^{o}C and 70 ^{o}C. 45 – 50 ^{o}C is obtained in the first 24 hours and 60 ^{o}C – 70 ^{o}C after 25 days, (Golueke, 1985).

Unpleasant odour occurred in earlier composting practices because of the activities of facultative and anaerobic microorganisms in the biodegradation process. It was therefore felt that there was the need to improve the control techniques, in order to eliminate this negative situation. The Beltsville aerated pile method was therefore developed. This is based on a good nutrient concentration in a short composting period, has low production cost, a bacteriologically safe final product and provides for enough aeration for the micro-organisms (Wilson and Dalmat, 1983; Sanchez – Monodero et al., 2001).

2.7.2.2 PASSIVELY AERATED WINDROWS METHOD

Under this method, air is supplied to the composting materials through perforated pipes embedded in each wind-row thereby eliminating the need for turning. The pipe ends are open. Air flows into the pipes and through the windrows because of the chimney effects created as the gases rise upwards out of the windrow. Windrows should be 90-120 cm high build on top of a base of straw peat mass or finished compost to absorb moisture and insulate the windrow. Materials for composting must be thoroughly mixed because the raw materials cannot be turned when windrows are formed.

2.7.2.3. AERATED STATIC PILE

The aerated static pile method takes the piped aeration system a step further, using a blower to supply air to the composting materials. The blower provides the direct control of the process allowing for the build up of larger piles. No turning or agitation of materials occurs once the pile is formed. Where the pile has been formed properly and air supply is sufficient and the distribution uniform, the active composting period is completed in about three to five weeks. The initial height of the piles should be about 150-245 cm high, and 240 cm-360 cm in diameter, depending on material porosity, weather conditions and the reach of the equipment used to build the pile. Aerated static pile composting offers a medium technology and sometimes results in a non-uniform product.

2.7.2.4 IN-VESSEL COMPOSTING

This refers to a group of methods that confine the composting materials within a building, container or vessel (NEAES 1992). In vessel methods rely on a variety of forced aeration and mechanical turning techniques to accelerate the composting process. There are a variety of in-vessel methods with different combinations of vessels, aeration devices and turning mechanisms.

2.7.2.5 BIN COMPOSTING

Bin composting methods are commonly used for yard waste; smaller amounts of manure. Turning compost can reduce decomposition time to two months or less. The materials are put in bins and usually have roofs. The bin may be simply wooden slatted walls (with or without a roof) a grain bin or a bulk storage building. Buildings or bins allow for higher stacking. Bins can eliminate weather problems, contain odours and provide better temperature control. Other bin composting methods are, Silos, rotating drums and transportable containers.

2.7.2.6 VERMICOMPOSTING

The term means the use of earthworms for composting organic residue. Earthworms can consume practically all kinds of organic matter and they can eat their own body weight per day, e.g. 1 kg of worms can consume 1 kg of residues every day. The excreta (casting) of the worms are rich in nitrate, available forms of phosphorous, potassium, calcium and magnesium. The passage of soil through earthworms promotes growth of bacteria and actinomycetes. Lumbricus terrestris (red worm) and Eisenia foetida are thermotolerant and so particularly useful field worms (Allolobaphora caliginosa) and night crawlers (Lumbricus terrestris) attack organic matter from below but the latter does not thrive during active composting because they are killed easily at high temperatures. Vermicomposting is in use in many countries, including the Philippines and Cuba (FAO, 1980).

A study has examined the possibility of integrating traditional thermophilic composting and vermicomposting (Ndegwa and Thompson, 2001). The work involved combining pertinent attributes from each of the two processes to enhance the overall process and improve the product quality.

2.8 COMPOSTING GIN TRASH

An effective method of handling gin trash in order to eliminate the problems of weed seeds and diseases which are associated with raw gin trash is by composing it. With adequate moisture, the heat generated in the composting process can be sufficient to kill weed seeds (60^{O}C for 10 days) and diseases organism 63^{O}C for four days (Parnell et al., 1980).

Commercial composting systems have demonstrated this. However the high cost of commercial composting systems tend to be prohibitive, so alternative composting methods have been investigated.

Windrow composting can generate the necessary heat if there is adequate volume, moisture and aeration. Aeration is usually provided by turning the trash with some type of tool. Recently new gin trash handling methods have been developed. The Lipsey-gin-trash-composting system requires the compost to stay in place. Compost made from gin trash has been tested as soil amendment in the field on green bean culture, Hileman and Morelock 1982, in pot mixer with soil on tomato culture (Pessarakli and Tucker 1984) and in a pot mix with peat and vermiculite a number of house plants with promising results (Parnell et al., 1980)

2.9 FACTORS AFFECTING COMPOSTING

Various factors affect the composting process; "so many factors are involved, nearly all are interrelated, and that this complex ecological process is unlikely to succumb to rigorous scientific analysis for many years" (Gray and Sherman, 1969). These factors are moisture content, aeration and oxygen supply, nutrients, temperature, pH, particle size and porosity of composting materials. These factors play major roles in the process of composting, influencing the direction and extent of the process. Since 1969 new chemical and physical techniques have provided scientific tools to examine and manipulate these factors. These factors affect the efficiency of the composting process and the quality of the product. The microbial decomposition of organic waste is controlled with aeration, temperature and moisture; these are important factors influencing microbial biodegradation rates.

2.9.1 Moisture Content

According to Obeng and Wright 1987, the moisture content of a composting mixture should be greater than 12-15 percent, being the lowest level at which bacterial activity will occur.

Moisture is necessary to support the metabolic activity of the micro-organisms. Composting materials should maintain moisture content of 40-65 percent. Where the pile is too dry, composting occurs more slowly, while moisture content in excess of 65 percent promotes the development of anaerobic conditions. In practice it is advisable to start the pile with moisture content of 50-60 percent, finishing at about 30 percent (FAO, 1980).

Sewage sludge and night soil contain a great deal of moisture (above 92 percent) in their untreated state. Sewage even when dewatered may still be too wet to be composted on its own and amendment or bulking agents will then be required to reduce the moisture content as well as increase the carbon content, (Obeng and Wright, 1987).

Sewage sludge can be composted aerobically over a wide range of moisture contents, 30% and higher, if aeration is adequate. However excessively high moisture content should be avoided because water displaces air from the pore spaces and can quickly lead to anaerobic conditions. On the other hand if the moisture content is below 40 %, stabilization will be slowed down because water is essential for microbial growth (USEPA, 1994).

2.9.2 Aeration and Oxygen Supply

Aerobic composting requires large amount of oxygen particularly at the initial stage. There is the need for oxygen greater than 5 % in piles for aerobic conditions. The optimum levels of oxygen required for the growth of aerobic micro organisms range from 5-15 percent of the air. Where the supply of oxygen is not sufficient, the growth of aerobic micro-organisms is limited resulting in slower decomposition. In composting sewage sludge, aeration is essential for the development of thermophilic micro-organisms to ensure rapid decomposition, odour abatement and stabilization of the residual organic fraction; which remains as compost. Aeration also removes excessive heat, water vapour and other gases trapped in the pile (FAO, 1980).

Oxygen consumption in a composting mass depends on several factors;

(a) the stage of the process

(b) temperature;

(c) the degree of agitation of the mass;

(d) the composition of the composting mass

(e) the particle size of the mass; and

(f) the moisture content,

Aeration is indispensable for efficient composting. This can be achieved by controlling the physical quality of the materials used in composting, the size of the piles, ventilation and frequency of turning (FAO, 1980).

2.9.3 Nutrients (C/N Ratio)

Nutrients especially carbon and nitrogen play an important role in the process as they are essential for microbial growth and activity. Carbon is the principal source of energy and the basic building block making up about 50 percent of the mass of microbial cells. Nitrogen is a crucial component of the proteins, nuclei acids, enzymes and co-enzymes necessary for cell growth and function. To obtain the optimal C: N ratio, the C: N ratios of each of the composting ingredients are used (Dickson et al., 1991).

Micro-organisms use about 30 parts of carbon for each part of nitrogen. Thus an initial C/N ration of 20-35 would be most favourable for rapid conversion of organic waste into compost. Sewage sludge usually have C/N ratio of less than 15. Although decomposition will be rapid at this ratio, nitrogen may be lost as ammonia (Hornic et al., 1979). The addition of amendments or bulking agents that have a high C/N ratio compared with sewage sludge or night soil can be used to adjust the final ratio within optimal range. The table below shows the C/N ratios of various wastes (Obeng and Wright, 1987).

Table 2.3: Approximate Nitrogen content and C/N Ratios for some Compostable Materials

Material	Nitrogen	C/N ratio% dry weight
Urine	15-18	0.8
Mixed slaughterhouse waste	7-10	2
Night soil	5.5-6.5	6-10
Digested sewage sludge	1.9	16
Activated sludge	5.0 6.0	6
Young grass clippings	4.0	12
Cabbage	3.6	12
Weeds	2.0	19
Grass clippings (average mixed)	2.4	19
Farmyard manure (average)	2.15	14
Seaweed	1.9	19
Potato haulms	1.5	25
Oat straw	1.05	48
Wheat straw	0.3	128
Fresh sawdust	0.11	511
Food waste	2.0-3.0	15
Fruit waste	1.5	35
Refuse	0.5-1.4	30-80
Wood	0.07	700
Paper	0.2	170

Source: Gotaas (1976)

When the C/N ratio is higher than 40:1, the growth of micro-organisms is limited resulting in a longer composting time. If the ratio is too low, the large amount of nitrogen present is rapidly lost by volatilization as molecular ammonia. A C/N ratio of less than 20:1 leads to underutilization of N and the excess may be lost to the atmosphere as ammonia or nitrous oxide and odour can be a problem (FAO, 1980).

Since nitrogen is a valuable plant nutrient, its level in mature compost needs to be kept reasonably high. Maintaining on optimum C/N ratio is advantageous to the process.

2.9.4 Temperature

Temperatures profoundly affect the growth and activity of micro organisms and consequently determine the rate at which organic materials decompose. Temperature increase is a result of microbial activity. The process of composting involves two temperature ranges; mesophilic (10-45 ^{o}C) and thermophilic (25-80 ^{o}C), (FAO, 1980).

According to Obeng and Wright, 1987, most microorganisms grow best within temperatures of 20-30 ^{o}C. Excreted pathogens thrive at body temperature of 37 ^{o}C.

The influence of temperature on microbial activity has caused several researchers to try to define the optimum temperature for composting (Batch et al., 1984; McKinley and Vestal 1984). The range of optimal temperature for the composting process as a whole is broad, from 35-55 ^{o}C because various microorganisms are involved in the decomposition of organic matter. Temperature is perhaps a more reliable indicator than moisture, aeration or nutrient concentrations since it directly affects pathogen control.

High temperatures during the composting of various materials is effective for the pasteurization of pathogenic micro-organisms in the materials, the promotion of water evaporation from the composting materials and the acceleration of the rate of degradation of organic matter in the composting materials. Thermophilic aerobic microorganisms develop only higher temperatures and grow fastest at 45 – 65 ^{o}C. These thermophiles generate high temperatures for the destruction of human pathogens.

2.9.5 pH

pH between 5.5 and 8.5 is optimal for compost microorganisms. As bacteria and fungi digest organic matter, they release organic acid. In the early stages of composting, these acids accumulate. The resulting drop in ph encourages the growth of fungi and the breakdown of lignin and cellulose during the composting process. If the system becomes anaerobic, however, acid accumulation can lower the pH severely limiting microbial activity. At a pH of 8-9, nitrogen may be lost through volatilization of molecular ammonia. pH may cause process malfunction. As the process approaches stability, the pH shifts towards neutrality (pH 7).

Sewage sludge can be composted over a pH range from 5 to 10. Nevertheless initial pH values as extreme as 5 or 11 do not seem to retard microbiological activity for more than 1 or 2 days.

2.9.6 Time

Length of time needed for degradation depends on all the other factors and the end use. Compost quality greatly depends on the length of time that a mixture is composted. If high temperature is not maintained throughout the material for a sufficient length of time (>2 days) pathogen destruction will not be achieved at the required level. Some heat resistant pathogen may survive this temperature range.

2.9.7 Porosity, Structure and Particle Size

Porosity and other physical factors limit air and oxygen movement in compost piles. Compost materials that are small in particle size are more readily decomposed than material of large particle size. Too fine particles have less oxygen diffusion tendencies. Bulking agents may need to be added to increase porosity e.g. yard trimmings, wood shavings, etc. Typical particle sizes of materials for composting range from 10 to 50 millimeters (Obeng and Wright, 1987).

2.9.8 Nutrient Balance

Phosphorus and sulphur are also important, but less is known about their role in composting. Microorganisms require the same micronutrients as plants and compete for available micronutrients. Micronutrients such as Copper, Nickel, Molybdenum, Iron, Zinc and Sodium are necessary for enzymatic functions but little is known about their importance to the composting process. Normally these nutrients are not limiting because they are present in ample concentration in the compost source materials.

2.9.9 Odour

The presence or absence of odour is not only an index of the efficiency of the process, but also affect public acceptance of and support for the siting of compost plants, especially in areas of high population densities. Excessive odour during composting can probably be attributed to inadequate stabilization of the compost due to too high moisture content of the material in the pile. Several interventions can help solve the problems of odour.

2.10 AMENDMENTS AND BULKING AGENTS

An amendment as a material added to other substances to condition the feed mixture (Haug, 1983). There are two types of amendments.

2.10. 1 Structural or drying amendment

An organic or inorganic material added to reduce bulk weight and increase air voids allowing for proper aeration.

2.10.2. Energy or fuel amendment

Is any organic material added to increase the quality of biodegradable organics in the mixture and thereby increase the energy content of the mixture.

Amendments that have been used to condition wet substrates such as Sludge Cake include sawdust, straw, peat, rice hulls, cotton gin trash, manure, refuse fractions of yard wastes and vermiculite. The ideal amendment is dry, has a low bulk weight and is relatively degradable.

A bulking agent is a material, organic or inorganic, of sufficient size to provide structural support and maintain air spaces within the composting matrix. Bulking agents form a three dimensional material of solid particle, capable of self support by particle – particle contact. Sludge Cake can be viewed as occupying part of the void between particles. If the bulking agent is organic an increase in the energy content of the mixture is a secondary benefit. Wood chips about 1 to 2 inches in size are the most commonly used bulking agents, although uses of other materials has been reported (tree trimmings, shredded tyres, peanut shells). Anything added to the composting heap should be considered a feedstock, whether it is termed a substrate, amendment or bulking agent (Haug, 1983).

2.11 DESTRUCTION OF PATHOGENS IN COMPOSTING

The destruction of pathogenic organisms is important especially involving compost containing night-soil, sewage or other highly contaminated materials. Excreted pathogens occur in sewage sludge at varying concentrations depending on their ability to survive the various sewage treatment processes and whether they accumulate in the sludge.

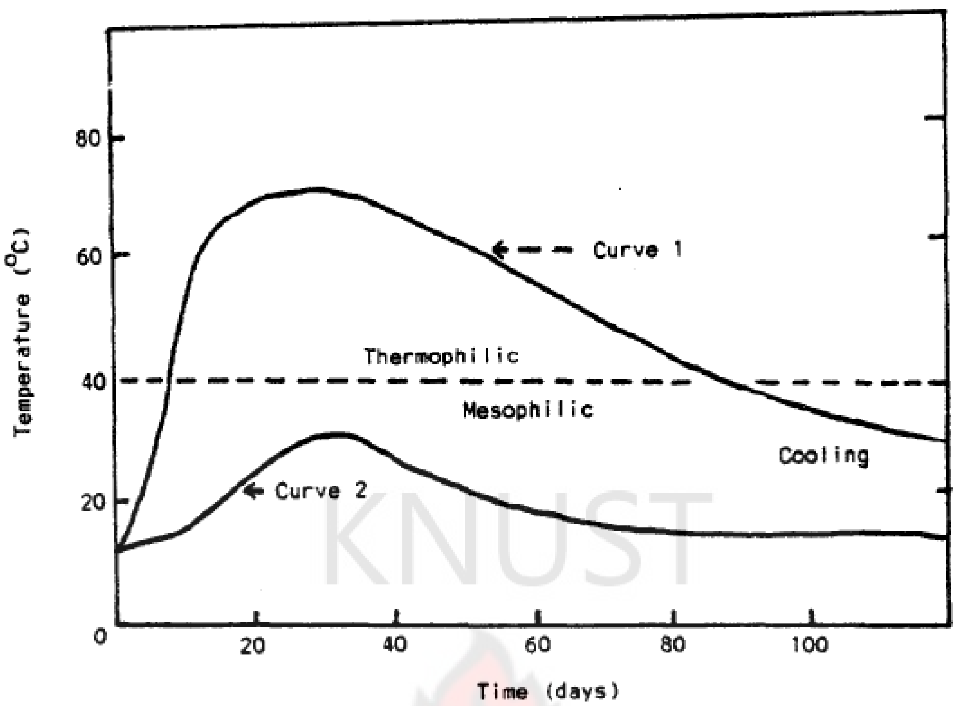
Pathogen destruction is significant evidence of the effectiveness of the thermophilic composting phase. The magnitude and duration of the high temperatures provide a sound basis for believing that no pathogens or parasite ova survives the aerobic composting process. Pathogen concentration in night soil and sludge depends entirely on the levels being excreted at any one time and on the ability of the pathogens to survive in the external environment. Feachem et al., 1983 have reviewed a lot of literature on the survival of enteric pathogens during various treatments and present detailed information on health and other aspects of excreta-related infections, in the table 2.4 below.

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

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

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

For the elimination of pathogens the application of temperature over 50 ^{o}C and microbial content are used as key parameters on composting. According to Feachem et al., (1983), the key factors in determining the survival of pathogens are the temperature-time interaction. They then went ahead and suggested various temperature time requires for selected pathogen to ensure their death in Sewage Sludge and night soil. These have been based on an evaluation of survival time for numerous pathogens over a wide range of temperature (Figure 2.2, below).



Source: Parr et al, 1978.

Figure 2.2: A typical time/temperature relationship for composting sewage sludge by the aerated pile method

Curve 1 depicts a situation where conditions of moisture, temperature, and aeration are at optimum levels for rapid transition from the mesophilic into the thermophilic stage. Curve 2 represents a condition where temperature, moisture and aeration are deficient or outside their optimum range, resulting in adverse effects on the growth and activity of the indigenous organisms.

Sample of sludge or night soil should be free of excreted pathogens if they are heated for 1 hour at > 62 ^oC, 1day at > 50 ^oC or at > 46 ^oC. Heat resistant bacterial spores such as those of Clostridium perfringens may however still persist. Small Scale studies, using 20 – 30 tons of compost material have shown that E.coli and Salmonella spp are destroyed by heat more easily than streptococci and even C perfringens numbers decrease during composting and maturation. Maintaining temperatures at 55 ^oC for 2 days as a minimum is within the safety zone as shown in the figure. This figure is a reliable indicator of survival times especially since the use of standard faecal coliform counts may not be reliable (these have been shown to multiply in mature compost (Burge et al., 1981). Turning, aerates the piles, ensures pathogen and parasite destruction particularly if a composting period of less than six months is used. Compost temperature curves and thermal-death point values may indicate that one turn will be sufficient to eliminate the pathogen and parasites if all the surface material is completely turned to the inside, thus exposing the organisms present to the lethal internal temperatures. As a factor of safety and to guard against failure to turn all of the material to the inside, at least two turns are required and at least three to provide maximum assurance of complete destruction when night soil and raw sewage sludge are composted

Survival times for some of the common disease causing organisms are shown in the Table 2.5 in next page.

Table 2.5: Temperature and Exposure Time Required for Destruction of some common Pathogens and Parasites

ORGANISM	OBSERVATION
Salmonella typhosa	No growth beyond 46 °C; death within 30 minutes at 55-60 °C and within 20 minutes at 60 °C; destroyed in a short time in compost environment
Salmonella sp.	Death within 1 hour at 55 °C and within 15-20 minutes at 60 °C
Shigella sp.	Death within 1 hour at 55 °C
Escherichia coli	Most die within 1 hour at 55 °C and within 15-20 minutes at 60 °C
Entamoeba histolytica cysts	Death within a few minutes at 45°C and within a few seconds at 55 °C
Taenia saginata	Death within a few minutes at 55 °C
Trichinella spiralis larvae	Quickly killed at 55 °C; instantly killed at 60 °C
Brucella abortus or Br. Suis	Death within 3 minutes at 62 °C-63 °C and within 1 hour at 55 °C
Streptococcus pyogenes	Death within 10 minutes at 54 °C
Mycobacterium tuberculosis var. hominis	Death within 15-20 minutes at 66 °C or after momentary heating at 67 °C
Necator americanus	Death within 50 minutes at 45 °C
Ascaris lumbricoides eggs	Death in less than 1 hour at temperatures over 50 °C

Source**:** Gotaas 1976, Page 81

Table 2.6: Examples of pathogens found in or generated during composting of sewage sludge and the diseases they are associated with

GROUP	EXAMPLE	DISEASE
PRIMARY PATHOGENS		
Bacteria	Salmonella enteritidis	Salmonellosis (food poisoning)
Protozoa	Entamoeba histolytica	Amoebic dysentery (Bloody diarrhea)
Helminthes	Ascaris lumbriocides	Ascariasis (worms infecting the Intestine)
Virus	Hepatitis virus	Infectious hepatitis
SECONDARY PATHOGENS		
Fungi	Aspergillus fumigatus	Aspergillosis (growth in lungs and other organs)
Actinomycetes	Micromonospora spp	Farmer's lung (Allergic response in lung tissue)

Ascaris eggs which seem to be the most resistant of the pathogens and parasites were completed destroyed in 36 days. With a sustained high temperature, more rapid Ascaris eggs destruction might have been achieved by turning at shorter intervals.

Flies which are important in the transmission of faecal born diseases can be controlled in aerobic composting if the compost piles are turned at least every 3-4 days, before they have the opportunity to hatch. After the food in the organic waste has undergone some decomposition, it ceases to be attractive to flies.

2.12 COMPOST QUALITY

Concepts of compost quality or compost test standardization were essentially unknown worldwide as recently as 1985. Outside of beneficial yields from compost usage, or reports of raising soil organic matter, there is little evidence of the application of a compost quality verification program. Even within organic farming, compost qualities were not examined closely. The pioneering manual about sludge composting, published by USDA-Beltsville only briefly mentioned “stabilization” but did not define it, nor did it discuss when a compost process is finished, or how that will be determined. Quality emphasis was focused on potential human pathogen content or in other words, the absence of danger (USDA, 1980).

As partially decomposed organic matter, compost can have a range of characteristics. Compost can vary in quality as a result of the type of the raw materials used, the degree of decomposition, moisture content, nutrient content, salt content, acidity/ alkalinity and contaminants (organic and inorganic materials or heavy metals). Some measures of compost quality are C/N ratio, smell and particle sizes. These measures are also indicative of the effectiveness of the composting process. Mature compost is free from odour, easy to handle, store and transport. Raw compost does not have these qualities but will acquire them with time if allowed. Large particle sizes are indicative of incomplete composition. Mature compost is dark brown, crumbly, and has an earthy smell. Mature compost contains trace and essential element, of which the most important are nitrogen, phosphorous, potassium and sulphur. These are available to the soil and plants depending on their initial concentrations in the compost materials and on the degree of mineralization that occurs. These elements become increasingly available with time. Compost can be used as an inorganic fertilizer, except that in many cases the concentrations of the elements are so low that excessively large quantities are required for application. Compost is therefore always considered as a low nutrient fertilizer or soil conditioner The N.P.K and other minerals content can be fortified with chemicals to enhance its fertilizing capacity (Hileman and Morelock, 1982).

Compost, depending on the source of the raw materials may contain high concentrations of heavy metals. However concentrations of heavy metals in sewage sludge, garbage and human waste is low. Common heavy metals that may be found in sludge, night, soil and compost are cadmium, chromium, copper, nickel, lead, zinc. The following analysis shows the range of values on a dry basis, in which the characteristics of most finished compost generally lie. These ranges are rather wide because different initial materials will yield final compost of widely varying chemical characteristics.

Substance	**Percentage by weight**
Organic matter	25 – 50
Carbon	8 – 50
Nitrogen (as N)	0.4 – 3.5
Phosphorous (as P_2O_5)	0.3 – 3.5
Potassium (as K_2O)	0.5 – 1.8
Ash	20 – 65
Calcium (as CaO)	1.5 – 7

Source: Composting by Gotass, 1976; page 105.

Compost is also believed to contain a great variety of micro-nutrient. Micronutrients (trace elements) are nutrients needed for life in small quantities. These include iron, cobalt, copper, iodine, manganese, zinc, selenium and molybdenum. Since most compost materials are products of agriculture, it is expected that these nutrients will be present. Agricultural experiments have indicated that compost manure has beneficial effects such as improving the physical and chemical properties and reducing soil erosion, than those to be expected from the nitrogen, phosphorus, potassium and humus content alone.

2.13 COMPOST APPLICATION TO LAND

Compost amendment to soil provides multiple benefits including reduced erosion, reduced runoff, improved soil physical and chemical properties and greater crop yield, and therefore is of agricultural importance. (Cox et al., 2001). Impacts on soil water holding capacity are of particular importance on disturbed sites because of soil erosion concerns.

Bazoffi et al., 1998 investigated effects of refuse compost application on various soil physical parameter and soil erosion in a three year study. They reported a positive effect on soil bulk density for the first year after application. Soil bulk density is the mass of soil per unit volume in its natural field state and includes air space and mineral plus organic materials. Bulk density gives useful information in assessing the potential for leaching of nutrients erosion and crop productivity. Siegrist et al., (1998) applied various test of erosion susceptibility to long term organically farmed soils. They concluded that erosion susceptibility was higher on conventionally farmed soils compared to soils where organic farming had been practiced.

Elevated concentrations of a number of heavy metals such as arsenic, cadmium, chromium, copper, mercury, nickel lead or Zinc in biosolids, particularly where industrial waste is discharged into sewerage system and this further increase negative perceptions about using biosolids from industrial (Ozores et al., 2002). Particular attention is paid to the level of pathogens in compost as public perception about the presence of pathogens can lead to resistance to compost use. The benefits in the application of any compost to soils include improvements in bulk density, cation exchange capacity, soil water holding capacity, organic matter content; microbial population size, soil texture and structure. These improvements results in soils being easier and more friable to cultivate than when conventional fertilizers are used. Soils that have had compost amendment allow, improved root penetration and growth and improved plant performance can thus be expected compared with intensively cropped soils that have not had compost application.

It is often the practice to grow crops continuously and allow little for the soil structure to recover or for soil organic matter levels to improve. This soil degradation can lead to structural breakdown and often result in poor crop yields, despite the addition of suitable levels of fertilizer. The addition of compost is a quick, efficient and long term way of restoring the soil structure, and in turn improving crop yields (Shepherd et al., 2001).

Most compost are low analysis fertilizers with Nitrogen and phosphorous levels near 1 % therefore nutrient amount supplied by compost are lower than those supplied by chemical fertilizer (Sikora, 1998). Although chemical fertilizers supply higher amount of nitrogen immediately compared to compost is as effective as chemical fertilizers because of their long term nutrient supplying characteristics (Edmeades, 1999). To ameliorate soil physical conditions it is important to build up organic matter in the soil and improve its structural stability (Ball et al., 1997).

The need to add compost to soil stems from the close relationship of a soils natural fertility and its organic matter content. Organic matter is vital to soil productivity and sustainability. Humic acids, one of the most active fractions of organic matter, improve the absorption of nutrients by plants and soil microorganism, have a positive effect on the dynamics of nitrogen (N), Phosphorous (P) and sulphur (S) in soil; stimulate plant respiration and the photosynthetic process, and favour the formation of soil aggregates. Soil Scientist and plant physiologist, state that plant growth and yield are largely determined by mineral nutrition, water and air supply to roots and environmental conditions such as light and temperature. A number of studies suggest that soil organic matter also affects plant growth. Correlations between organic matter content of soils and plant yields are reported in literature (Olsen, 1986). Soil organic matter (S.O.M) may affect soil fertility indirectly through the following mechanisms;

- Supply of mineral nutrient N.P. K and micronutrients to roots
- Improved soil structure, thereby improving water-air relationships in the rhizosphere
- Increased microbial population including beneficial microorganisms.
- Increased cation exchange capacity (CEC) and the pH buffering capacity of soil.
- Supply of defined biochemical compounds to plant roots such as acetamide and nucleic acid and supply of humic substances. Humic substances serve as carriers of micronutrients and growth factors.

Singer et al., (2004) reported 11 percent greater corn yields in no-tillage with compost amended soil and about 30perccent less fertilizer nitrogen compared to no compost in the last two years of their four-year study.

Tomatoes have also been shown to be very yield responsive to additions of compost (MSW). An 18 % yield improvement in tomatoes was recorded in a study on fine sandy loam in Connecticut. This increase in yield was the result of both an increase in the number of fruit per plant and in the individual weight of each fruit (Maynard, 1995). Warman (1998) reported that when compost was amended to a plot trial, marketable carrot yield as a percentage of total yields was increased by 9 %, from 67 % to 76 % compared with chemical fertilizers. Smith et al., (1992) also reported yield increases in pepper and cucumber crops where compost was added at a rate of 360 kg/ha to a sandy soil. Use of compost for horticultural production has the dual benefits of recycling waste and improving soil physical, chemical and biological conditions.

Large amounts of sludge are used on golf courses and cemeteries, and for landscaping the grounds of public buildings. Sludge compost has a major potential for use in the re-vegetation and reclamation of lands disturbed by surface mining, removal of topsoil and by excavation of gravel deposits.

2.14 FAECAL COLIFORM AND SALMONELLA

Depending on the type of raw material used, a variety of pathogens may occur in compost. Material of faecal origin may contain bacteria like salmonella and shigella, viruses like polioviruses and rotaviruses, protozoan like Giadia and cryptosporidium and different parasitic Helminth eggs (Feachem et al., 1983).

Faecal bacteria, like coliforms, Escherichia coli and faecal streptococci, occur in high numbers in the intestine. They are often used to determine water and waste quality (Bendixien, 1999).

Faecal coliforms are good long-term indicators of pathogenic bacteria. These organisms (faecal coliform and salmonella) serve as compost safety indicators with respect to the potential presence of pathogenic organisms in compost.

Coliform consist of a related group of bacteria species. 60 % to 90 % of total coliforms are faecal coliforms and 90 % and above of faecal coliforms are Escherichia coli. When recycling organic waste products the hygienic quality is of great importance to avoid spreading enteric and other disease and plant pathogens in the environment. The Agricultural and Agric Food Canada (AAFC), the Canadian Council of Ministers of the Environment (CCME) and the standards Council of Canada (SCC) through the Bureau de Normalization du Quebec (BNQ) all agree that the quantity of faecal coliforms must be < 1000 MPN/g of total solids (oven dried mass) and no salmonella present. The CCME however prescribes that salmonella spp should be < 3 MPN/4g total solids calculated on a dry weight basis.

CHAPTER THREE

3.0 MATERIALS AND METHODS

The project was carried out in two phases;

1. The compost production phase using Sewage Sludge, Ginnery trash and soil
2. The cultivation of lettuce (lactuca sativa) using the resulting compost produced in phase one.

3.1 Sample collection and set-up

Composting was carried out at the KNUST Sewage treatment plant where dewatered Sewage Sludge was available. Ginnery trash was transported from the Ghana Cotton Company limited. Ginnery plant in Bolgatanga, Upper East Region; where trash is readily available. A 4.8 m × 5.4 m × 2.4 m structure was erected for shade over concrete floor to protect the composting process from extreme environmental conditions of rain and sunlight (Plate 3.1).

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

3.2 The Composting Procedure

Three different compost heaps were prepared, two from dewatered sludge and ginnery trash in the ratio of 1:1, and 1:2 (v/v) respectively and one from ginnery trash and sandy soil in the ratio of 1:1(v/v). Each ratio was replicated. Dewatered sludge was taken directly from the sludge drying beds of the treatment plant. The Windrow Pile method was adopted.

3.2.1 Soil Characterization

51.0 g air – dried soil was weighed into 1liter screw lid shaking bottle. 100 ml distilled water was added and the mixture was swirled to thoroughly wet the soil. 20 ml of 30 % H_2O_2 was then added. 50 ml of 5% sodium hexametaphosphate solution was also added. Three drops of amyl alcohol was then added to minimize foaming. The mixture was then put o a mechanical shaker for 2 hours. The content was then transferred into a 1000 ml sedimentation cylinder and all soil particles washed off the shaking bottle was added and topped up to the 1000 ml mark with distilled water. The first hydrometer and temperature readings were then taken at 40 seconds. The sample was allowed to stand for 3 hours undisturbed and the second hydrometer and temperature readings were taken.

<u>Calculation</u>

% Sand = 100 - [H1 + 0.2 (T1 – 20) - 2] × 2

% Clay = [H2 + 0.2 (T2 – 20) - 2] × 2

% Silt = 100 – (% Sand + % Clay)

3.2.2 Watering and turning of compost piles

The compost piles/heaps were turned every three days for the first 15 days. Turning was done at this frequency to ensure that the entire compost piles were exposed to the same conditions of sufficient air flow, and moisture conditions. Sufficient heating of piles as a result of the turning is very necessary for efficient pathogen destruction. After 15 days turning was done weekly for the rest of the composting period. At each turn about 8 liters of water was added depending on the moisture content at the time. Before each turn the moisture content was determined both in the field and in the laboratory. This informed the quantity of water that needed to be added. When the moisture levels were sufficient, no water was added.

3.3 Hydrogen ion determination

One gram of the compost was weighed into a beaker and dissolved 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 appeared digitally and was recorded.

3.4 Determination of Moisture Content

Two methods of moisture content determination were employed. The "squeeze test" as described by the Federal Compost Quality Assurance Organization 1994, U S A, provides a rough estimate of moisture content.

It gave an indication as to whether the piles were "too dry" or "too wet" for composting. Too dry compost will render composting microbes inactive; whiles too wet will lead to the development of anaerobic conditions. A fresh sample is placed in the palm and squeezed firmly and the fist opened. If compost is sufficiently moist it would crumble with slight pressure. If the sample deforms and does not fall apart when pressure is applied or if water is released, it is too wet. On the other hand if the sample crumbles when the fist is opened, the sample is too dry.

This test provides a rough estimate of moisture content, but it cannot be used to estimate the volume of water required to be added to the compost materials, samples were therefore further taken to the laboratory for moisture content determination.

In the laboratory 10 g of each sample was weighed and put into crucibles and designated as W_1. The samples are oven dried at a temperature of 105 ^oC for 24 hours, cooled and reweighed as W_2. The difference in weight was then expressed as the amount of moisture in percentage using the formula, % moisture = $\frac{W_1 - W_2}{W_1} \times 100$.

3.5 Temperature Measurement

A thermometer attached to a rod of about 50 cm long was inserted into each pile one in the middle of the pile and another at the edge of the pile. The temperatures were recorded. The average was then calculated. Temperature measurements were taken three (3) times at 8 am, 12 pm and 4 pm. Readings were taken daily for the entire composting period.

3.6 Pile Volume Determination

With the aid of a measuring tape and a rod the height (h) and the circumference (c) of each pile were measured. The volume of each pile was determined by using the following equation.

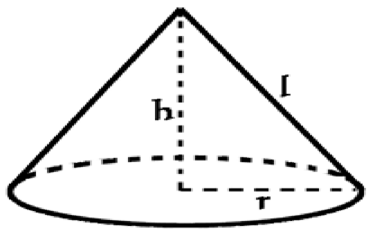


Figure 3.1: The shape of the compost heap, indicating parameters measured for heap volume calculation.

Volume of pile (heap) = $\pi r^2 h/_3$, where

$$r = {}^{c}\!/_{2\pi}$$

r = radius of pile

h = height of the pile

Piles volume was determined after each turn for the entire composting period.

3.7 Total Dry Solids

Total dry solids content was determined by weighting 10 g of each sample into a Petri dish and designated W_1, oven dried for 24 hours at 105 ^oC and then reweighed, W_2. The percentage of total dry solid is then calculated using the formula;

% Total Solids (T S) = $\frac{W_2}{W_1} \times 100$.

This was determined at the end of every month for the four month period.

3.8 Organic Matter and Ash Content

10 g of compost sample was put into dry porcelain crucible and dried for 24 hours at 105 ^oC. Samples were then transferred into an ignition furnace where the temperature was gradually increased to 550 ^oC and then maintained for 8 hours. The crucibles

containing a grayish white ash were removed and cooled in a desiccator and reweighed. The percentage ash and organic matter were then calculated by the differences in weight of the crucibles before and after combustion as follow;

Ash % = $[(W_3 - W_1)/ (W_2 - W_1)] \times 100$ and

Organic matter % = 100% - ash %

Where W_1 = weight of empty dry crucible

W_2 = weight of dry crucible containing sample

W_3 = weight of dry crucible containing sample after ignition

$W_3 - W_1$ = weight of the ash

3.9 Total Organic Content

Total organic carbon (T O C) was calculated from the equation

% oC = 0.51 ×% OM 40.48

Where O M, is the organic matter content. This equation is according to Navarro et al., 1993. This was done at the end of every month.

3.10 Nitrogen Content Determination

One gram of well dried compost sample of each pile was weighed into a 500 ml Kjeldahl flask. 50 ml of distilled water was used to rinse down the particles of the compost that were attached to the walls of the Kjeldahl flasks. 10 ml of concentrated sulphuric acid and a tablet of selenium catalyst were added to the flask and heated in a digester in a fume chamber until the mixture became straw yellowish in colour. The digested material was allowed to cool. The mixture was topped up with distilled water to the 300 ml mark. The flask was then swirled for uniform mixing. 50 ml of sodium hydroxide and sodium thiosulphate solution was added to the digested mixture to provide the necessary alkaline conditions for the release of organic nitrogen. 200 ml of the mixture was distilled into a conical flask containing 50 ml of blue boric acid serving as the absorbent indicator. A change in colour from blue to green indicated the presence of organic nitrogen. The solution in the conical flask was then titrated against standard 0.2 N sulphuric acid until the indicator changed from green to pale lavender. The end volume was noted as V_1. A blank was then prepared by heating 10 ml of concentrated sulphuric acid and selenium catalyst, digested and filtrated to get a volume V_0.

Nitrogen concentration was then calculated using the formula;

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

Where;

V_1 = Volume in milliliter (ml) of 0.2 N sulphuric acid used in the titration of the sample.

V_0 = Volume in milliliters of 0.02 N sulphuric acid used in blank titration test.

m = mass of test sample in gram (g)

3.11 Phosphorus Content Determination

1 gram of dried compost sample was weighed out into conical flask, and dissolved in 100 ml of distilled water. The resulting mixture is then shaken on a mechanical shaker for one hour for thorough mixing to take place. The mixtures were then filtered out into 10 ml sample cells.

A sachet of phos Ver 3 phosphate powder pillows were then added to each 10ml cell. The mixture was swirled immediately to mix and left to stand for 3 mins. The mixture turns blue indicating the presence of phosphorous. The content in the 10 ml cell was then placed in the portable data logging spectrophotometer and the phosphorous content determined digitally in milligram per liter (mg/l).

3.12 Potassium Content Determination

Two grams of sun-dried compost samples were weighted into crucibles. These were then transferred into a muffle furnace set to a temperature of 550 ^{o}C and left for 2 hours. After the 2 hours the crucibles were removed and allowed to cool.

2 ml of distilled water was added to each crucible followed with 5 ml of 8 N HCL to dissolve the Potassium in the ash. Samples were then evaporated for 20 mins in a water bath. The solutions were then filtered through. Whatman No 40 filter papers into 100 ml volumetric flasks. The crucibles were washed with distilled water through the filter to get all the soluble salts washed out of the filter paper. 10 ml portions are then used for the potassium determination in the flame photometer. However before using the flame photometer it was calibrated using the following standards

Ppm	Emission
0	0
5	31
10	56
15	80
20	100

A standard curve was constructed with the potassium readings to obtain actual concentrations in the compost samples in solutions. The following graphical equation was derived by plotting concentration against emission.

$$X = Y/5.213$$

X = Concentration of potassium

Y = Emission

The percentage potassium was then derived using the equation;

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

Wt = 2 g

3.13 Total Coliform Determination

Total coliform was estimated using the Three Most Probable Number method (MPN) according to Standard Methods (Anon, 1994). Ten grams(10 g) of each compost sample was weighed into a stomacher bag and pulsified in 90 ml of 0.9 % NaCl MQ-water for 30 sec using a pulsifier (PUL 100E). Serial dilutions of 10^{-1} to 10^{-13} were prepared. One milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 35 ^{o}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} (Anon, 1994).

3.14 Faecal Coliform Determination

Faecal coliform was estimated following the same procedure as in 3.13 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} (Anon, 1994).

3.15 Salmonella spp Determination

Salmonella levels were determined using the membrane filtration method. Ten grams of sample was put into a conical flask. 100 mls of sterilized distilled water was added to the sample. The conical flask was then shaken on a mechanical shaker for an hour to stir for uniformity. This was then allowed to settle. Serial dilutions from 10^{-1} to 10^{-11} were prepared. One (1) ml was taken from each dilution and put into 99 ml of sterilized distilled water in 100 ml bottles. These were then transferred into the filtration system containing 0.45 µm filter membranes.

Membranes were then transferred onto Petri dishes containing chromocult coliform Agar. Petri dishes were incubated at 37 °C for 18-24 hours. The appearance of light blue to turquoise colonies is indicative of the presence of Salmonella. After 24 hours, counting was done with the aid of a magnifying lens.

PHASE TWO

3.16 Cultivation of lettuce

Randomized Complete Block Design (RCBD) was used in the cultivation of the lettuce. Each block consisted of ten plots of dimension 2 m x 3 m wide. The plots were given treatments of the various composts including dewatered sewage sludge and a control. The plots and treatments were replicated three times in RCBD. 0.028 m^3 of each compost type and sludge was applied per plot on each block. The figure 3.3 on the next page depicts the arrangements of the plots and treatments. The lettuce seeds were nursed for three weeks and then transplanted onto the prepared plots. The lettuce was transplanted at a spacing of 20 cm x 30 cm. Water from a nearby pond was used in watering the lettuce twice between 7.30 am -8.00 am and 5.00 pm-5.30 pm each day except on days that there was a heavy downpour. Plots were well drained. Weeding and forking of the plots was done every two (2) weeks. The chemical bithin was sprayed at the nursery, before transplanting and at two (2) weeks interval to prevent pest infestation. Harvesting was done after five weeks when lettuce had reached maturity (Plate 3.2). Plates 3.3-3.6 depict lettuce plants grown with various compost treatments.

← 3m →

2m ↕

A S/T 1:1 b	Soil/T 1:1 a	Soil/T 1:1 b	S	S/T 1:2 b	S/T 1:1 a	NT	S/T 1:2 a
B S/T 1:1a	NT	S	Soil/T 1:1 b	S/T 1:2 b	S/T 1:2 a	Soil/T 1:1 a	S/T 1:1 b
C NT	Soil/T 1:1 a	S/T 1:2 a	S	S/T 1:2 b	S/T 1:1 b	Soil/T 1:1 b	S/T 1:1 a

Figure 3.2: Layout of experimental plots

S/T—Sludge/Trash ratio N/T—No treatment A—1st Block C—3rd Block

Soil/T—Soil/Trash S—Sludge B—2nd Block

Plate 3.2: Lettuce plants prior to harvesting

Plate 3.3 Sludge/trash (1:2a) applied lettuce plot

Plate 3.4: Control plot (No treatment)

Plate 3.5 sludge/trash (1:1a) applied lettuce plot

Plate 3.6 Dewatered Sludge applied lettuce plot

3.17 Soil and the Treatments Analysis

The different compost types and dried uncomposted sewage sludge were taken to the laboratory for tests to be conducted. The tests determined the moisture, total solids, pH, organic matter, ash content, carbon, nitrogen, phosphorus, potassium, total coliforms, faecal coliform and Salmonella of the samples using standard methods used in earlier analysis. (Sections 3.5 to 3.15)

3.18 Lettuce Analysis

Total coliform, Faecal coliform, salmonella and average yield of lettuce were determined for each plot. Lettuce samples were analyzed for thermotolerant coliforms. Ten grams of lettuce from each category/plot was aseptically cut and placed in a stomacher bag and pulsified in 0.9 Sodium Chloride MQ – water for 30 seconds using a pulsifier.

3.18.1 Total Coliform

The Methodology was the same as total coliform determination in section 3.13

3.18.2 Faecal Coliform

The Methodology was the same as faecal coliform determination in section 3.14

3.18.3 Salmonella

The Methodology was the same as Salmonella determination in section 3.15

3.18.4 Yield Determination

Five samples of lettuce were taken at random from each of the treatment plots (2mx3m). The lettuces were weighed with a metler 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 ^{o}C for 24 hours and their dry weights taken.

CHAPTER FOUR

4.0 RESULTS

Results obtained from the monitoring of parameters used to assess the composting process and subsequent quality of the compost of the various compost ratios are represented in Figs. 4.1 to 4.15. These were; pH, organic matter, total solids, carbon, ash content, phosphorous, nitrogen, potassium, C/N ratio, temperature, heap volume, moisture, total coliforms, faecal coliforms and Salmonella .

Fig. 4.1 represents the changes in hydrogen ion concentration during the whole period of composting. From an initial mean pH of 6.94, 7.21 and 7.62 for the heap ratios of 1:1, 1:2 S/T and 1:1 Soil/T to 6.04, 6.1, and 6.74 for the same heap ratios respectively. There was a general decline in pH values over the period with the lowest being 6.04 for the 1:2 S/T ratio.

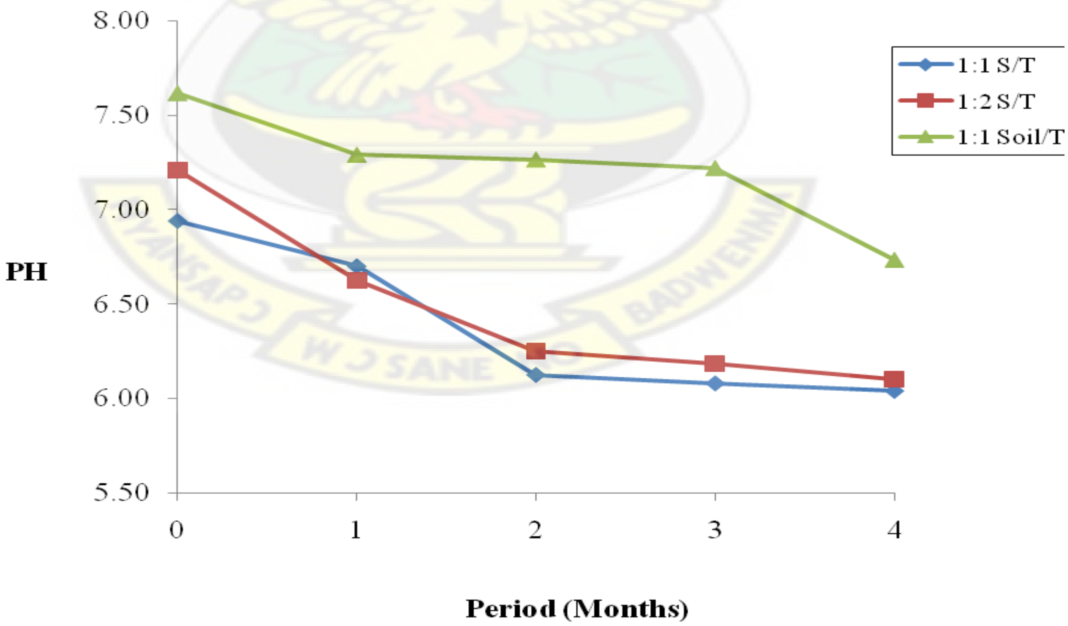


Figure 4.1: Mean monthly pH of the various Compost Heaps

Organic matter content decreased from means of 63.55 %, 70.27 % and 19.34 % to 50.82 %, 49.30 and 6.93 % for the heap ratios 1:1, 1:2 S/T and 1:1 Soil/ Trash respectively as captured in Fig 4.2. However as the organic matter content decreased, with the highest being 20.97 % for 1:2 S/T and lowest, 12.41 % for 1:1 Soil/Trash, ash content increased from 36.46 %, 29.73 % and 80.67 % to 51.8 %, 50.71 % and 93.07 % for the same ratios respectively, as depicted in Fig 4.3.

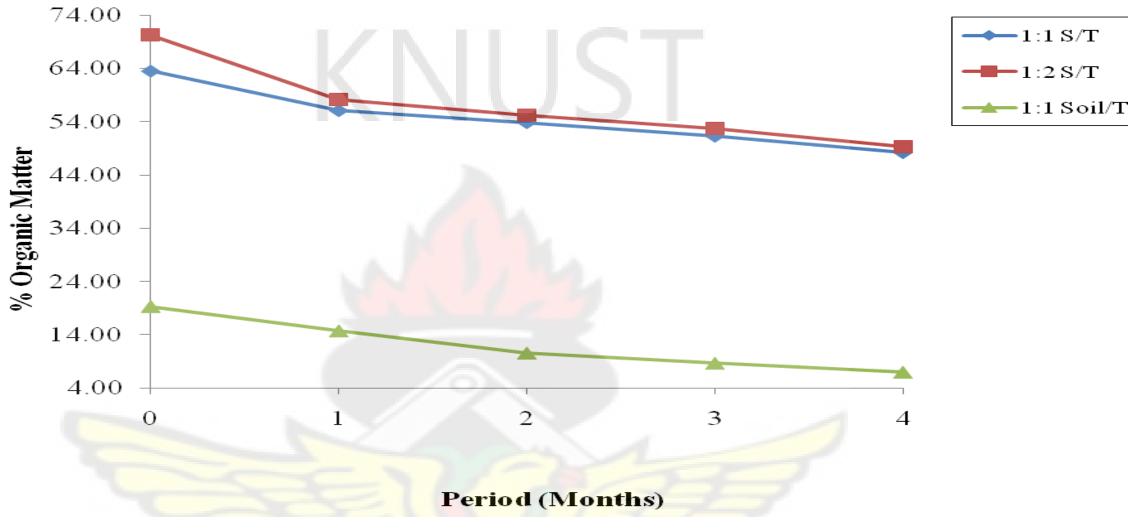


Figure 4.2: Mean monthly Organic matter content (%) in the various Compost Heaps

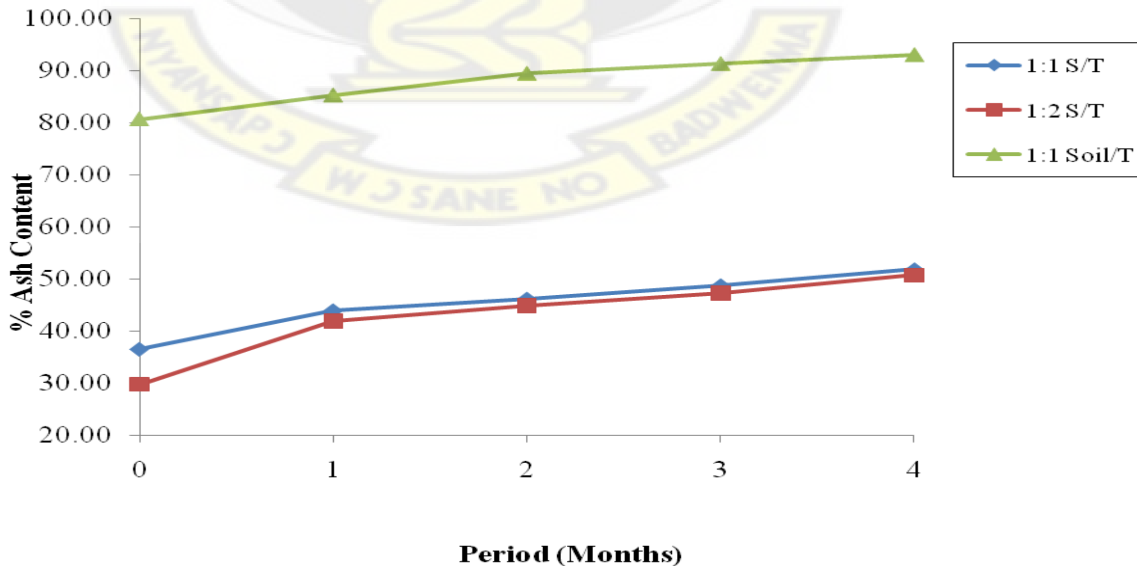


Figure 4.3: Mean monthly Ash content (%) of the various compost heaps

Fig. 4.4 represents an increase in total solids from 41.02 %, 40.92 % and 75.11 % to 72.28 %, 69.67 % and 89.09 % for the ratios 1:1, 1:2 S/T and 1:1 Soil/ Trash respectively.

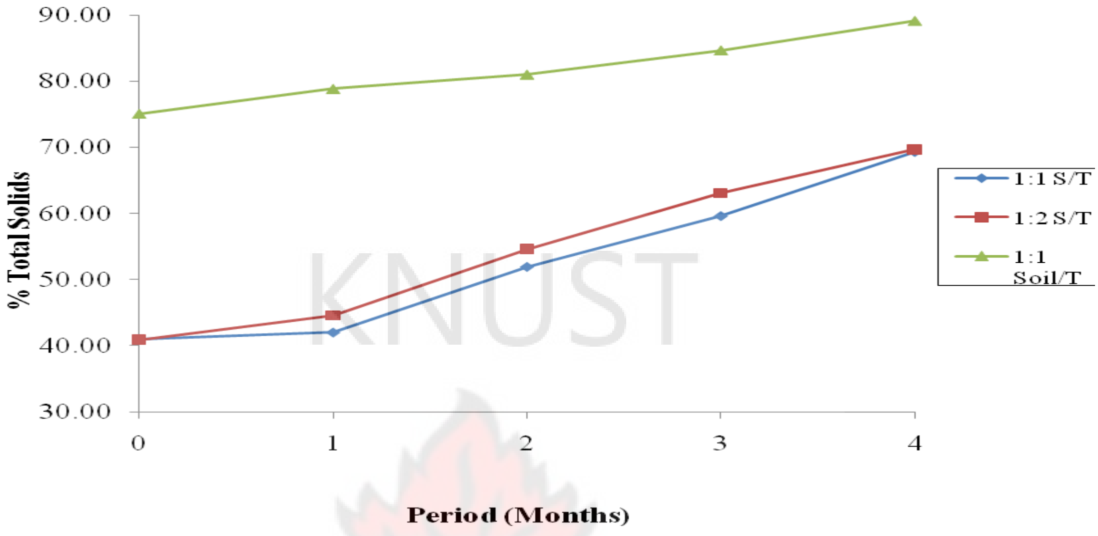


Figure 4.4: Mean monthly total solids (%) in the various compost heaps

Carbon content reduced from 32.89 %, 36.32 % and 10.34 % to 25.05 %, 25.62 % and 4.01 % as represented in Fig. 4.5 for the ratios 1:1, 1:2S/T and 1:1 Soil/ Trash respectively.

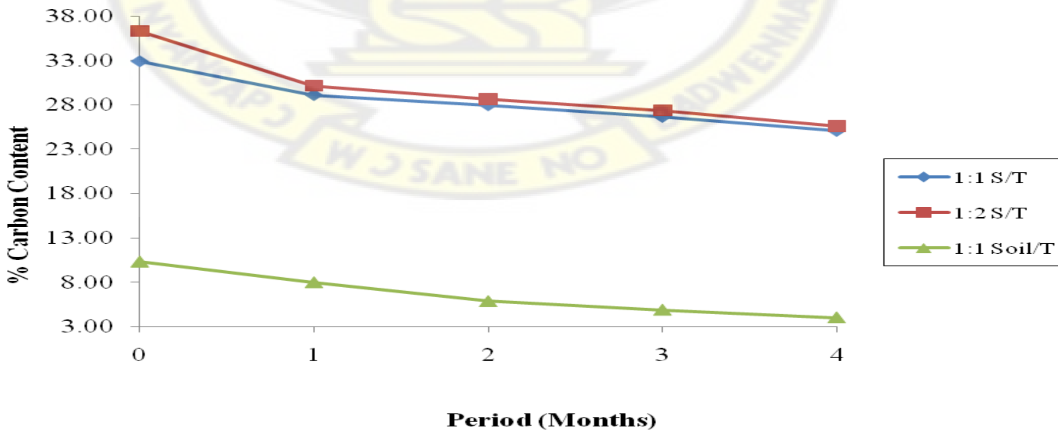


Figure 4.5: Mean monthly Carbon content (%) of the various compost heaps

Fig. 4.6 depicts a reduction in phosphorous content from initial values of 0.67 %, 0.56 % and 0.27 % to final values of 0.11 %, 0.17 % and 0.05 % for the respective heap ratios 1:1, 1:2 S/T and 1:1 Soil/ Trash, with the highest loss of 0.56 % for 1:1 S/T and lowest 0.22 % for 1:1 Soil/T.

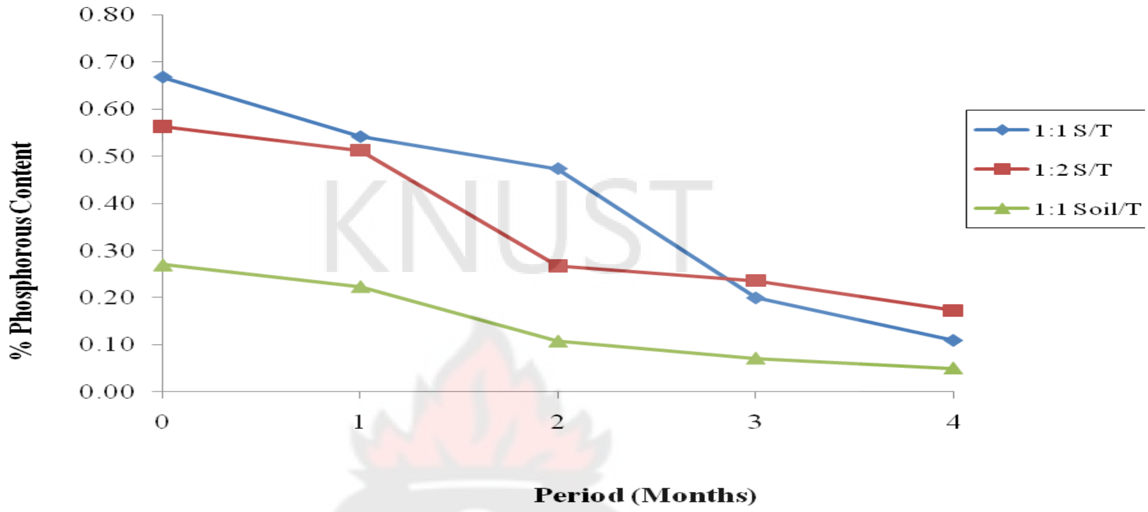


Figure 4.6: Mean Phosphorus content (%) of the various heaps

Potassium content also showed reduction in the heap ratios of 1:1, 1:2 S/Trash and 1:1 Soil/Trash, with initial value of 0.34 %, 0.58 % and 1.25 % to 0.17 %, 0.37 % and 0.53 % as depicted in Fig. 4.7. Highest reduction was 0.72 % for 1:1 Soil/T and lowest 0.17 %, 1:2 S/T

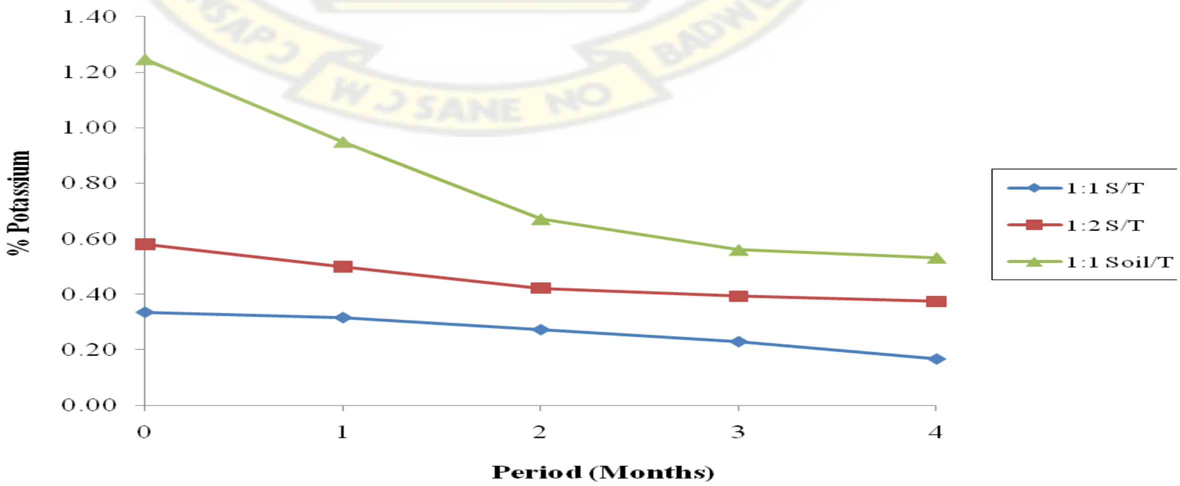


Figure 4.7: Mean monthly potassium Content (%) in the various compost heaps

Mean nitrogen content also decreased from 1.6 %, 1.56 % and 0.38 % to 1.52 %, 1.37 % and 0.24 % for the ratios of 1:1, 1:2 S/T and 1:1 Soil/ Trash respectively, as captured in Fig. 4.8.

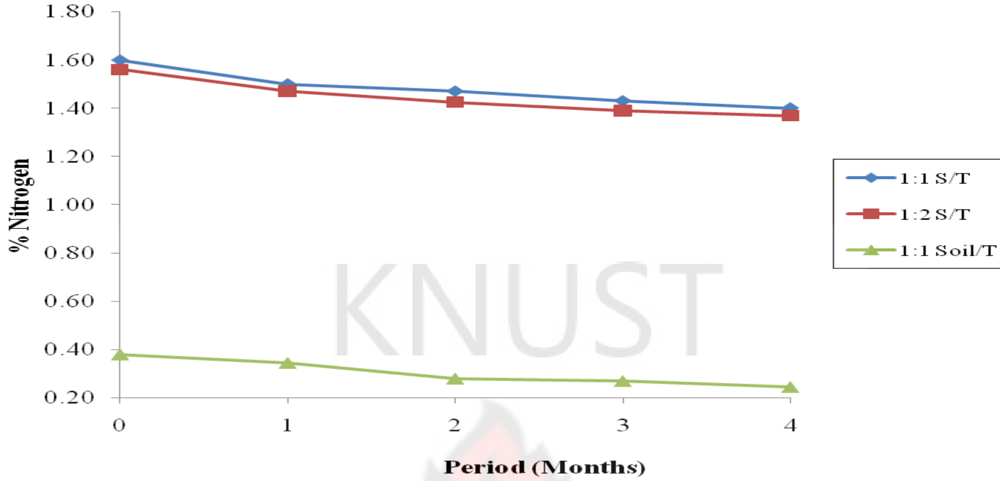


Figure 4.8: Mean monthly Nitrogen content (%) in the various Compost heaps

Fig. 4.9 shows a decline in carbon-nitrogen ratio in the different heap ratios from initial values of, 20.58 %, 23.28 % and 27.39 % to 17.88 %, 18.72 % and 16.36 % for the heap ratio 1:1, 1:2 S/T and 1:1 Soil Trash, however the highest decrease was 11.03 % for 1:1 Soil/T and lowest, 2.70 % in 1:1 S/T.

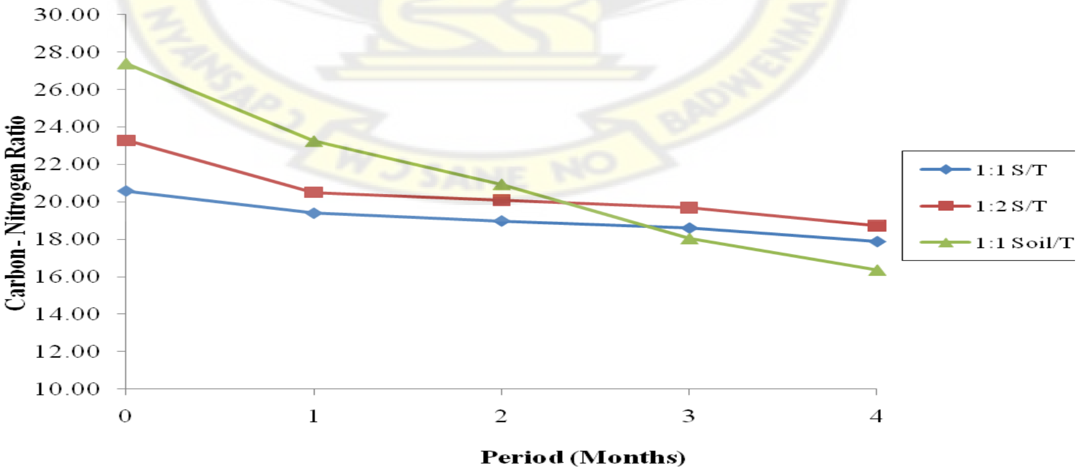


Figure 4.9: Mean monthly Carbon-Nitrogen Ratio in the various Compost heaps

Fig. 4.10 represents the mean weekly volume changes over the entire composting period from initial values of 0.3 m^3 for all three heap ratios of 1:1, 1:2 S/T and 1:1 Soil/ trash, reducing by 54 %, 60 % and 50 % to final values of 0.1374 m^3, 0.1201 m^3 and 0.1513 m^3 respectively.

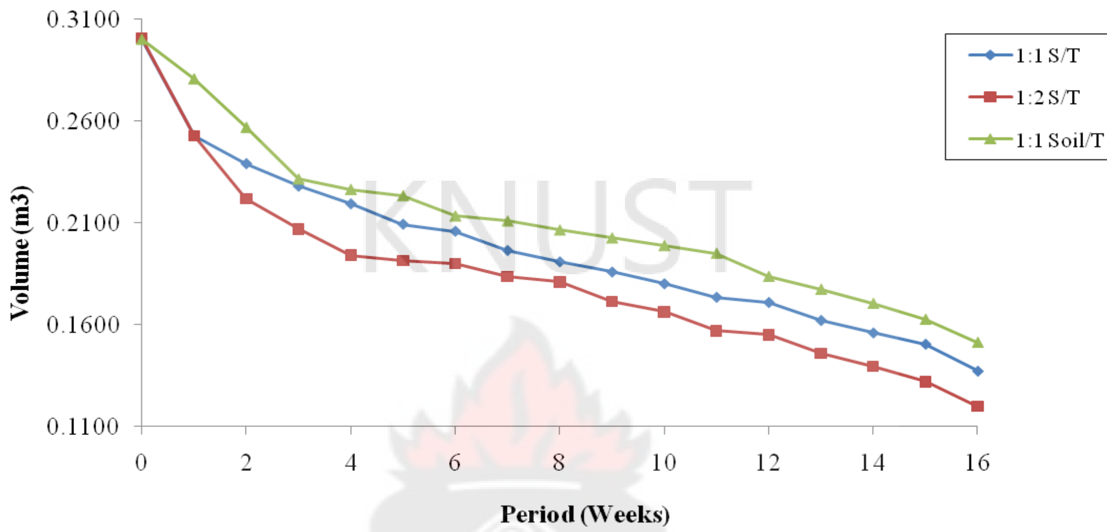


Figure 4.10: Mean weekly volume of the various Compost heaps

As total solids increased in Fig. 4.4, moisture content decreased as depicted in Fig 4.11. A decrease from initial values of 58.99 %, 59.08 % and 24.89 % to 30.69 %, 30.33 % and 10.91 % with 1:2 S/T recording the highest of 28.75 % and the lowest 13.98 % for the ratio 1:1 Soil/T.

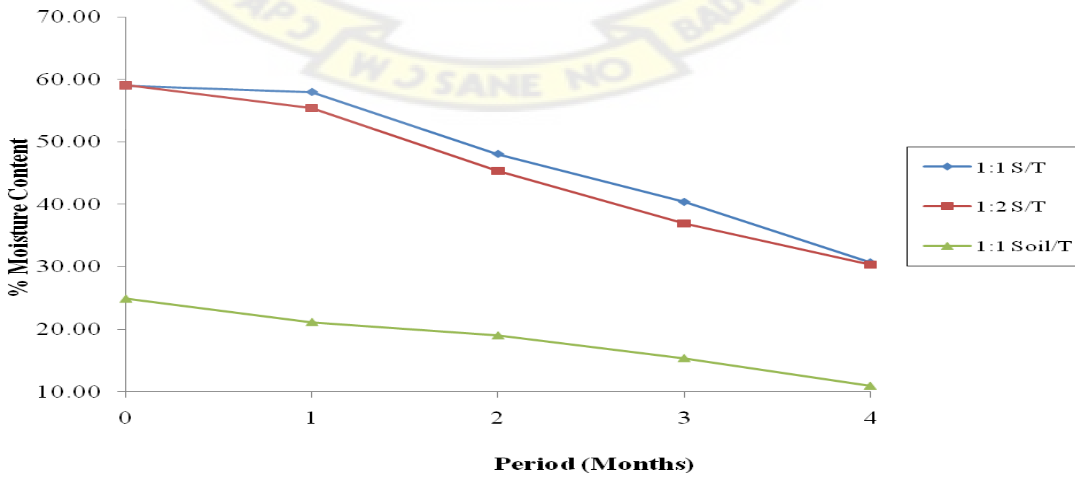


Figure 4.11: Mean Monthly Moisture Content in the various Compost heaps

Fig 4.12 clearly depicts the typical temperature variations experienced during the composting process over a ninety 90 day period. It is worth noting that all the heap ratios of 1:1, 1:2 S/T and 1:1 Soil/ trash, attained the highest temperatures of 50.67 %, 58.17 % and 42.92 % between the 6th day to 15th day. Mean temperatures thereafter dropped gradually to 23 ºC, 23.08 ºC and 23.17 ºC, for the respective ratios.

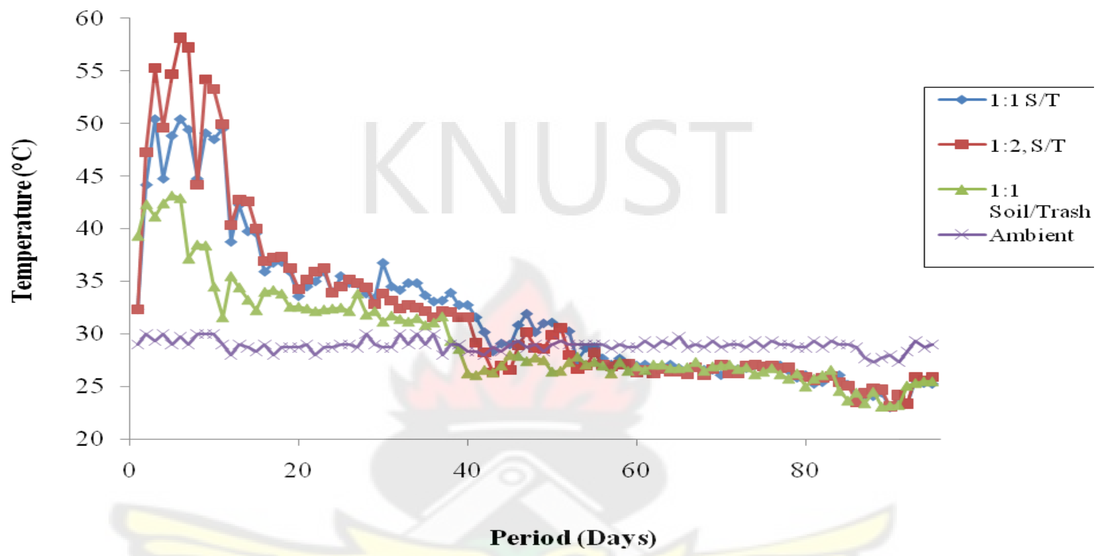


Figure 4.12: Variation in process temperature (1:1, 1:2 Sludge/Trash and 1:1 Soil/Trash and Ambient Temperature over the period (Days)

Total coliforms, faecal coliforms and salmonella levels determined during the period are shown in Fig. 4.13, 4.14 and 4.15 respectively. In all three heap ratios, pathogen levels reduced very significantly. Total coliforms reduced from the mean log values of 13.66, 11.08 and 14.64 to 2.62, 2.06 and 3.44 respectively, faecal coliforms decreased from mean logs of 11.23, 9.49 to 0.48 and 0.24 for the ratio 1:1, 1:2 S/T and 1.50 to zero level from the second month onwards for the Soil/Trash ratio of 1:1.

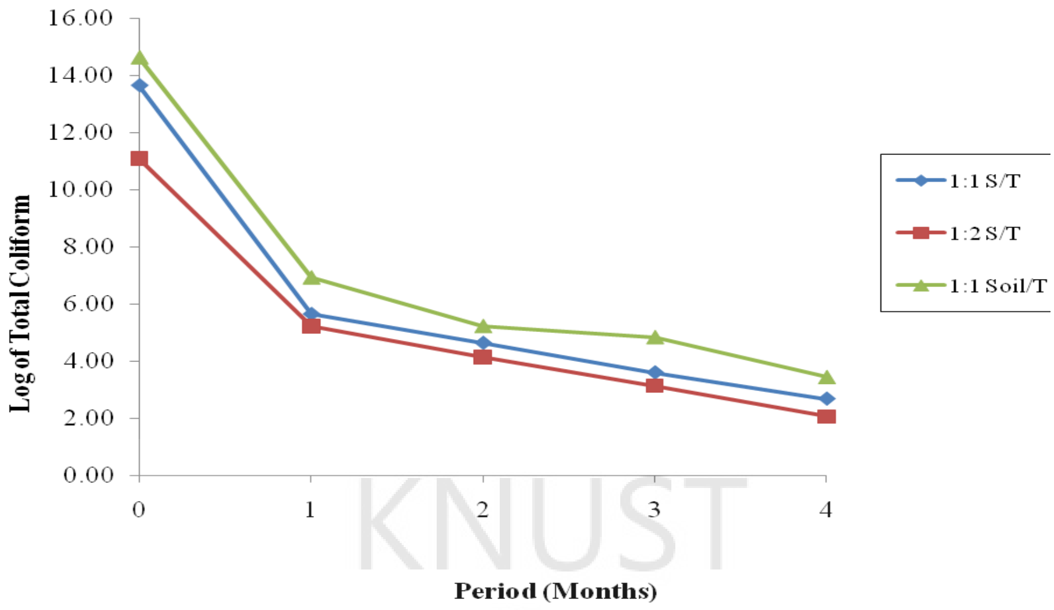


Figure 4.13: Log of Mean Monthly Total Coliform in 10 g of the various compost heaps

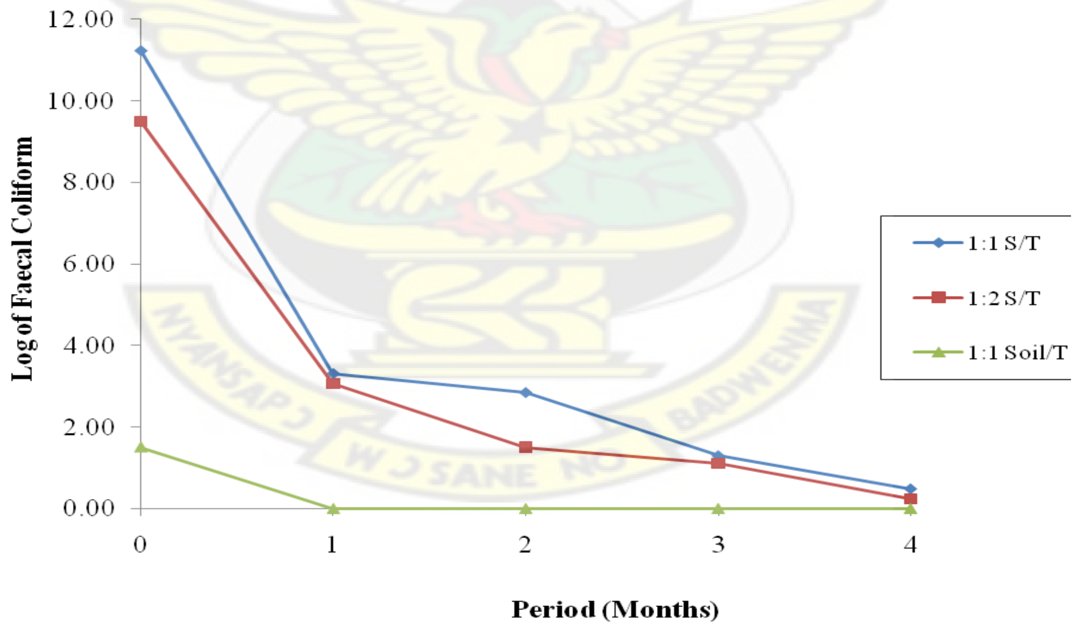


Figure 4.14: Log of Mean Monthly Faecal Coliform in 10 g of the various compost heaps

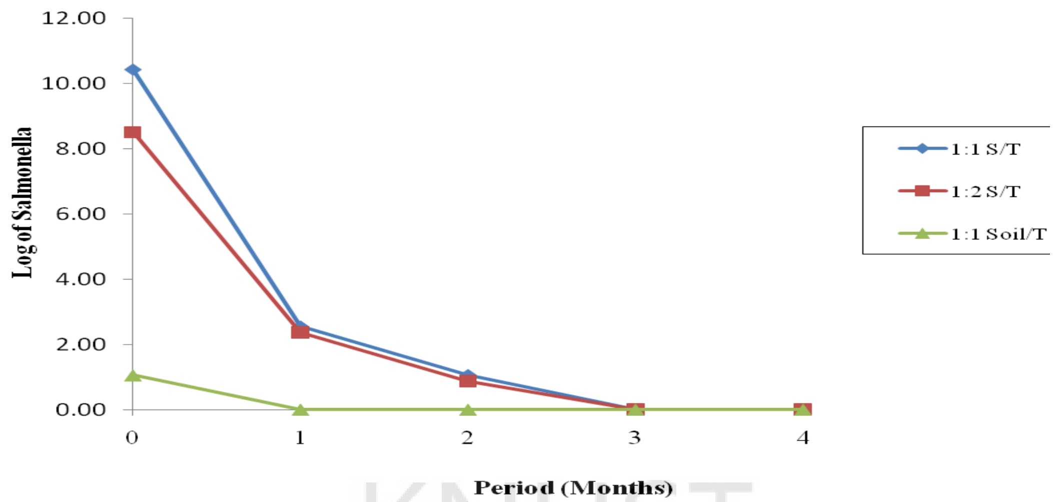


Figure 4.15: Log of Mean Monthly Salmonella in 10 g of the various compost heaps

Salmonella spp levels decreased from the means of log 10.43, 8.50, and 1.06 to zero after one month of composting and remained so till the end of the composting period. Appendix E to Appendix R shows the results of the various parameters of the composting processes.

A one way ANOVA was carried out for all the three ratios, 1:1, 1:2 Sludge/Trash and 1:1 Soil/Trash, to determine the significance or otherwise of the various parameters. The one way ANOVA for the ratio 1:1 Sludge/Trash showed significant levels for moisture content, Total Solids, Faecal coliforms, Salmonella, Phosphorous, Potassium, pH and Total coliforms ($P \leq 0.05$) (Appendix A). However organic matter, Ash, carbon, nitrogen and carbon nitrogen ration showed insignificant levels ($P \geq 0.05$). For the ratio 1:2 Sludge /Trash the ANOVA showed significant levels for each of the composting parameters (Appendix B). The one way ANOVA for the ratio 1:1 soil/trash showed significant levels between all the composting parameters except Nitrogen content (Appendix C).

A one way ANOVA carried out to determine the significance of the various parameters between and within the composting ratios, 1:1, 1:2 Sludge/Trash and 1:1 Soil/Trash did not show significant levels for Moisture Content, Total Solids, Organic Matter, Ash Content, Carbon, Nitrogen and Potassium($p \geq 0.05$). Carbon-Nitrogen Ratio, Phosphorus, pH, Total Coliforms, Faecal Coliforms and Salmonella spp. showed significant differences ($P \leq 0.05$) (Appendix D).

The Table below shows the yield, faecal colifom and Salmonella analysis of the lettuce after harvesting. The results show a high Salmonella spp concentration on the lettuce leaves at harvesting (>3CFU/4g)

Table 4.1: Analysis of Lettuce Grown with Different Organic Fertilizer

Treatment	Mean fresh Weight per lettuce (g)	Mean dried Weight per 100g of lettuce	Geomean Total coliforms (MPN/1g)	Geomean Faecal coliforms (MPN/1g)	Geomean Salmonella (CFU/4g)
1:1 S/T	67.86	7.35	33500	302	10
1:2 S/T	84.405	7.23	17400	249	9
1:1 Soil/T	52.7	7.43	32500	166	5
Uncomposted Dried Sludge	103.41	7.80	40500	717	36
No Treatment	7.45	5.43	37500	147	4

Table 4.2: Values of Parameters measured on the various ratio mixes of trash and dewatered sewage sludge/soil at the end of the composting process

Parameters	Ratio of raw materials and means of Parameters		
	1:1S/T	**1:2S/T**	**1;1Soil/T**
p H	6.04	6.1	6.74
M C	30.69	30.33	9.46
T S	69.31	69.67	89.09
O M	48.19	49.3	6.93
Ash	51.42	50.71	93.07
N	1.4	1.37	0.24
C	25.05	25.62	4.01
C/N	17.88	18.72	16.36
P	0.11	0.17	0.05
K	0.17	0.37	0.53
T Coliform	475	115	2850
F Coliform	3	1.5	0
Salmonella	0	0	0

CHAPTER FIVE

5.0 DISCUSSION

5.1 pH

pH levels below 7 obtained at the end of the composting period were an indication that aerobic compositing conditions prevailed during the composting period. A decrease in pH levels to 6.04, 6.1 and 6.74 for the compost ratio 1:1S/T, 1:2S/T and 1:1 Soil/T respectively was due to the production of organic acids during the composting process (Chen and Inbar, 1993). This compares favourably with results obtained by Golueke, 1985, who had a pH of 6.2 in the composting of Cotton Gin trash. Ohtaki et al., 1998 also obtained decreasing pH values in the degradation of food which he attributed to the accumulation of organic acids.

These final pH values however also fall within the optimum range of 6-8 for most microorganisms to exhibit maximum growth and activity (NRAES, 1992). A pH above 8 would enhance ammonia volatilization, and therefore pH is an important parameter that can control nitrogen losses from ammonia volatilization (Qiao and Ho, 1997).

5.2 MOISTURE CONTENT AND TOTAL SOLIDS

A lot of water was used during the composting period, as all three heaps were watered and turned every three (3) days for the first 15 days. The mean difference in moisture content in the final compost was statistically insignificant ($P = 0.065$, Appendix D). However, monthly reduction for individual heaps was significant ($P \leq 0.05$). This could be attributed to the fact that decomposer microorganisms need water for activities such as transportation and assimilation. Microbial activity occur must rapidly in thin water films on the surface of organic molecules and that microorganisms can only utilize organic molecules that are dissolved in water. Water is essential for bacterial activity in the composting process because the nutrients for the microorganism must be dissolved in water before they can be assimilated (Hamoda et al., 1998). This is corroborated by Richard, 1996, whose study indicated that water provides a medium for the transportation of dissolved nutrients required for metabolic and physiological activities of microorganisms.

Moisture loss over the composting period was highest in the ratio 1:2 S/T, followed by 1:1 S/T and then 1:1 Soil/T. This is validated by the observation that the heap ratio 1:2 S/T recorded the highest temperature within the first month of the composting process. The high temperature is as a result of the production of heat from the decomposition of volatile organics by microorganisms. Frequent turning provided enough aeration to remove water vapour from the heaps. High build-up of heat might therefore be the reason for the high loses of moisture, (Zhu et al., 2004). Finstein (1992) also found out that during the decomposition of organic matter heat built-up is enough to vapourize moisture and as temperature increases more heat is lost.

It was observed that the heap ratio 1:1 Soil/T could not hold moisture above 30 % no matter the level of water added. This could be attributed to the fact that characterization of the soil revealed 88.4 % sand, 8.0 % clay and 3.6 % soil, making it a sandy soil type. Sandy soils are known to have a very low water holding capacity, hence the inability to hold water. Final results obtained however showed that composting was successful in the long run. Obeng and Wright (1987) said that the lowest moisture level at which bacterial activity will occur is, greater than 12-15 %.This was aided by the frequent addition of water and the initially lower levels of pathogens in the soil and thrash.

Total solids content increased with the increasing loss of water and therefore the more the loss of water the higher the total solid content depicting an inverse relationship between moisture content and total solids. The heap ratio 1:1 Soil/T ended up with the highest total solid content followed by 1:2 S/T and the 1:1 S/T. Total solid levels in the ratio 1:1 S/T and 1:2 S/T showed statistical significance ($P \leq 0.05$) emphasizing the relevance of total solid content and moisture content. However for the ratio 1:1 Soil/T total solid level showed statistical insignificance as water was much more easily lost as biodegradation took place

5.3 ORGANIC MATTER AND ASH CONTENT

The experiment revealed a loss in organic matter in all three heaps during the composting period. The highest loss was observed in 1:2 S/T, followed by 1:1 S/T and then 1:1 Soil/T. Amir et al., 2005 indicated that composting transforms organic matter into stable humic compounds. A rapid degradation period was observed within the first 15 days followed by a longer period of slow degeneration (Fig 4.12). This phenomenon was also observed by Diaz et al., (2002). Fang et al., (1999) reported a 9 % loss in organic matter in the composting of sewage sludge and sawdust-fly ash. Decrease in organic matter is as a result of its conversion into water and carbon dioxide. Losses however depend on the type of feedstock used. Said-Pullicino and Gigliotti (2007) showed that during the initial stages of composting, organic matter is highly degradable under aerobic conditions, particularly due to the predominance of labile hydrophilic compounds such as carbohydrates, amino acids and proteins. However as such compounds are degraded more resistant aromatic moieties accumulate resulting in reduction in degradation with composting time.

Slow degradation of organic matter over a longer period may be as a result of the presence of lignin and polyphenols especially in the cotton trash. Lignin is one of the main constituents of plant cell walls and its complex chemical structure makes it highly resistant to microbial degradation (Richard, 1996) Lignin reduces the bioavailability of other cell wall constituent, whiles polyphenols bind cell walls and proteins making them physically or chemically less accessible to decomposers as composting takes place (Schorth, 2003). Palm et al., (2001) suggest that the inhibitory effect of Lignin and polyphenols should be used to classify organic material for more efficient composting. Organic matter and ash content did not show any statistically significant differences in all three final compost and therefore are all expected to exhibit the quality effects when utilized.

Ash content was found to have an inverse relationship with organic matter. Therefore as ash content increased, organic matter decreased. This is because ash content also referred to as the inorganic fraction, increases due to the loss of the organic fraction (volatile solids) as carbon dioxide. Therefore as the organic fraction is a good indication of the organic content ash content is a crude indicator of the extent of composting.

5.4 CARBON, NITROGEN AND CARBON - NITROGEN RATIO

Carbon and nitrogen are key elements which affect the composting process and their relative proportions in the form of C/N ratio influence the decomposition rate. There was a gradual monthly decrease in total carbon content in all the piles over the entire composting period Monthly mean reduction in the 1:2 S/T and 1:1 Soil/T was statistically significant ($P \leq 0.05$) whiles 1:1 S/T was insignificant. This suggests that the level of trash in the 1:2 S/ T and 1:1 Soil/T ratios had a very important role in the composting process as a carbon source. However the ANOVA for all the ratios showed no significant difference total carbon levels ($P > 0.05$, Appendix D). This implies that irrespective of the quantity or level of carbon in all three ratios, all was adequately decomposed and transformed into stable compounds. The decrease is a result of the fact that microorganisms involved in composting use carbon for energy and to build microbial cells. Larney et al., 2006 also concluded that composting is associated with nitrogen and carbon losses. Haug, 1983 noted that carbon is used as an energy source by the responsible organism and is released in the form of carbon dioxide which means that its value declines with time. Loss of carbon was found to be 23 % in 1:1 S/T, 29.5 % in 1:2 S/T and 61 % in 1:1 Soil/T. Eghball et al., (1997) found 20 – 40 % loss of nitrogen and 42 to 62 % loss of carbon during composting of beef cattle manure. The decomposition of easily degradable carbon by the thermophilic microorganisms result in a more stable form of carbon felt in the composting. Fig 4.8 shows a much lower decrease in nitrogen level 12.5 % in 1:1 S/T, 12.2 % and 36 % in 1:1 soil/T as compared to carbon loss. Mahimairaja et al., (1994) reported 11.19 to 14.54 % loss of nitrogen in the composting of poultry manure. Still higher reduction was reported by Das et al., (2002) while composting hatchery waste. Available nitrogen generally decreases during composting due to its conversion into bacterial proteins and therefore immobilized and stored in the bodies of the microorganism Wilson (1983).

Most nitrogen is converted from ammonium–N to ammonia and its subsequent volatilization, while some is emitted as N_2O, (Hao et al., 2004). Loss could also be attributed to microbial denitrification to NO, N_2O and N_2 (Groenestein and Van Faasen 1996). Volatilization losses however may vary depending on nitrogen balance with available carbon. Krichman and Witter 1992 had more nitrogen loss due to volatilization of ammonia from poultry manure composting. There was statistically insignificant differences in the final compost ($P > 0.05$), and this could be as a result of the nitrogen loss being offset by the much greater loss of carbon through its conversion from organic carbon to CO_2 and water.

Carbon-nitrogen ratio for all the ratios decreased gradually over the whole composting process. The initial C/N ratio of 20.58, 23.28, 27.39 for 1:1 S/T, 1:2 S/T and 1:1 Soil/T reduced to 17.88, 18.72 and 16.36 respectively. Composting microorganisms require the appropriate balance of carbon and nitrogen in the medium. Organic matter mineralization and loss of CO_2 and water causes the decrease in C/N ratio (De-Bortoldi et al., 1983). Apart from the transformation of carbon into CO_2, decreases in concentration of organic acids contribute to the decrease in C/N ratio. In the composting of palm oil-mill sludge and Sawdust, a final C/N ratio of 19.5 was obtained from an initial of 25, which was considered mature. It was also observed that a negative correlation occurred between temperature and carbon-nitrogen ratio (Chefez et al., 1998).

The higher temperatures attained by the 1:2 S/T ratio within the first 15 days resulted in an increase in organic matter mineralization and a decrease in C/N ratio. This was followed by 1:1 S/T. The carbon nitrogen ratio for all ratios was statically significant ($P < 0.05$). This confirms the importance of C/N ratio in influencing the composting process. The C/N ratio of moderately stable finished mature compost is between 15:1 to 20:1 (NRAES, 1992). C/N ratio may be used as an indicator of organic stability and nitrogen availability. Also C/N ratio is regarded as a criterion of maturity of compost (Hardy et al., 1993).

5.5 POTASSIUM AND PHOSPHOROUS

As was observed with nitrogen, phosphorous and potassium showed a monthly decreasing trend. However the level for both elements was lower than that observed with nitrogen. (Fig 4.6 and 4.7). The ratio 1:1 Soil/ T however registered a higher potassium level than 1:1 S/ T and 1:2 S/T. The final compost from all three ratios showed statistically significant differences ($P \leq 0.05$) for both elements. The levels of potassium and phosphorous though small were very necessary for the composting process. This is because micro-organisms require potassium and phosphorous as primary nutrients. Phosphorous is a constituent of microbial protoplasm while potassium is necessary for regulating osmotic pressure within bacterial cells. Microbial activities during the composting process therefore lead to a reduction in their respective levels.

5.6 TEMPERATURE

Temperature is the main indicator for an active or passive composting process. The principal mode of pathogen destruction is based on the time-temperature relationship (Epstein, 1997). The time temperature profile in the experiment was typical for the composting of organic material and more so similar to those reported for window composting of feed lot manure in Nebraska (Eghball et al., 1997). Three distinct stages were observed in all three compost heaps. An initial early rise in temperature from 29 °C to about 35 °C (Mesophilic stage, 25-40 ^{o}C) for all three ratios, followed by a rapid rise to above 45 °C for 1:1 S/T and 1:2 S/T and about 42 °C for 1:1 soil/ T (thermophilic stage,45 ^{o}C and above) within 5 – 10 days. Eventually with the depletion of food sources, overall microbial activity decreased and the temperature dropped resulting in a second mesophilic phase. As the readily available microbial food supply is consumed the temperature fell towards ambient temperature about 30 °C and even below and the material entered the maturation (curing) phase. Slight temporal temperature decreases were observed with each turning event. The secondary peaks in temperature observed were possibly due to mesophilic organisms getting active again after turning caused temporal decrease in temperature. Distinct troughs in temperature may also be due to the excessive presence of ammonia and phenols which inhibit bacterial growth and activity. Turning provided the opportunity for most of the ammonia and phenols to be released into the air and bacterial population can resume growth (Liao et al., 1994). All compost ratios entered the curing phase by the 55th day of composting (Fig 4.12).

5.7 COMPOST VOLUME

Over the entire 16 weeks of composting there was a consistent reduction in heap volumes of all the three ratios used. 50 % and above reduction was registered in all heap ratios (Plate 5.1) This is in agreement with Larney et al., (2006) when they arrived at the conclusion that composting decreases manure volume. Mass reduction following composing may be in excess of 50 % during composting experiments. Dao, 1999 also registered over 50 % loss in volume when he composted manure. The reduction in volume could be explained by the fact that active composting especially during the first 15 days generated considerable heat and large quantities of carbon dioxide and water vapour. These were released into the air, and that water loss account for half the weight of the initial material. This reduces the volume and mass of the final compost. The heap ratio 1:2 S/T recorded the highest reduction of 60 % followed by 54 % for 1:1 S/T and 50 % for 1:1 Soil/T. 1:2 Soil/T recorded the highest because it had a higher trash content (Carbon and energy source) than the others and this further manifested in the higher temperature experienced during the first 15 days. Rate of volume reduction slowed down towards the end of the composting period because the readily decomposable organic materials got exhausted with time, leaving the resistant material, which needed more time to decompose.

5.8 COLIFORMS IN COMPOST

Total coliforms, faecal coliforms and salmonella (Microbial parameters) showed considerable decrease over the composting period. All compost ratios showed statistically significant differences ($P \leq 0.05$) for the individual compost and all ratios compared. By the end of the first month of composting total coliforms had reduced drastically by 58 %, 52 % and 52 % for the 1:1 S/T, 1:2 S/T and 1:1 Soil/T respectively. Faecal coliforms had reduced in all ratios to levels below the standard of less than 3.00 log10 MPN/g (< 1000 MPN/g) as set by USEPA, (1994) and the Canadian Council of Ministers of the environment guide lines 1996. Notably, by the end of the four weeks salmonella had been completely eliminated, which is below the standard of less than 3 MPN/4 g for all compost ratios. By the end of the first month salmonella was absent in the Soil/T. This could be because pathogen levels were initially very low and so the high temperature recorded within the first 15 days of the composting process. From the results obtained all three compost types qualify to be of class A standard, establishing them all to be suitable for use as a safe soil amendment for food and non-food plants. Pathogen destruction during composting was achieved through the thermal environment experienced, and therefore the time-temperature relationship. Antagonistic micro-organisms and ammonia may also have contributed to pathogen destruction as experienced in the composting of beef cattle feedlot manure (Epstein, 1997). Antagonistic microorganisms found in compost and manures include streptomyces, Aspergillus falvipes, Penicillium janthinellium and Tricoderma globosum (Heller and Theiler-Hedrich, 1994) .Lack of nutrients caused by high populations of indigenous microorganisms in manure or the production of compounds detrimental to coliforms may also have played a part in the reduction of pathogens during composting (Himathongkham et al., 1999). Pietronave et al., 2002 also demonstrated that indigenous microbial suppressed Escherichia coli growth in non-sterilized finished compost while E. coli grew rapidly in sterilized compost) Pathogen destruction is the result of thermal kill and antibiotic action or by decomposing organisms or their products. Microbial suppression of Salmonella could be as a result of inhibition resulting in reduced growth rate and death as corroborated by Millner et al., 1987. They also concluded that with proper curing, negligible regrowth of Salmonella occurs because curing at mesophilic temperature encourages the growth of numerous microbes that would be antagonistic to Salmonella.

It was observed that the compost ratio 1:1 S/T and 1:1 Soil/ T did not attain the recommended standard temperature of > 55 °C maintained for at least 15 days (USEPA, 1994). However the desired level of pathogen reduction was still achieved. This could be a result of the assertion that apart from thermal destruction, antagonistic organism, indigenous organisms, production of antibiotic substances, time acts as a factor. This is corroborated by Golueke (1983) who concluded that time provides for the combination of several inhibitory factors to act on pathogenic organisms. Gaby (1975) also reported that Salmonella and Shigella originally present or introduced into refuse-biosolids mixture were absent within 7 to 21 days of windrow composting.

5.9 YIELD OF LETTUCE GROWN WITH COMPOST

Harvested lettuce at five weeks of growth registered variable mean fresh and dry weight values (Table 4.1). The ratio 1:2 S/T registered the highest mean fresh weight among the compost ratios followed by 1:1 S/T and then 1:1 Soil/T. High lettuce growth for the ratio 1:2 S/T was probably due to its relatively higher nutrient status (phosphorous and potassium). Mean fresh weight of lettuce harvested from the plot treated with uncomposted dried sludge was highest at 103.41 g. This is probably because dried sludge had the highest nutrient levels for nitrogen, phosphorous and potassium. It also registered the highest levels of total coliforms, faecal coliforms and salmonella. (Appendix S). Mean fresh weight obtained from no-treatment plot was the lowest. Dry weights of lettuce from the various treatments were between 7.23-7.8 g except for the no-treatment which registered 5.43 g. These results tend to allude to the positive contribution manure and compost amended soils have over non-amended soils. The composting process which involves successive microbial populations and the generation of heat leads to the loss of nutrients, hence the reduction in nutrient levels by the end of the composting period.

5.10 COLIFORMS ON LETTUCE

Compost produced from the three ratios was applied to plots on which lettuce was cultivated. Total coliform, faecal coliform and Salmonella showed acceptable levels. (Table 4.1). Results obtained from harvested lettuce showed an increase in faecal coliforms and Salmonella compared to levels in the matured compost as shown in Appendix S. Lettuce harvested from uncomposted dried sludge treated plots registered the highest total coliforms faecal coliforms and Salmonella. This can be explained by the fact that dried sludge did not go through the process of composting, as the heat generated during composting makes it an accepted manure pathogen reduction treatment. Total coliforms, faecal coliform and Salmonella, were lowest on lettuce harvested from the no- treatment plots. This is because the soil on these plots had never been cultivated with any crop before. Lettuce from 1:1 S/T amended plot registered the highest faecal coliforms followed by 1:2 S/T and then 1:1 Soil/T corresponding to the pathogen levels of the finished compost. This is because studies by (Solomon et al., 2002) have shown that the concentration of pathogens also play a role in the contamination of vegetables from manure and hence the uptake of bacteria. Transfer of pathogens might be from splash effects caused by raindrops or irrigation or via transport of soil particles onto the lettuce by weeding. The water used for irrigating the lettuce could be another source of contamination. This is corroborated by Solomon et al., 2002 who concluded that water used, in the production and harvesting operations may contaminate lettuce by the direct contact of water, which contains human pathogens, with edible portions of lettuce, or by means of water-to-soil and soil to lettuce contact. Bacteria have been known to survive up to 100 days once they get into soil (Ingham et al., 2004).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Compost produced from trash, sewage sludge and soil were very low in nutrient content in all three (3) ratios, nitrogen (0.24-1.4 %), potassium (0.05-0.11 %), and phosphorous (0.53-0.17 %) as compared to 15 %-15 %-15 %, N P K compound chemical fertilizers.

The study showed that the 1:2 S/T ratio was the preferred mix ratio because it produced compost with higher nutrient content of potassium and phosphorous as compared to the other ratios.

Composting of trash and dewatered sewage sludge produced compost of quality that could be used as organic fertilizer or for soil amendment. This would help reduce the volume of both trash and sludge in an environmentally friendly manner.

Composting of trash with dewatered sludge proved effective in reducing pathogen concentrations in the sewage sludge to below acceptable standard levels as prescribed by the USEPA (1994). Acceptable concentration levels are less than 1000MPN/g for faecal coliform and less than 3 CFU/4 g for Salmonella.

Compost is deemed safe for use in agriculture when these standards are achieved. Dried non composted sewage sludge produced the highest yield when applied to soil for lettuce cultivation (wet and dry weight) as compared to the compost of the other ratios. However this compost was not suitable for the cultivation of vegetables that are eaten raw due to the high concentration of Salmonella (>3CFU/4 g) that was detected in it (Table 4.1).

1:2 S/T mix ratio could be used to reduce the amount of trash faster than the other ratios since it involved the use of more trash.

6.2 RECOMMENDATIONS

Since composting of trash and sewage sludge produced good results it is recommended that composting of trash with other household waste should be carried out to determine their suitability for composting.

With 1:2 S/T mix ratio being the preferred mix it is recommended that further work should be carried out using wider ratios of trash and sewage sludge to determine their effects on compost quality.

Therefore composting can be employed by the cotton ginneries to dispose of their trash in an environmentally friendly manner.

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APPENDICES

APPENDIX A:

One Way ANOVA for 1:1 Sludge Trash Ratio Compost within Composting Period

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	1150.94	4	287.734	33.03	0.001
	Within Groups	43.556	5	8.711		
	Total	1194.49	9			
TS	Between Groups	1150.94	4	287.734	33.03	0.001
	Within Groups	43.556	5	8.711		
	Total	1194.49	9			
OM	Between Groups	270.081	4	67.52	3.76	0.089
	Within Groups	89.796	5	17.959		
	Total	359.877	9			
Ash	Between Groups	270.081	4	67.52	3.76	0.089
	Within Groups	89.796	5	17.959		
	Total	359.877	9			
C	Between Groups	70.269	4	17.567	3.762	0.089
	Within Groups	23.35	5	4.67		
	Total	93.619	9			
N	Between Groups	0.048	4	0.012	1.617	0.303
	Within Groups	0.037	5	0.007		
	Total	0.084	9			
CN	Between Groups	8.025	4	2.006	2.824	0.143
	Within Groups	3.552	5	0.71		
	Total	11.577	9			
P	Between Groups	0.443	4	0.111	76.098	0
	Within Groups	0.007	5	0.001		
	Total	0.45	9			
K	Between Groups	0.037	4	0.009	10.185	0.013
	Within Groups	0.004	5	0.001		
	Total	0.041	9			
pH	Between Groups	1.373	4	0.343	61.193	0
	Within Groups	0.028	5	0.006		
	Total	1.401	9			
TC	Between Groups	154.947	4	38.737	1.10E+03	0
	Within Groups	0.176	5	0.035		
	Total	155.123	9			
FC	Between Groups	147.482	4	36.871	3.37E+03	0
	Within Groups	0.055	5	0.011		
	Total	147.537	9			
Sal	Between Groups	153.833	4	38.458	2.53E+03	0
	Within Groups	0.076	5	0.015		
	Total	153.909	9			

APPENDIX B:

One Way ANOVA for 1:2 Sludge Trash Ratio Compost within Composting Period

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	1170.891	4	292.723	32.431	
	Within Groups	45.13	5	9.026		
	Total	1216.021	9			0.001
TS	Between Groups	1170.891	4	292.723	32.431	
	Within Groups	45.13	5	9.026		
	Total	1216.021	9			0.001
OM	Between Groups	516.445	4	129.111	65.474	0
	Within Groups	9.86	5	1.972		
	Total	526.305	9			
Ash	Between Groups	516.445	4	129.111	65.474	
	Within Groups	9.86	5	1.972		
	Total	526.305	9			0
C	Between Groups	134.232	4	33.558	65.325	
	Within Groups	2.569	5	0.514		
	Total	136.801	9			0
N	Between Groups	0.046	4	0.012	27.001	
	Within Groups	0.002	5	0		
	Total	0.048	9			0.001
CN	Between Groups	23.372	4	5.843	29.684	
	Within Groups	0.984	5	0.197		
	Total	24.356	9			0.001
P	Between Groups	0.247	4	0.062	49.536	
	Within Groups	0.006	5	0.001		
	Total	0.253	9			0
K	Between Groups	0.058	4	0.015	30.146	
	Within Groups	0.002	5	0		
	Total	0.061	9			0.001
pH	Between Groups	1.676	4	0.419	5.658	
	Within Groups	0.37	5	0.074		
	Total	2.046	9			0.042
TC	Between Groups	99.683	4	24.921	6.86E+03	
	Within Groups	0.018	5	0.004		
	Total	99.701	9			0
FC	Between Groups	111.029	4	27.757	1.10E+03	
	Within Groups	0.126	5	0.025		
	Total	111.155	9			0
Sal	Between Groups	102.215	4	25.554	7.07E+03	
	Within Groups	0.018	5	0.004		
	Total	102.233	9			0

APPENDIX C:

One Way ANOVA for 1:1 Soil Trash Ratio Compost within Composting Period

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	230.753	4	57.688	7.699	0.023
	Within Groups	37.464	5	7.493		
	Total	268.217	9			
TS	Between Groups	230.753	4	57.688	7.699	0.023
	Within Groups	37.464	5	7.493		
	Total	268.217	9			
OM	Between Groups	200.878	4	50.22	28.02	0.001
	Within Groups	8.961	5	1.792		
	Total	209.839	9			
Ash	Between Groups	200.878	4	50.22	28.02	0.001
	Within Groups	8.961	5	1.792		
	Total	209.839	9			
C	Between Groups	52.237	4	13.059	28.029	0.001
	Within Groups	2.33	5	0.466		
	Total	54.566	9			
N	Between Groups	0.025	4	0.006	3.403	0.106
	Within Groups	0.009	5	0.002		
	Total	0.035	9			
CN	Between Groups	151.891	4	37.973	19.885	0.003
	Within Groups	9.548	5	1.91		
	Total	161.439	9			
P	Between Groups	0.075	4	0.019	5.593	0.043
	Within Groups	0.017	5	0.003		
	Total	0.092	9			
K	Between Groups	0.734	4	0.184	16.756	0.004
	Within Groups	0.055	5	0.011		
	Total	0.789	9			
pH	Between Groups	0.796	4	0.199	29.311	0.001
	Within Groups	0.034	5	0.007		
	Total	0.83	9			
TC	Between Groups	157.562	4	39.391	192.592	0
	Within Groups	1.023	5	0.205		
	Total	158.585	9			
FC	Between Groups	3.616	4	0.904	1.36E+03	0
	Within Groups	0.003	5	0.001		
	Total	3.619	9			
Sal	Between Groups	1.788	4	0.447	344.199	0
	Within Groups	0.006	5	0.001		
	Total	1.794	9			

APPENDIX D:

All Ratios ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
MC	Between Groups	2293.191	4	573.298	2.534	
	Within Groups	5655.151	25	226.206		
	Total	7948.342	29			0.065
TS	Between Groups	2293.191	4	573.298	2.534	
	Within Groups	5655.151	25	226.206		
	Total	7948.342	29			0.065
OM	Between Groups	937.872	4	234.468	0.451	
	Within Groups	12996.36	25	519.855		
	Total	13934.24	29			0.771
Ash	Between Groups	937.872	4	234.468	0.451	
	Within Groups	12996.36	25	519.855		
	Total	13934.24	29			0.771
C	Between Groups	243.867	4	60.967	0.451	
	Within Groups	3379.135	25	135.165		
	Total	3623.002	29			0.771
N	Between Groups	0.115	4	0.029	0.08	
	Within Groups	8.991	25	0.36		
	Total	9.106	29			0.988
CN	Between Groups	130.969	4	32.742	9.169	
	Within Groups	89.276	25	3.571		
	Total	220.245	29			0
P	Between Groups	0.655	4	0.164	8.132	
	Within Groups	0.504	25	0.02		
	Total	1.159	29			0
K	Between Groups	0.539	4	0.135	1.889	
	Within Groups	1.782	25	0.071		
	Total	2.321	29			0.144
pH	Between Groups	3.417	4	0.854	4.131	
	Within Groups	5.169	25	0.207		
	Total	8.586	29			0.011
TC	Between Groups	407.16	4	101.79	105.737	
	Within Groups	24.067	25	0.963		
	Total	431.226	29			0
FC	Between Groups	199.772	4	49.943	9.481	
	Within Groups	131.692	25	5.268		
	Total	331.463	29			0
Sal	Between Groups	188.904	4	47.226	10.995	
	Within Groups	107.385	25	4.295		
	Total	296.289	29			0

APPENDIX E:

Mean Monthly PH in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	6.84	7.04	6.94	7.37	7.05	7.21	7.71	7.52	7.62
1	6.75	6.65	6.70	7.02	6.23	6.63	7.34	7.24	7.29
2	6.11	6.14	6.13	6.30	6.20	6.25	7.31	7.22	7.27
3	6.06	6.10	6.08	6.21	6.16	6.19	7.24	7.20	7.22
4	6.01	6.07	6.04	6.08	6.12	6.10	6.79	6.68	6.74

APPENDIX G:

Mean Monthly Ash Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	38.66	34.25	36.46	31.16	28.30	29.73	79.80	81.53	80.67
1	46.34	41.46	43.90	43.18	40.48	41.83	84.90	85.64	85.27
2	50.00	42.31	46.16	44.44	45.21	44.83	88.48	90.46	89.47
3	52.24	45.21	48.73	47.76	46.76	47.26	90.11	92.62	91.37
4	54.45	49.18	51.82	49.89	51.52	50.71	92.05	94.09	93.07

APPENDIX H:

Mean Monthly Total Solids Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	41.59	40.44	41.02	40.26	41.58	40.92	72.55	77.67	75.11
1	42.98	41.00	41.99	43.56	45.66	44.61	78.43	79.27	78.85
2	55.24	48.60	51.92	51.92	57.28	54.60	78.67	83.33	81.00
3	58.82	60.40	59.61	61.39	64.71	63.05	83.17	86.14	84.66
4	66.34	72.28	69.31	66.34	73.00	69.67	87.00	91.18	89.09

APPENDIX I:

Mean Monthly Carbon Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	**Sludge/Trash Heap (Ratio)**						**Soil/Trash Heap (Ratio)**		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	31.76	34.01	32.89	35.59	37.05	36.32	10.78	9.90	10.34
1	27.85	30.34	29.09	29.46	30.84	30.15	8.18	7.80	7.99
2	25.98	29.90	27.94	28.82	28.42	28.62	6.36	5.35	5.85
3	24.84	28.42	26.63	27.12	27.63	27.38	5.52	4.24	4.88
4	23.71	26.40	25.05	26.04	25.20	25.62	4.53	3.49	4.01

APPENDIX J:

Mean Monthly Phosphorous Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	**Sludge/Trash Heap (Ratio)**						**Soil/Trash Heap (Ratio)**		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	0.69	0.65	0.67	0.61	0.52	0.56	0.33	0.21	0.27
1	0.54	0.55	0.54	0.51	0.52	0.51	0.27	0.18	0.22
2	0.45	0.50	0.47	0.26	0.28	0.27	0.16	0.06	0.11
3	0.18	0.22	0.20	0.21	0.27	0.24	0.10	0.04	0.07
4	0.06	0.16	0.11	0.16	0.18	0.17	0.06	0.04	0.05

APPENDIX K:

Mean Monthly Potassium Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	**Sludge/Trash Heap (Ratio)**						**Soil/Trash Heap (Ratio)**		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	0.31	0.36	0.34	0.56	0.60	0.58	1.21	1.29	1.25
1	0.30	0.34	0.32	0.48	0.52	0.50	1.06	0.84	0.95
2	0.28	0.27	0.27	0.41	0.43	0.42	0.77	0.58	0.67
3	0.20	0.26	0.23	0.38	0.40	0.39	0.61	0.51	0.56
4	0.18	0.15	0.17	0.36	0.38	0.37	0.59	0.48	0.53

APPENDIX L:

Mean Monthly Nitrogen Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	1.51	1.69	1.60	1.54	1.58	1.56	0.42	0.34	0.38
1	1.43	1.57	1.50	1.46	1.48	1.47	0.37	0.32	0.35
2	1.42	1.52	1.47	1.43	1.42	1.43	0.31	0.25	0.28
3	1.41	1.45	1.43	1.38	1.40	1.39	0.30	0.24	0.27
4	1.35	1.45	1.40	1.35	1.39	1.37	0.27	0.22	0.24

APPENDIX M:

Mean Monthly Carbon - Nitrogen Ratio of the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	21.04	20.13	20.58	23.11	23.45	23.28	25.67	29.12	27.39
1	19.47	19.32	19.40	20.18	20.83	20.51	22.11	24.39	23.25
2	18.30	19.67	18.98	20.15	20.02	20.08	20.50	21.38	20.94
3	17.62	19.60	18.61	19.65	19.74	19.70	18.41	17.68	18.05
4	17.56	18.21	17.88	19.31	18.13	18.72	16.79	15.94	16.36

APPENDIX N:

Weekly Volume Readings (m3) of the Difference Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Weeks)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	0.3006	0.3002	0.3004	0.3008	0.3009	0.3008	0.3002	0.3002	0.3002
1	0.2616	0.2439	0.2527	0.2593	0.2459	0.2526	0.2876	0.2739	0.2807
2	0.2407	0.2373	0.2390	0.2406	0.2032	0.2219	0.2602	0.2536	0.2569
3	0.2322	0.2238	0.2280	0.2109	0.2032	0.2070	0.2309	0.2322	0.2316
4	0.2159	0.2228	0.2193	0.1983	0.1901	0.1942	0.2218	0.2311	0.2265
5	0.2099	0.2089	0.2094	0.1937	0.1892	0.1914	0.2218	0.2250	0.2234
6	0.2030	0.2089	0.2059	0.1919	0.1882	0.1901	0.2148	0.2119	0.2134
7	0.1901	0.2030	0.1965	0.1872	0.1802	0.1837	0.2148	0.2070	0.2109
8	0.1882	0.1936	0.1909	0.1863	0.1758	0.1811	0.2069	0.2061	0.2065
9	0.1828	0.1891	0.1860	0.1758	0.1672	0.1715	0.2040	0.2012	0.2026
10	0.1767	0.1837	0.1802	0.1706	0.1621	0.1663	0.1965	0.2012	0.1989
11	0.1714	0.1758	0.1736	0.1602	0.1539	0.1571	0.1946	0.1956	0.1951
12	0.1680	0.1740	0.1710	0.1578	0.1524	0.1551	0.1820	0.1854	0.1837
13	0.1589	0.1656	0.1622	0.1513	0.1405	0.1459	0.1758	0.1791	0.1774
14	0.1557	0.1566	0.1561	0.1427	0.1365	0.1396	0.1714	0.1695	0.1705
15	0.1557	0.1455	0.1506	0.1332	0.1309	0.1321	0.1656	0.1598	0.1627
16	0.1398	0.1350	0.1374	0.1264	0.1138	0.1201	0.1533	0.1493	0.1513

APPENDIX O:

Mean Monthly Moisture Content (%) in the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	58.41	59.56	58.99	59.74	58.42	59.08	27.45	22.33	24.89
1	57.02	59.00	58.01	56.44	54.34	55.39	21.57	20.73	21.15
2	44.76	51.40	48.08	48.08	42.72	45.40	21.33	16.67	19.00
3	41.18	39.60	40.39	38.61	35.29	36.95	16.83	13.86	15.35
4	33.66	27.72	30.69	33.66	27.00	30.33	13.00	8.82	10.91

APPENDIX P:

Log of Mean Monthly Total Coliform in 10g of the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	**Sludge/Trash Heap (Ratio)**						**Soil/Trash Heap (Ratio)**		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	13.60	13.72	13.66	11.08	11.09	11.08	14.13	15.14	14.64
1	5.82	5.46	5.64	5.30	5.13	5.22	6.45	7.41	6.93
2	4.56	4.70	4.63	4.15	4.12	4.14	5.18	5.28	5.23
3	3.81	3.38	3.59	3.10	3.18	3.14	4.88	4.81	4.84
4	2.72	2.62	2.67	2.08	2.04	2.06	3.32	3.56	3.44

APPENDIX Q:

Log of Mean Monthly Faecal Coliform in 10g of the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	**Sludge/Trash Heap (Ratio)**						**Soil/Trash Heap (Ratio)**		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	11.13	11.33	11.23	9.53	9.45	9.49	1.54	1.46	1.50
1	3.18	3.43	3.31	3.05	3.08	3.07	0	0	0
2	2.88	2.81	2.84	1.56	1.45	1.50	0	0	0
3	1.30	1.28	1.29	1.15	1.08	1.11	0	0	0
4	0.48	0.48	0.48	0.48	0	0.24	0	0	0

APPENDIX R:

Log of Mean Monthly Salmonella in 10g of the Different Compost Heaps of Sludge/Trash and Soil/Trash

Time	Sludge/Trash Heap (Ratio)						Soil/Trash Heap (Ratio)		
(Months)	1:1, a	1:1, b	Mean	1:2, a	1:2, b	Mean	1:1, a	1:1, b	Mean
0	10.52	10.33	10.43	8.51	8.50	8.50	1.11	1	1.06
1	2.38	2.72	2.55	2.33	2.40	2.36	0	0	0
2	1.08	1.04	1.06	0.78	0.95	0.87	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0

APPENDIX S:

Characteristics of the Different Compost of Sludge/Trash, Soil/Trash and Dried Non-composted Sewage Sludge Applied on the Soil for the Cultivation of Lettuce

Material	pH	MC (%)	TS (%)	OM (%)	Ash (%)	N (%)	C (%)	C/N	P (%)	K (%)	TC (MPN)	FC (MPN)	Sal/g
Sludge/Trash 1:1, a	6.01	33.66	66.34	45.55	54.45	1.35	23.71	17.56	0.06	0.18	5.30E+02	3	0
Sludge/Trash 1:1, b	6.07	27.72	72.28	50.82	49.18	1.45	26.40	18.21	0.16	0.15	4.20E+02	3	0
Mean	**6.04**	**30.69**	**69.31**	**48.19**	**51.82**	**1.40**	**25.05**	**17.88**	**0.11**	**0.17**	**4.75E+02**	**3**	**0**
Sludge/Trash 1:2, a	6.08	33.66	66.34	50.11	49.89	1.35	26.04	19.31	0.16	0.36	1.20E+02	3	0
Sludge/Trash 1:2, b	6.12	27.00	73.00	48.48	51.52	1.39	25.20	18.13	0.18	0.38	1.10E+02	0	0
Mean	**6.10**	**30.33**	**69.67**	**49.30**	**50.71**	**1.37**	**25.62**	**18.72**	**0.17**	**0.37**	**1.15E+02**	**1.5**	**0**
Soil/Trash 1:1, a	6.79	13.00	87.00	7.95	92.05	0.27	4.53	16.79	0.06	0.59	2.10E+03	0	0
Soil/Trash 1:1, b	6.68	5.91	91.18	5.91	94.09	0.22	3.49	15.94	0.04	0.48	3.60E+03	0	0
Mean	**6.74**	**9.46**	**89.09**	**6.93**	**93.07**	**0.24**	**4.01**	**16.36**	**0.05**	**0.53**	**2.85E+03**	**0**	**0**
Soil	**6.58**	**12.11**	**87.89**	**2.52**	**97.48**	**0.23**	**1.77**	**7.72**	**0.83**	**0.35**	**1.34E+05**	**36**	**15**
Dried Non-composted sludge	**4.96**	**45.63**	**54.37**	**39.29**	**60.71**	**2.07**	**20.52**	**9.90**	**3.65**	**0.75**	**2.18E+10**	**6.40E+07**	**9.30E+06**