EFFECT OF SAWDUST AND GRASS CLIPPING AS BULKING MATERIALS ON COMPOSTING OF ORGANIC WASTE FROM KNUST CAMPUS

BY

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CERTIFICATION

I hereby declare that this submission is my original work towards a Master of Science (Environmental Science) degree. This thesis has not been submitted in whatever form to any other institution or organization for the award of any degree. All inclusions from the work of others have been duly cited and acknowledged.

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DEDICATION

I DEDICATE THIS WORK TO MY PARENTS DR. AND MRS. PREMPEH AND FAMILY.

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Glory be to the Almighty God for His guidance and directions that saw me successfully through this work.

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ABSTRACT

The increase in student population has led to a corresponding increase in the generation of waste on the KNUST or university campus. Composting of the biodegradable portion of waste is seen as a better option to reducing the volume of waste and managing it at the same time. This study hence aimed to investigate the effect of some bulking materials on composting of the biodegradable portion of the waste generated. Bin composting was employed for this analysis. Composting was conducted over a 60 days period at the sewage treatment plant on the KNUST campus. Wastes were mixed in ratios of 1:1, 1:2, and 2:1 (v/v) ratio for sawdust/food waste (SSD 1:1, SSD 1:2, SSD 2:1) and grass clipping/food waste (SGC 1:1, SGC 1:2, SGC 2:1). Turning of compost was done manually at three days interval during which the volume was also recorded. Temperatures were taken on daily basis, three times within a day. Total coliform and faecal coliform decreased to levels even below the standard of less than 3.00log10 MPN/g (< 1000 MPN/g) set by the USEPA for sanitary composting. There was a steady decrease in carbon content, nitrogen content and C/N ratio for all the ratios. Percentage content of potassium, phosphorus and pH all decreased gradually to appreciable levels which was adequate for compost manure. Volume of all bins reduced as percentage organic matter decreased leading to an increase in percentage ash to between 39.1 % and 64.5 %. Percentage moisture showed a decreasing trend as percentage total solids increased. By the end of eight weeks of analysis, the grass clipping/food (SGC 1:1, SGC 1:2, and SGC 2:1) waste ratios were seen to decompose faster than the sawdust/food (SSD 1:1, SSD 1:2, and SSD 2:1) waste ratios. Again, the grass clipping/food waste ratios had C/N ratio levels below 20 which are deemed matured for land or soil application as compared to the sawdust/food waste ratios which had C/N ratio levels above 20. The grass clipping/food waste ratios (especially the SGC 2:1) therefore gave better compost compared to the sawdust/food waste.

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LIST OF ABBREVIATIONS

SSD	Sawdust/solid waste ratio
SGC	Grass clipping/solid waste ratio
CS	Control (only solid waste)
AAS	Atomic Absorption Spectrophotometer
MPN	Most Probable Number
ANOVA	Analysis of Variance
pH	Hydrogen ion concentration
N	Nitrogen
C	Carbon
P	Phosphorus
OM	Organic matter
K	Potassium
MC	Moisture content
TS	Total solids
TC	Total coliform
FC	Faecal coliform

CHAPTER ONE

1.0 INTRODUCTION

Man's activities in his attempt to survive create environmental conditions (pollution from waste) that are detrimental to his very survival. Pollution of the environment with waste is either deliberate or accidental.

Waste is something for which we have no immediate further use and which we wish to get rid of. It can be solid or liquid and may also include waste products arising from our way of life. Waste may therefore range from the materials which we discard in our household dustbins and other products which are not of use to a particular person at a particular time and at a particular point (Kharbanga, 1989).

The United Nations Statistics Division (UNSD) defined wastes as materials that are not prime products (that is products produced for the market) for which the generator has no further use in terms of his or her own purposes of production, transformation or consumption, and of which he or she wants to dispose. Waste may be generated during the extraction of raw materials, the processing of raw materials into intermediate and final products, the consumption of final products, and other human activities. Residuals recycled at the place of generation are excluded (OECD, 2009).

According to Razvi *et al*., (1989) approximately 70 % (by weight) of waste generated is biodegradable.

Pollution from waste has become a problem to tackle in both developed and developing countries (Anko, 1999). In developing countries most especially, the problem stems from increase in population and issues of waste management (OECD, 2004). Anko, (1999) corroborated by intimating that waste pollution is partly due to the population explosion of the cities resulting from urbanization and rapid economic growth and also due to issues of refuse management.

Ghana as a developing country produces a lot of refuse especially in the cities as a result of growth in population, rapid urbanization and industrialization. On an average daily waste generation per capita of 0.45 kg, Ghana generates annually about 3.0 million tons of solid waste based on an estimated population of about 18 million in which Accra and Kumasi alone produces about 3,000 tons of solid waste daily (Mensah and Larbi, 2005).

In Ghana for instance, landfills used for waste management are primarily open dumps that have no leachate or gas recovery systems. Mensah and Larbi, (2005) also estimated that throughout the country only about 10 % of solid wastes generated are properly disposed off. Hill and Cook, (1980) also indicated that lack of adequate waste management facilities often creates an unhealthy environment which eventually could result in serious incidence of diseases.

Kotoka, (2001) indicated that, Kumasi produces about 1000 tons of waste of which Kumasi central market alone produces about 250 tons a day, out of the total amount of waste generated of which majority of them are organic in nature. In all about 44 % of waste produced in Kumasi are biodegradable organics (Mensah and Larbi, 2001).

Public awareness to the negative impacts of waste to public health and the environment has led to a call for innovative practices to control waste.

There is therefore the need for more prudent measures to manage waste to protect the environment. Some methods employed to managing waste created are incineration, landfilling, and composting. Nevertheless landfilling and incineration are known to have serious and negative environmental impacts such as the discharge of pollutants into the atmosphere and unto land. They are also known to be more expensive to operate and maintain.

Composting is more environmentally friendly, less expensive to operate and maintain and is a sustainable means of recycling waste when used as fertilizers and soil conditioners (Epstein, 1997). Composting is a controlled biological decomposition and conversion of solid organic material into a humus like substance called compost. Gotass, (1956) indicated that compost, an end product of composting contains essential plant nutrient such as nitrogen, phosphorus, potash and trace elements which are important assets to good and high crop yield in agriculture.

The benefit of using bulking agent in composting is to increase aeration in compost pile and improve pile structure, while providing sufficient carbon for the compost structure.

Good quality compost can be obtained by composting organic solid waste with the aid of some bulking agents which are good in providing aeration.

Existing ways of handling sawdust and grass clippings as waste is either to gather them and throw away or burn them both of which impacts negatively on the environment and hence require new and innovative handling systems to reduce their negative environmental impacts. They can hence be used as bulking agents during composting.

1.1 PROBLEM STATEMENT

The increase in student population on the Kwame Nkrumah University of Science and Technology (KNUST) campus has led to a corresponding increase in the generation of waste on campus.

Nsaful *et al.*, (2006) in his analysis of the percentage waste composition of four halls of residence on the KNUST campus indicated that more than 50 % of waste generated in each hall was organic. Percentage organic composition for each of the four halls were as follows; Unity hall (55.55 %), Independence hall (60.59 %), Africa hall (60.76 %), Queens hall (60.49 %).

Wastes on campus are not pretreated prior to disposal and can also lead to adverse environmental conditions and the spread of diseases.

1.2 JUSTIFICATION

As the disposal of waste still remains a major challenge on the KNUST campus, there is the need to put in place more prudent measures to manage the increasing amount of waste generated on campus.

Incineration is known to be a controversial method of waste disposal, due to impacts such as emission of gaseous matter. Hu and Shy, (2001) corroborated this by indicating that flying ashes and other hazardous pollutants like dioxins and furans as well as high cost of skilled labour and spare parts acquisition combine to make incineration expensive to operate.

Landfilling apart from being expensive may also serve to pollute the environment through the discharge of leachate unto land and greenhouse gases into the atmosphere.

Warren, (2007) has also indicated that organic waste decomposed in landfills leads to the production of methane gas which is about 21 times more potent than carbon dioxide as a green house gas.

In Ghana, many communities have refused the siting of landfills in their area. Kotoka, (2001) indicated that Afrancho and Aburuso, all suburbs in Kumasi as well as people of Kwabenya (AMA, 2000) have all refused the siting of landfill in their vicinity due to experiences of poor maintenance in other areas.

Composting nevertheless is more environmentally friendly and also less expensive to operate compared to incineration and landfilling. It has also been observed that the use of natural compost or manure arising from composting of organics helps to re-nourish soils. Massiani and Domeizel, (1996) indicated that recycling of organic waste as soil amendments is a useful alternative to incineration, landfill or rubbish dumps.

This was corroborated by Tuomela *et al*., (2000) who in his work indicated that, composting was a more successful strategy for the sustainable recycling of organic waste.

1.3 GENERAL OBJECTIVE

To investigate the effect of some bulking materials on composting using organic waste from KNUST campus.

1.4 SPECIFIC OBJECTIVES

- To determine the characteristics of feedstock and mixed ratios (grass clippings/sawdust and organic solid waste) to achieve favorable C/N ratio, temperature and moisture content necessary for efficient composting.
- To determine the effect of bulking material on the rate of decomposition of the organic waste.
- To determine the effect of bulking material on compost quality.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORY OF COMPOSTING

It is believed that composting began shortly after humans started to cultivate food. The type of compost was most likely animal manure. In fact, nature has been engaged in composting since the very beginning. The wonderful smell of a forest floor is the smell of humus which is, quite simply, completely rotted plants and animals.

It is difficult to attribute the birth of composting to a specific individual or even one society.

The ancient Akkadian Empire in the Mesopotamian Valley referred to the use of manure in agriculture on clay tablets 1,000 years before Moses was born. There is evidence that Romans, Greeks and the Tribes of Israel knew about compost. The Bible and Talmud both contain numerous references to the use of rotted manure straw, and organic references to compost are contained in tenth and twelfth century Arab writings, in medieval Church texts, and in Renaissance literature.

According to Gotass, (1956) this process 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, a British agronomist, went to India in 1905 and spent almost 30 years experimenting with organic gardening and farming. In 1943, Sir Howard published a book, An Agriculture Testament, based on the work he had done (Vermont State Agency of Natural Resources Compost Center, 1992).

Today organic methods of farming and gardening are more popular than ever as farmers are moving away from harmful fertilizers and pesticides. With this growing movement and trend, there comes ironically, a return to past methods involving the use of natural compost or manure to re-nourish soils.

2.2 COMPOSTING

Tammemagi, (1999) defined composting as a specialized part of recycling in which organic wastes are biologically decomposed under controlled boundaries that convert them into a product that can be applied to the land beneficially without environmental harm.

Williams, (2000) also defined composting as aerobic rather than anaerobic degradation of biodegradable organic waste such as food and garden waste. It has several advantages over other methods of waste management options.

Finstein and Miller, (1984), also indicated that composting is an ecosystem, which self heats i.e. temperature within the composting mass rises because heat is released metabolically, accumulates faster than it is dissipated to the surrounding environment. This self-heating tends to increase decomposition rate unless inhibitive high temperatures are reached. Activity is much more rapid and less odorous under fully aerobic conditions.

Razvi *et al.*, (1989) however indicated that, composting MSW does not eliminate the need for landfill. Studies have however shown that, only 30 % to 40 % of incoming MSW will have to be landfilled after composting; this amount could be reduced still further in communities with active recycling programs. The amount of compost produced is 25 % to 35 % (by weight) of the incoming wastes. The remaining weight is lost to the atmosphere in the form of carbon dioxide gas and water.

The stabilized end-product (compost) is widely used as a soil amendment to improve soil structure, provide plant nutrients, and facilitate the revegetation of disturbed or eroded soil.

2.3 PRINCIPLES OF COMPOSTING

Composting is the controlled biological decomposition and conversion of solid organic material into a humus like substance called compost.

Compost is a combination of decomposed plant and animal materials and other organic materials that are being degraded largely through aerobic conditions into a rich black soil.

Holmer, (2002) noted that, in the process of composting, microorganisms break down organic matter and produce carbon dioxide, water, heat, and humus, the relatively stable organic end product.

The actual breakdown of organic materials is accomplished by a wide variety of microorganisms. Managing the composting process for peak effectiveness can be seen as making sure that this vast workforce of tiny labourers is provided with everything that is needed. These needs include:

- a favourable carbon to nitrogen ratio
- sufficient moisture and
- Adequate oxygen (http://www.recycle.com/compost/compost.html).

2.4 THE COMPOSTING PROCESS

Composting is a managed system that uses microbial activity (Psychrophiles, Mesophiles, and Thermophiles) to degrade raw organic materials, such as yard trimmings, so that the end-product is relatively stable, reduced in quantity (when compared to the initial amount of waste), and free from offensive odors.

Hagerly *et al.*, (1977) also defined refuse composting as the aerobic, thermophilic degradation of putrescible in refuse by microorganisms and some other invertebrates.

Tammemagi, in (1999) noted that during the composting process, microorganisms break down complex organic molecules (i.e. proteins, amino acids, carbohydrates, etc.) into simpler ones like cellulose.

Inckel *et al.*, (1990) however, noted that there are basically two main types in a composting process. These are:

Pit process: This is the simplest way for composting kitchen scraps. In this process, a pit is dug and materials placed inside. Usually, a porous bottom is provided for ventilation and drainage. Here, the pit may either be lined or unlined. The lining prevents the walls from collapsing and maintains the shape of the pit. It also helps to maintain a good insulation of the pit against heat losses. In this process, the pit may be a one-foot-deep hole.

Stacking/windrow process: In the aerated static pile process, it requires that the composting mixture be placed in piles that are mechanically aerated. The piles are then placed on some pipe networks that are connected to a blower. The blower supplies air for composting; air may be supplied under positive or negative pressure.

Air circulation in the compost piles provides the needed oxygen for the composting microbes and also prevents excessive heat buildup in the pile.

In the windrow method, a pile, triangular in cross-section, with a length exceeding its width and height is heaped up. Temperature control in the windrow is more difficult in comparison to other technologies. Normally, minimum temperatures of 56 °C should be maintained to ensure pathogen destruction. Windrows must be placed on a paved surface, to allow ease in turning piles. In most cases, the windrow method is used for curing (finishing) the compost.

It is well documented that a minimum height of 1.5 m and width of 2.5 m is necessary to retain enough heat in composting mass to promote the desirable thermophillic activity (Biddlestone *et al*., 1987).

2.5 MICROORGANISMS AND INVERTEBRATES

Both mesophilic and thermophilic organisms are involved in composting and are widely distributed in nature and form part of the micro community of the refuse, sewage sludge and human excreta.

Dindal, (1971 and 1981) in his works, showed that soil invertebrates such as termites, worms, ants etc. are usually found in compost piles and they contribute to the decomposition process. Gotass, (1956) also indicated that temperature changes and the availability of food may probably exert the greatest influence in determining the species of organisms present in the colony at any given time.

At the initial stages of composting mesophilic bacteria are the most predominant readily utilize available substrate. As temperature begins to rise, thermophilic bacterial populations then take over the decomposition process. In later stages other organisms including Actinomycetes, Centipedes, Millipedes, Fungi, Sow bugs, Spiders and Earthworms assist in the process.

Research by Gotass, (1956) has shown that compost piles do not necessarily require any supplementary inoculums. Beffa *et al.*, (1996) as well as Millner *et al.*, (1994) on the other hand noted that, the composting process can, if not properly managed, induce the proliferation and dispersion of potentially pathogenic and/or allergenic thermo tolerant/ thermophilic fungi and bacteria.

2.6 COMPOSTING METHODS

The secret to successful composting is to select an approach and technique that suits ones needs and lifestyle. Inckel *et al.*, (1990) described them to be of three main methods which are;

The Indore method – this was an important advance in the practice of composting made at Indore in India by Howard during the period 1924 to 1926.

The traditional procedure was systematized into a method of composting now known as the 'Indore method'.

Here, the mixture of different kinds of organic material residues ensures a more efficient decomposition. Again green materials, which are soft and succulent, are allowed to wilt for two to three days to remove excess moisture before stacking and while stacking, each type of material is spread in layers about 15 centimetres thick until the heap is about one and a half metres high.

The heap is then cut into vertical slices and about 20-25 kilograms are put under the feet of cattle in the shed as bedding for the night. The next morning the bedding, along with the dung and urine and urine-earth, is taken to the pits where the composting is to be done (FAO, 1980).

The Bangalore method - this method of composting was developed at Bangalore in India by Acharya (1939).

The method is basically recommended when night soil and refuse are used for preparing the compost. The method overcomes many of the disadvantages of the Indore method such as problem of heap protection from adverse weather, nutrient losses due to high winds / strong sun rays, frequent turning requirements, fly nuisance etc. but the time involved in production of a finished compost is much longer. The method is suitable for areas with scanty rainfall (FAO, 1980).

The Heating Process Method - This form of compost is prepared mainly from night soil, urine, sewage, animal dung, and chopped plant residues at a ratio of 1:4. The materials are heaped in alternate layers starting with chopped plant stalks and followed by human and animal wastes; water is added to optimum amount.

At the time of making the heap, a number of bamboo poles are inserted for aeration purposes. After the heap formation is complete, it is sealed with 3 cm of mud plaster. The bamboo poles are withdrawn on the second day of composting leaving the holes for aeration of the heap. Within four to five days, the temperature rises to 60-70 °C and the holes are then sealed (FAO, 1980).

FAO, (1980) again described another method using worms known as vermicomposting where earthworms are used for composting organic residues. Some of the types of worms used are; *Lumbricusrubellus* (the red worm) and *Eiseniafoetida* which are thermo-tolerant, Field worms *Allolobophoracaliginosa* and night crawlers (*Lumbricusterrestris*). Jambhhekar, (2002) and Cracas, (2000) also described how vermicomposting is practiced in India known as vermiculture and in Cuba using worm troughs in a row and also by the windrows method. Eyers *et al*., (1998) indicated that in vermicomposting, the worms bury themselves in a bedding and consume up to their own weight in organic food waste daily.

2.7 FACTORS AFFECTING COMPOSTING

There are certain environmental factors that affect the rate and speed of composting. The organisms that make the compost need food (carbon and nitrogen), air, and moisture. When provided with a favorable balance, they will produce compost quickly. Other factors affecting the speed of composting include surface size/particle size, temperature, volume, and pH.

2.7.1 MOISTURE CONTENT

Decomposer organisms need water to live. Microbial activity occurs most rapidly in thin water films on the surface of organic materials. Microorganisms can only utilize organic molecules that are dissolved in water.

The optimum moisture content for a compost pile should range from 40 to 60 percent. If there is less than 40 percent moisture, bacteria slow down and may become dormant.

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

If there is more than 60 percent, water will force air out of pile pore spaces, suffocating the aerobic bacteria. Additionally, it creates conditions that favor odor production in the pile and restrict its temperature rise (Kube, 2002).

As a rule of thumb, if the compost mixture feels moist without water dripping from a handful when squeezed, the moisture is adequate (Looper, 2002).

2.7.2 AERATION AND OXYGEN SUPPLY

Proper aeration is a key environmental factor. Many microorganisms, including aerobic bacteria, need oxygen. They need oxygen to produce energy, grow quickly, and consume more materials.

Oxygen consumption in a composting mass depends on several factors such as the moisture content, temperature, the particle size of the mass or porosity (spaces between particles in the compost pile), the stage of the process, wind etc.

Natural aeration occurs when air warmed by the composting process rises through the pile, bringing in fresh air from the surroundings. Where the supply of oxygen is insufficient, the growth of aerobic micro-organisms responsible for decomposition is limited hence hindering decomposition.

Work done by (Henry, 2003) indicated that when there is not enough air in the compost pile, its aerobic biodegradation to decompose organic material decreases, nitrogen loss by denitrification increases and the temperature diminishes.

Aeration is also seen to play an essential role in the reduction of odour.

2.7.3 TEMPERATURE

Temperature is another important factor in the composting process and is related to proper air and moisture levels. As the microorganisms work to decompose the compost, they give off heat which in turn increases pile temperatures.

The temperature within a composting mass determines the rate at which many of the biological processes take place and plays a selective role on the evolution and the succession of the microbiological communities (Mustin, 1987).Temperature is directly proportional to the biological activity within the composting system. As the metabolic rate of the microbes accelerates the temperature within the system increases. Conversely, as the metabolic rate of the microbes decreases, the system temperature decreases.

In biological terms the operating temperature ranges are as follows: > 55 °C to maximize sanitation, 45-55 °C to maximize the biodegradation rate, and 35-40 °C to maximize microbial diversity (Stentiford, 1996).

The process of aerobic composting can be divided into three major steps, a mesophilic-heating phase, a thermophilic phase and a cooling phase (Leton and Stentiford, 1990).

Since weed seeds are usually destroyed at 62 °C (144 °F), thermophilic temperatures inactivate weed seeds, which may be present if the animals ingested weeds (Looper, 2002).

2.7.4 VOLUME

Volume is a factor in retaining compost pile heat. In order to become self insulating and retain heat, piles may be made to a one cubic size. The one cubic yard size retains heat and moisture, but is not too large that the material will become unwieldy for turning.

Smaller compost piles will still decompose material, but they may not heat up well, and decomposition is likely to take longer.

Hoitink *et al*., (1993) indicated that large piles are useful for composting diseased plants as the high temperatures will kill pathogens and insects.

2.7.5 PARTICLE SIZE

Particle size affects the rate of organic matter breakdown. The more "surface area" available, the easier it is for microorganisms to work, because activity occurs at the interface of particle surfaces and air. Microorganisms are able to digest more, generate more heat, and multiply faster with smaller pieces of material.

In a composting process, aeration and degradability can be improved by reducing the particle size while increasing the surface area, as long as porosity remains above 30 % (Rynk, 1992). Looper (2002), on the other hand, indicated that the optimum particle size of composting material for proper aeration of a compost pile ranges from 3.1 to 12.7 mm (1/8 to 1/2 in).

2.7.6 pH

The composting process is relatively insensitive to pH within the range commonly found in mixtures of organic materials, largely because of the broad spectrum of microorganisms involved.

It has been observed that each of the microbes responsible in the biological transformation of the compost pile has their own optimum pH ranges.

It has also been noticed that the acidity of compost most often depends on the amount of moisture available and the degree of aeration.

Inckel *et al.*, (1990) thus intimated that a compost heap which is properly constructed will seldom get too acidic.

In composting Operations, pH will fall initially as the process begins. As the biological decomposition process continues, the pH will increase to near neutral levels.

Carr *et al.*, (1998) indicated that, a proper C/N ratio keeps pH in the range of 6.5 to 7.2, which is optimum for composting.

When the pH of compost pile reaches a range of 8 to 9, strong ammonia and amine related odors may be generated for the first two weeks of composting (Henry, 2003).

Langston *et al.*, (2002) indicated that a pH of 6.5-8.0 is optimal for composting.

2.7.7 C/N RATIO

Organic material provides food for organisms in the form of carbon and nitrogen. Carbon and nitrogen levels vary with each organic material. Carbon-rich materials tend to be dry and brown such as leaves, straw, and wood chips. Nitrogen materials tend to be wet and green such as fresh grass clippings and food waste.

When there is too much nitrogen, piles will likely release the excess as smelly ammonia gas. Too much nitrogen can also cause a rise in the pH level which is toxic to some microorganisms.

Acceptable C/ N ratio generally ranges from 25:1 to 40:1, and may even reach as high as 50:1.

Reduction of the C/N ratio during the composting process is a good indication of digestion of carbon sources by microorganisms and production of CO and heat.

Table 2.1: Approximate Nitrogen content and C/N Ratios for some Compostable Materials

Material	Nitrogen (% dry weight)	C/N ratio
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
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*:* Gotass, (1956)

2.7.8 ODOUR

One of the major complaints faced during composting is the smell that is generated. This has been attributed to the release of sulfur compounds such as hydrogen sulfide, methyl mercaptan and methyl sulfide in the early stages of composting and also inadequate stabilization of the compost which might be due to too high moisture content of the material used for composting. This slows down the process and usually leads to an unpleasant odour and low heat generation (Tiquia *et al.*, 1996).

The presence or absence of odour is not only an index of the efficiency of the process, but also may affect public acceptance of and support for the siting of compost plants, especially in areas of high population densities. There are simple solutions that can be used to take care of this problem. The size of the materials composted change the amount of scent produced. Large un-chopped items do not break down quickly. Small items offer more surface area for decomposition, therefore reducing the smell (City of Toronto, 2003).

2.8 COMPOST QUALITY

Compost Quality reflects the chemical makeup of a given compost. A compost can be mature (i.e., fully composted) but can be of poor quality due to low nutrient levels.

The nutrient value of composts varies widely, depending upon the nature of feedstock composted. If initial material contains grass clippings, weeds, or manure, it will be richer in nitrogen and other nutrients than if it contains mainly straw, litter, dirt or corn stalks.

The percentage composition of the mineral elements in the finished compost has been indicated by Gotass (1956) in the table below. He however intimated that the composition of these nutrients varied according to the nature of the composition of the composting materials.

Table 2.2: Composition of mineral elements in finished compost

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: Gotass, 1956

CONTRIBUTIONS OF BULKING AGENTS TO COMPOST QUALITY

A bulking agent or material is a material added to other substances to condition the feed mixture. The use of bulking agents involves composting of two or more raw materials together such as municipal solid waste, animal manure, sawdust, wood chips, bark, slaughterhouse waste, sludge or solid residues from food and beverage industries. This is described as advantageous since the materials used complement each other. Bulking agents are normally added to reduce bulk weight and increase air voids allowing for proper aeration and hence a faster rate of decomposition since decomposing microbes are well aerated.

2.9 BENEFICIAL USES OF COMPOST MATERIAL

DISEASE CONTROL FOR PLANTS AND ANIMALS

Users are discovering that compost enriched soil can also help suppress diseases and ward off pests. It destroys disease organisms and creates a nutrient-rich product that can be used or sold. These beneficial uses of compost save revenue, reduce the use of pesticides, and help conserve natural resources.

SOIL REMEDIATION

A new compost technology, known as compost bioremediation, is currently being used to restore contaminated soils, manage storm water, control odors, and degrade volatile organic compounds.

The composting process has been shown to absorb odors and treat semi volatile and volatile organic compounds (VOCs), including heating fuels, polyaromatic hydrocarbons (PAHs), and explosives. It has also been shown to bind heavy metals and prevent them from migrating to water resources or being absorbed by plants. The compost process degrades and, in some cases, completely eliminates wood preservatives, pesticides, and both chlorinated and nonchlorinated hydrocarbons in contaminated soils.

WETLANDS RESTORATION AND HABITAT REVITALIZATION

Native plants inhabiting our country sides provide food for nearly every other member of the habitat. As plants die, they continue to support grasses, flowers, and trees by becoming the humus. Original wetland plants can be restored with the use of compost during planting. Compost provides tree seedlings with added rigor for survival and growth.

SOIL ENRICHMENT

Compost has the ability to help regenerate poor soils. The composting process encourages the production of beneficial micro-organisms (mainly bacteria and fungi) which in turn break down organic matter to create humus. Humus--a rich nutrient-filled material--increases the nutrient content in soils and helps soils retain moisture. Compost has also been shown to suppress plant diseases and pests, reduce or eliminate the need for chemical fertilizers, and promote higher yields of agricultural crops.

CHAPTER THREE

3.0 METHODOLOGY

3.1 STUDY AREA AND SAMPLING

The study area is the Kwame Nkrumah University of Science and Technology located in Kumasi, Ghana.

The main university campus which is about seven square miles in area, is located about eight miles (13 km) to the east of Kumasi, the Ashanti Regional capital with coordinates 06°41′5.67″N and 01°34′13.87″W. There are six Halls of Residence at the Kumasi Campus, these are; Africa Hall, Independence Hall, Queen's Hall, Republic Hall, Unity Hall, and University Hall. The university has an average student population of about 23,591 as at 2011 (KNUST official website, 2010). There is thus increasing pressure on the various halls of residence especially with the waste management systems which were constructed over three decades ago to manage waste for quite a smaller population.

3.1.1 EXPERIMENTAL DESIGN

The set up for the experiment was done at the sewage treatment plant on the campus of the Kwame Nkrumah University of Science and Technology.

A suitable and level piece of plot was identified and adequately prepared by clearing the weeds and laying a concrete base for use as place of set up.

A shed was constructed on the piece of plot prepared for the set up. This was done to provide shelter for the set up and protect the composting process from extreme environmental conditions of rain and excessive sunlight.

Portable wooden containments (boxes) constructed in windrow form with dimensions of (0.7 × 0.9 × 1.6) metres were used to hold the raw waste. (Plate 3.1) the wooden boxes were opened at both the top and base with one side movable to allow for the turning of waste in the boxes. The waste in each box was stirred to effect aerobic decomposition of waste.

Plate 3.1: Set up for the experimental composting process.

3.1.2 SOURCE OF WASTE

Solid waste was collected from the waste receptors at the halls of residence on KNUST campus. This was done with the help of labourers working at the various halls of residence. Refuse consisting of solid organic waste materials such as peels of foodstuff, leaves, green plants, wood, ashes, and twigs was collected from the halls of residence on KNUST campus using large sacks. Sawdust (brown and dry) was collected in sacks from the KNUST carpentry shop at the Ayeduase gate. Fresh grass clippings (green and wet) were also collected with the help of labourers who mow lawns on campus.

3.1.3 SORTING ANALYSIS

A grab amount of waste was collected using shovel into empty rice sacks for separation of the waste into organic biodegradable (peels of foodstuff, leaves, green plants, wood, ashes, and twigs) and non biodegradable (broken glasses, metal bits, empty food cans, rubbers and polythene bags) at site. Separation of waste was done manually.

Organic biodegradable portion of waste was then cut into small sizes using a cutlass for composting.

3.1.4 PRELIMINARY TESTING AND PROCEDURE

Materials (waste) used in the experiment comprised of food waste, sawdust, and fresh grass clippings. The idea behind this project was to investigate the effect that the sawdust and the grass clipping would have on the quality of the compost and the rate of decomposition of compost when mixed in different proportions with the food waste.

Carbon – Nitrogen ratio is a critical factor in the composting process as microorganisms require carbon for energy and nitrogen for protein synthesis for building cell structure in order to facilitate effective decomposition.

Preliminary analysis of the individual substrates indicated a C/N ratio of 250:1, 23:1, and 19:1 for sawdust, grass clipping and food waste respectively.

Preliminary adjustments were hence made to bring the mixtures of sawdust/food waste and grass clipping/food waste to operate within the optimum standard of C/N ratio necessary for efficient and effective composting.

The ratios used for the mixing of the sawdust/food waste were 1:1 (1 part of sawdust to 1 part of food waste), 1:2 (1 part of sawdust to 2 parts of food waste), and 2:1 (2 parts of sawdust to 1 part of food waste) all measured in volume by volume.

These ratios were used as their initial C/N (Carbon – nitrogen) ratios fell within the optimum range (25:1 to 50:1) necessary for efficient composting.

C/N ratios achieved were 37.1, 30.2, and 40 for SSD 1:1, SSD 1:2, and SSD 2:1 ratios (v/v) respectively.

Again, the ratios used for the mixing of the grass clipping/food waste were 1:1 (1 part of grass clipping to 1 part of food waste), 1:2 (1 part of grass clipping to 2 parts of food waste), and 2:1 (2 parts of grass clipping to 1 part of food waste) all measured in volume by volume.

The initial C/N ratios were 25.2, 25.4, and 25.9 for SGC 1:1, SGC 1:2, and SGC 2:1 ratios (v/v) respectively.

These results obtained complimented the selection of the 1:1, 1:2, and 2:1 ratios in both mixtures of sawdust/food waste and grass clipping/food waste because they were adequate for an efficient composting process.

Again, preliminary test were conducted to adjust the moisture content in the range 50 to 60 % for all the ratios to enable efficient composting. This was achieved by adding water in some cases and in others by adding dry shredded waste materials.

Preliminary adjustment resulted in the attainment of 59.2 %, 58.8 %, and 57.5 % moisture content for 1:1, 1:2, and 2:1 sawdust/food waste ratios and 58.9 %, 57.8 %, and

59.5 % moisture content for 1:1, 1:2, and 2:1 grass clipping/food waste ratios respectively.

The sawdust/food waste ratios were labeled SSD 1:1, SSD 1:2, and SSD 2:1.

The grass clipping/food waste ratios were labeled SGC 1:1, SGC 1:2, and SGC 2:1.

The bin composting method with wooden slatted walls was adopted. This allowed for higher stacking of materials and better use of floor space than free-standing piles. Bins can also eliminate weather problems and provide better temperature control.

In all, twenty one windrow boxes were constructed and used to hold the heap of each ratio.

This was so as each ratio together with the control (consisting of food waste only) was replicated. The preliminary results obtained were then put in a table to be discussed at the results section.

3.1.5 TURNING OF REFUSE

The refuse heap in each bin was turned regularly initially at regular intervals of three (3) days for the first four weeks after which turning was done at a regular interval of seven (7) days for the remaining four weeks. Turning was done using a shovel with the front side of the wooden bin removed to facilitate turning and for easy access.

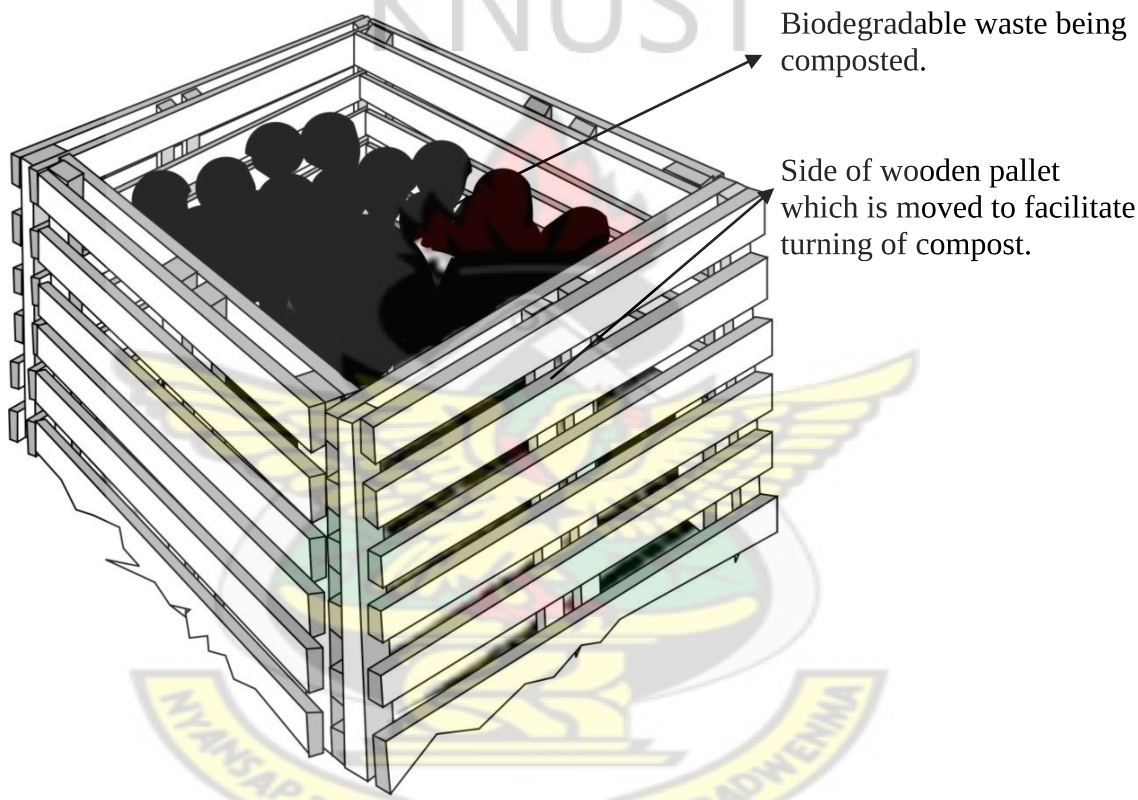

Figure 3.1: Schematic diagram showing how the wooden pallet bin was constructed to facilitate turning of biodegradable waste being composted.

3.2 LABORATORY ANALYSIS OF COMPOST

3.2.1 MOISTURE CONTENT DETERMINATION

Typically, 50 % to 60 % moisture is considered optimum for the composting process. Water is the most commonly used as moisture source.

Compost sample (10.0 g) was weighed using mettlar balance. The samples were oven-dried at a temperature of 105 ºC for 24 hours and reweighed. The difference in weight expressed the amount of water in the sample taken.

The percentage (%) moisture content was then calculated using the formula:

$$\left[\frac{\mathrm{W1} - \mathrm{W2}}{\mathrm{W1}}\right] \times 100\ \%$$

Where

W1 is the initial weight of sample before drying. And W2 is the final weight of sample after drying.

3.2.2 MEASUREMENT OF TEMPERATURE

A thermometer (Mercury in glass thermometer with a temperature range of 0°C to 100°C) was attached to a metal rod of about 60 cm long was inserted into each pile at five different points; one in the middle of the pile and the other four at the four edges of the pile. The temperatures were recorded for all the five different points. The average for all the points recorded was then calculated. Temperature measurements were taken three times daily at 8 am, 12 pm and 4 pm. Readings were taken daily for the entire composting period.

3.2.3 TOTAL SOLIDS

The total solids content is a measure of the amount of material remaining after all the water has been evaporated.

Total dry solids content was determined by weighting 10g of each sample into a Petri dish and designated W_1, oven dried for 24 hours at 105^{o}C and then reweighed, $W_{2.}$

The percentage of total dry solid is then calculated using the formulae;

$$\% \text{ Total solids} = \left[\frac{W2}{W1}\right] \times 100\ \%$$

Thus, $\% \text{ Total solids} = (100 - \% \text{ Moisture})$

This was determined at the end of every week for the two months period.

3.2.4 MEASUREMENT OF REFUSE VOLUME

This was done by using a tape measure attached to a metal rod. The height occupied by the waste before and after decomposition can thus be measured with the tape measure and calculated by the formula;

$\text{Volume} = (0.7\ \text{m} \times 0.9\ \text{m} \times \text{h m})$ where h, is the height occupied by refuse heap in wooden bin.

This was measured and calculated on weekly basis for the two months period.

3.2.5 ORGANIC MATTER AND ASH CONTENT

Compost sample (10.0g) was put into dry porcelain crucible and dried for 24 hours at 105^{o}C. Samples were then transferred into an ignition furnace where the temperature was gradually increased to 550^{o}C 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 follows:

$\% \text{ ash} = \left[\frac{W3-W1}{W2-W1}\right] \times 100\ \%$ and

$$\% \text{ Organic matter} = 100 - \% \text{ ash}$$

Where W1 = the weight of the empty, dry crucible; W2 = the weight of the dry crucible containing the compost or manure before ignition; and W3 = the weight of the dry crucible containing the compost or manure after ignition.

Note that the weight of the ash = W3 – W1

3.2.6 CARBON CONTENT DETERMINATION

After heating at a temperature of 550 °C, all the organic and inorganic carbon was burnt off and hence percentage carbon was calculated using the formula:

$$\% \text{ Carbon} = (100 - \% \text{ ash})/1.72$$

3.2.7 pH DETERMINATION

The pH meter (Hanna instrument Hi 9017 micro processor) was calibrated, using two buffer solutions (7 and 10), of which one was the buffer with neutral pH (7.0) and the other buffer in the range of the pH in the sample (7.2-first week, 6.9-second week, 6.2-fourth week, 6.4-sixth week, 6.8-eigth week).

Compost sample (10.0 g) was placed into a 50 ml beaker, and 20 ml of water was added. The sample was allowed to absorb the water without stirring, and then stirred thoroughly for 10 seconds using a glass rod for uniform mixture of sample and water.

The suspension was stirred for 30 minutes, and then recordings of the pH were taken by immersing the pH electrode in the suspension.

3.2.8 TOTAL NITROGEN

Well dried compost sample of each pile (0.2 grams) was weighed into a Kjeldahl flask. To this was added 5 ml of concentrated sulphuric acid, 0.2 g of catalyst mixture (selenium powder and copper sulphate powder) and 1 gram of sodium sulphate. The mixture was heated in the digestion block until the solution was clear and digestion continued for 30 minutes. The samples were allowed to cool to the ambient temperature; then 60 ml of distilled water added to the digested samples and transferred into distilling flasks. 20 ml of sodium hydroxide solution was added to the digested mixture to provide the necessary alkaline conditions for the release of ammonia. 200 ml of the mixture was then distilled into a conical flask containing 25 ml of blue boric acid mixture serving as the absorbent indicator. A change in colour from blue to green indicated the presence of ammonia. The solution in the conical flask was then titrated against standard 0.02 N HCl to grey end point. Blank was determined on reagents using the same quantity of standard acid in a receiving conical flask. Percentage nitrogen in each sample was calculated using the formula below:

$$\%N = \frac{(T - B) \times N(0.1) \times 14.007}{W \times 1000} \times 100\%$$

Where;

% N = Percentage nitrogen

T = titration volume for sample (ml)

B = titration volume for blank (ml)

N = normality of acid

W = Weight of sample

3.2.9 C / N RATIO

Carbon and nitrogen levels vary with each organic material and thus their C/N ratios.

This was calculated using the formula:

$$\mathrm{C/N\ Ratio} = \frac{\mathrm{CarbonContent}}{\mathrm{NitrogenContent}}$$

3.2.10 PHOSPHORUS DETERMINATION

Estimation of total P was carried out by the spectrophotometric vanadium phosphomolybdate method.

Standard curve was prepared by putting 0, 1, 2, 3, 4, 5, and 10 ml of standard solution (50 µg P/ml) in 50 ml volumetric flasks respective. Ten ml of vanadomolybdate reagent was added to each flask and then made up to the mark with distilled water. The concentrations were measured using the Buck Scientific (210 VGP) spectrophotometer (420 nm) and the corresponding absorbances recorded.

Compost sample (0.25 g) was then taken and digested as per the wet digestion (tri-acid digestion with a mixture of HNO_3, H_2SO_4, and $HCLO_4$ in a ratio 9:4:1) method and made up to the 100 ml volume. In this method, 0.25g of ground compost sample was taken and placed in a 100ml volumetric flask, and 2.5ml of acid was added and swirled. The flask was then heated at a temperature starting at 80 - 90°C and then raised to about 150 - 200°C until the production of red NO_2 fumes ceased. The contents were heated further until there was a volume reduction and became colourless. Cooling was then done and the volume made up to the mark with distilled water. It was then filtered through a No.1 filter paper. The solution was then used for phosphorous estimation

Five ml of digest was then taken and put in a 50 ml volumetric flask after which 10 ml of vanadomolybdate reagent was added. The digest was then made up to the 50 ml volume with distilled water and then mixed thoroughly and then allowed to stand for 30 minutes.

A yellow colour developed which was stable for days, and the absorbance read at 420 nm on the spectrophotometer.

For the observed absorbance, the P content was then determined from the standard curve. P was then calculated by:

$$\text{P content } (\mu g) \text{ in } 1.0g \text{ of sample} = \text{Average reading} \times 58.625 \times 0.04$$

3.2.11 POTASSIUM

A standard solution of KCl was prepared by dissolving 1.908 g of KCl in 1 liter of distilled water. An aliquot of 100 ml of this solution was diluted to 1 liter to give 100 µg K/ml as stock solution. Stock solution (5 ml, 10 ml, 15 ml and 20 ml) were put in 100 ml volumetric flasks and distilled water added to make up the volume giving 5, 10, 15 and 20 µg K/ml respectively. Each sample (0.25 g) was acid-digested (tri-acid digestion with a mixture of HNO_3, H_2SO_4, and $HCLO_4$ in a ratio 9:4:1) and made up to 100 ml. The samples were kept for estimation in the range 5-10 mg K/kg (5 – 10 µg K/ml). A blank was prepared in the same way with no compost sample.

Five ml aliquot was taken for estimation and made up to 100 ml. It was atomize on the calibrated Atomic Absorption Spectrophotometer (Buck Scientific 210 VGP) on which the standard curve has been prepared. The absorbance was recorded for each sample on the Atomic absorption spectrophotometer. The concentration of K for absorbance noted for each sample was used to determine the K content as below;

$$\text{Percentage K} = \text{Average reading} \times 0.205 \times 0.04$$

3.2.12 MICROBIAL ANALYSIS

Total and faecal coliforms were estimated using the most probable number method (MPN) according to Standard Methods (Anon, 1994). 10 g of each compost sample was introduced into 90 ml of distilled water. Serial dilutions of 10^{-1} to 10^{-13} were prepared. One milliliter aliquots from each of the dilutions was inoculated into 5 ml of MacConkey Broth (oxoid) with inverted Durham tubes and incubated at 37 ^{o}C for total coliform and 44 °C for faecal coliform for 24 hours. Tubes showing change in colour and gas formation after 24 hours were considered presumptive positive for coliform bacteria. From the number and distribution of positive and negative reactions, count of the most probable number (MPN) of indicator organisms in the samples were estimated by reference to MPN statistical tables and expressed as MPN/g.

3.3 STATISTICAL ANALYSIS

One factor (one way) ANOVA was used in making comparisons amongst all the different compost types and ratios at 95 % significance level.

CHAPTER FOUR

4.0 RESULTS

Results obtained from the monitoring of parameters for the experimental and control treatments used to indicate the quality of the compost and rate of decomposition of the various compost ratios are represented. These parameters used are; carbon, nitrogen, C/N ratio, phosphorus, potassium, pH, organic matter, ash content, moisture content, total solids, total coliform, faecal coliform and temperature.

From the results obtained, indications shows that parameters such as total solids and ash content increased gradually whilst pH decreased steadily, it increased at the latter stage of the composting process for all the seven treatments.

The results again indicated that the mean differences for carbon, phosphorus, potassium, ash and organic matter in all seven treatments were statistically significant ($P<0.05$, Appendices N, Q, R, S and T).

However results for the mean differences for nitrogen and C/N ratio (Appendices O and P) for all seven treatments were not statistically significant ($P>0.05$).

pH results for all seven bins (Appendix U) indicated that differences in reading were statistically significant ($P<0.05$).

Results obtained for the other parameters such as moisture content, total solids and volume (Appendices V, W and X) were also found to be statistically significant ($P<0.05$).

Again results of the total coliforms and faecal coliforms (Appendices Y and Z) were also found to be statistically significant ($P<0.05$).

Table 4.1: Mean values of Parameters measured for the different ratios of waste at the start of the composting process

Parameters	Mean Values of the various parameters						
	Ratios Of Raw Materials						
	SSD1:1	**SSD1:2**	**SSD2:1**	**SGC1:1**	**SGC1:2**	**SGC2:1**	**CS**
C (%)	52.00	51.10	52.40	50.30	46.90	49.20	50.80
N (%)	1.40	1.69	1.31	2.00	1.85	1.90	1.70
C/N	37.14	30.24	40.00	25.15	25.35	25.89	29.59
P (%)	0.64	0.96	0.76	0.56	0.54	0.64	0.77
Ash (%)	10.50	12.10	9.80	13.40	19.30	15.40	12.60
OM (%)	89.50	87.90	90.20	86.60	80.70	84.60	87.40
pH	7.30	7.20	7.40	7.20	7.40	7.10	7.00
K (%)	1.33	1.31	1.77	1.58	2.02	1.40	1.53
MC (%)	59.18	58.84	57.49	58.95	57.75	59.50	57.57
TS (%)	40.82	41.16	42.51	41.05	42.25	40.50	42.43
LogTC (MPN/g)	8.36	7.36	7.63	8.63	8.72	8.98	6.36
LogFC (MPN/g)	5.36	4.38	4.63	5.59	4.63	5.72	3.36

Table 4.1 above shows the mean readings for the various parameters at the beginning of the composting process. These preliminary readings were used to determine the optimum readings before composting.

Table 4.2: Mean values of Parameters measured for the different ratios of waste at the end of the composting process

Parameters	Mean Values of the various parameters						
	Ratios Of Raw Materials						
	SSD1:1	**SSD1:2**	**SSD2:1**	**SGC1:1**	**SGC1:2**	**SGC2:1**	**CS**
C (%)	35.40	31.40	31.40	26.70	27.10	26.80	25.70
N (%)	1.12	1.15	0.85	2.21	2.19	1.79	1.70
C/N	32.18	27.30	36.94	12.08	12.36	12.73	15.12
P (%)	0.24	0.24	0.31	0.28	0.21	0.29	0.30
Ash (%)	39.10	41.10	46.00	53.20	57.20	56.50	64.50
OM (%)	60.90	58.90	54.00	46.80	42.80	43.50	35.50
pH	6.80	6.70	6.80	6.90	6.70	6.80	6.90
K (%)	0.51	0.52	0.50	0.82	0.69	0.66	0.66
MC (%)	34.42	37.09	20.06	27.27	32.87	36.44	33.01
TS (%)	65.58	62.91	79.94	72.73	67.13	63.56	66.99
Log TC	2.36	2.81	2.63	2.59	2.72	2.86	2.36
LogFC (MPN/g)	2.04	2.28	2.04	2.08	2.11	2.17	2.15

Table 4.2 above shows the final mean readings recorded for the various parameters at the end of the composting process. These readings were used to determine the quality of compost for each windrow at the end of the composting period.

Organic carbon content (%) decreased from 52 %, 51.1 %, 52.4 %, 50.3 %, 46.9 %, 49.2%, and 50.8 % to 35.4 %, 31.4 %, 31.4 %, 26.7 %, 27.1 %, 26.8 %, and 25.7 % for compost treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, and SGC 2:1 and the control (CS) respectively as shown in Fig 4.1.

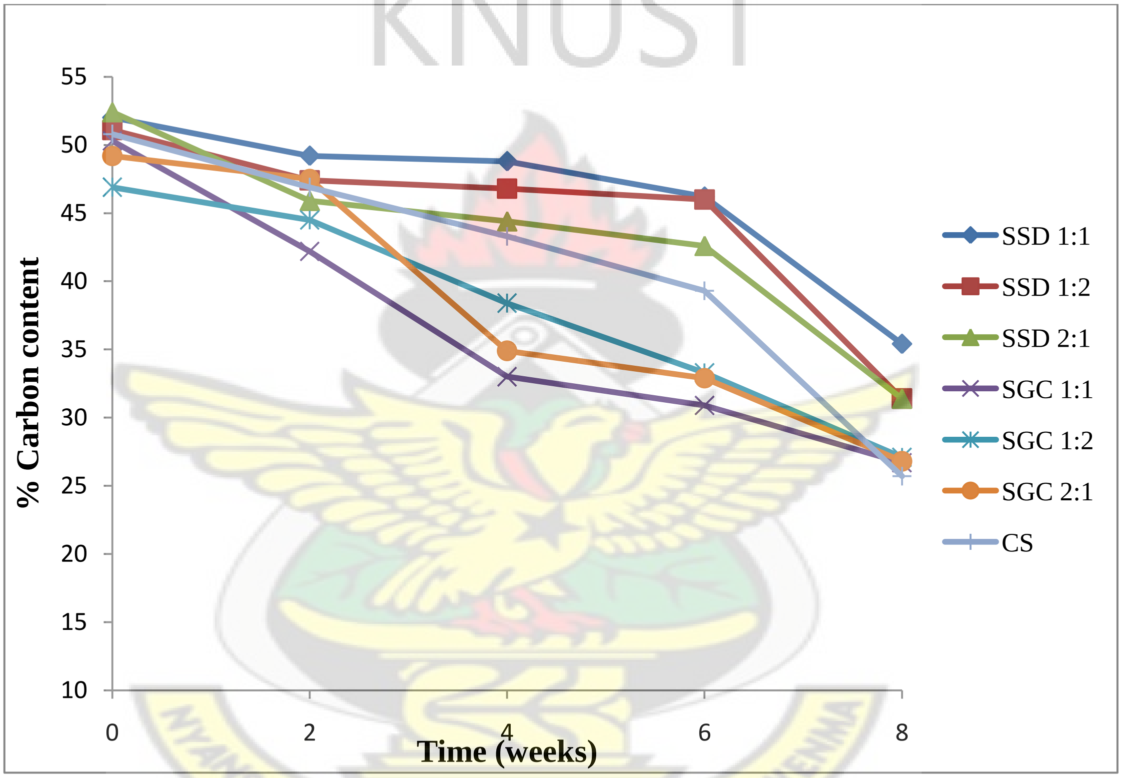

Fig 4.1: Mean fortnightly carbon content of both control and experimental treatments.

Fig 4.2 illustrates the trend of total nitrogen occurrence in various compost treatments throughout the composting period. The trend shows a gradual increase for the SGC 1:1, SGC 1:2, and SGC 2:1 ratios of grass clipping/solid waste and the control (CS) from initial values of 2.0 %, 1.85 %, 1.90 %, and 1.70 % through to 2.55 %, 2.49 %, 2.56 %, and 2.19 % by the sixth week and finally dropping to 2.21 %, 2.19 %, 1.79 %, and 1.70% by the end of the composting period. Treatments SSD 1:1, SSD 1:2, and SSD 2:1 for the sawdust/solid waste on the other hand dropped from initial values of 1.40 %, 1.69%, and 1.31 % to final values of 1.12 %, 1.15 %, and 0.85 % respectively.

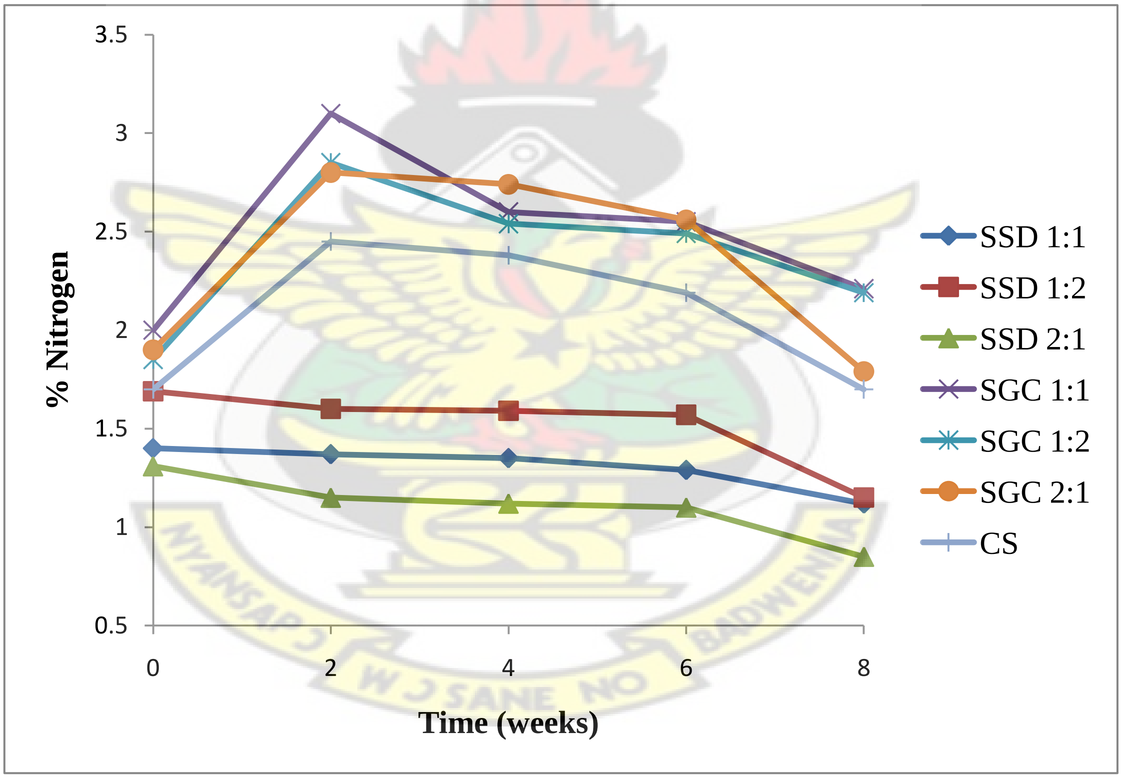

Fig 4.2: Mean fortnightly nitrogen content of both control and experimental treatments.

Fig 4.3 shows a decreasing trend in the carbon - to - nitrogen ratio for all experimental treatments including the control treatment. Initial C/N ratios of 37.14, 30.24, 40.0, 25.15, 25.35, 25.89, and 29.59 were obtained for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, and SGC 2:1 and the control (CS) but finished with 32.18, 27.30, 36.94, 12.08, 12.36, 12.73, and 15.12 respectively.

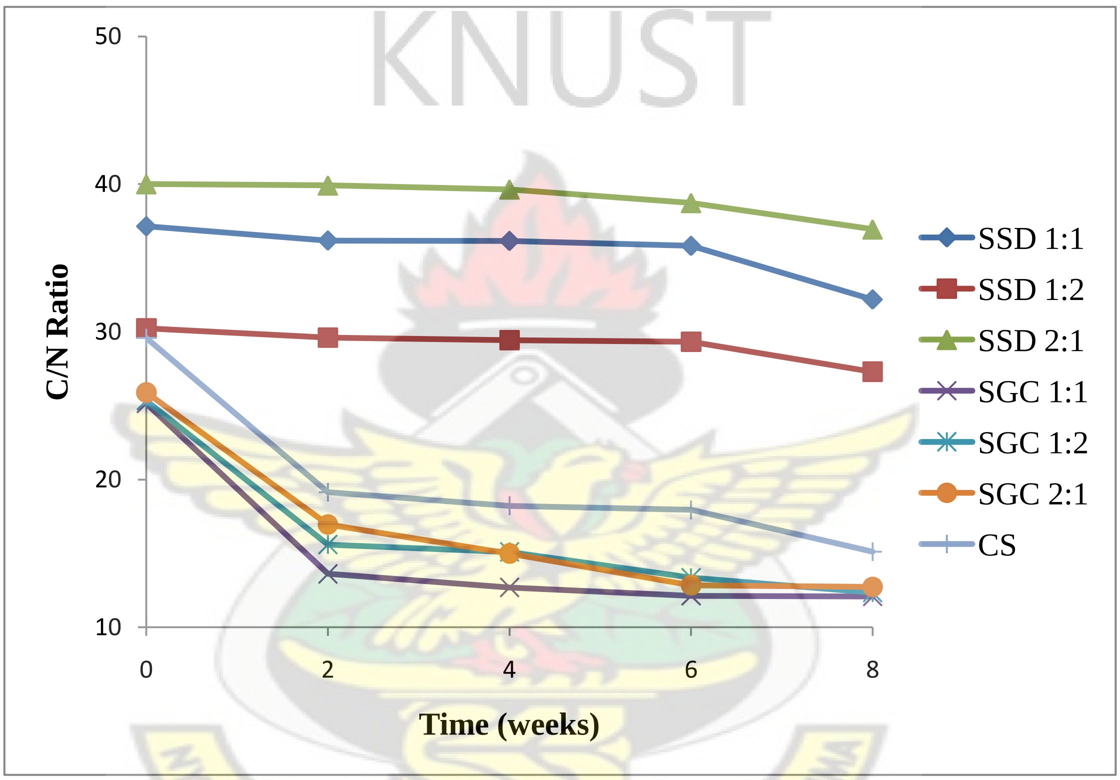

Fig 4.3: Mean fortnightly C/N ratio of both control and experimental treatments.

Percentage phosphorus as captured in Fig 4.4 showed lower levels in the final compost as compared to values recorded at the initial stage of composting. 0.64 %, 0.96 %, 0.76%, 0.56 %, 0.54 %, 0.64 %, and 0.77 % were recorded for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, and SGC 2:1 and the control (CS) with the final compost attaining values of 0.24 %, 0.24 %, 0.31 %, 0.28 %, 0.21 %, 0.29 %, and 0.30% respectively.

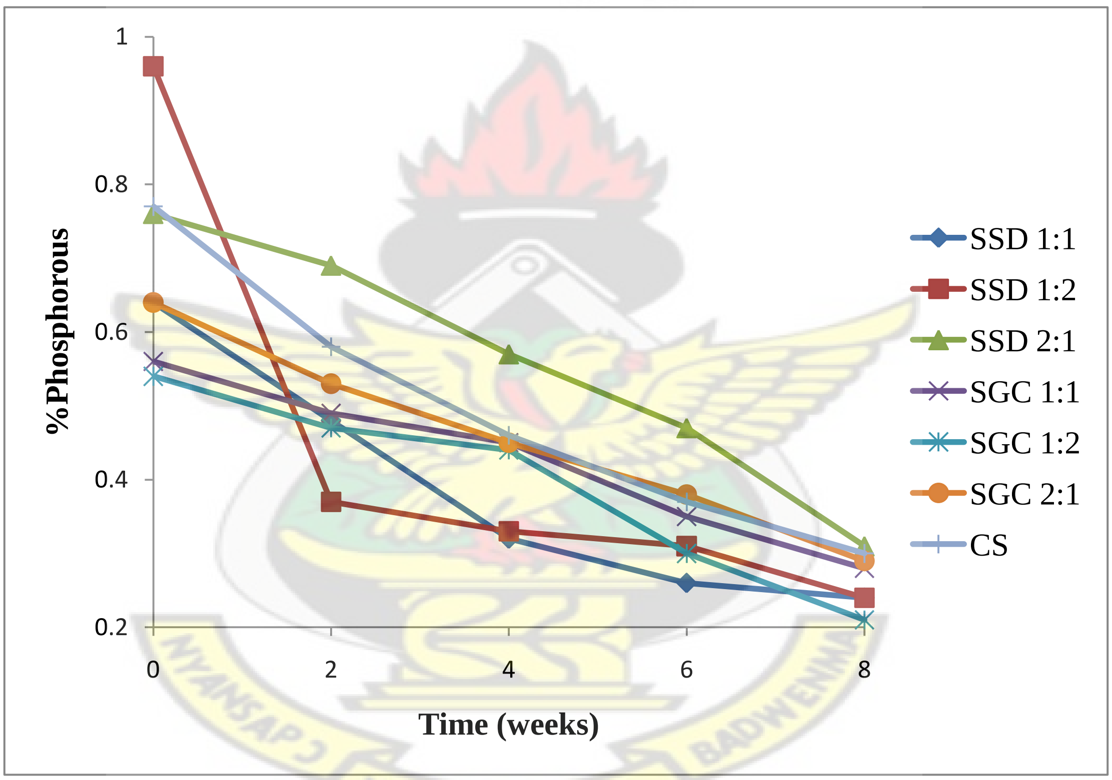

Fig 4.4: Mean fortnightly phosphorus content of both control and experimental treatments.

Percentage levels of potassium are shown in Fig 4.5: 1.33 %, 1.31 %, 1.77 %, 1.58 %, 2.02 %, 1.40 %, and 1.53 % were measured in SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS treatments of sawdust/solid waste, grass clipping/ solid waste and that of the control at the beginning of composting. The above treatments however finished with 0.51 %, 0.52 %, 0.50 %, 0.82 %, 0.69 %, 0.66 %, and 0.62 % for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, and SGC 2:1 and CS respectively.

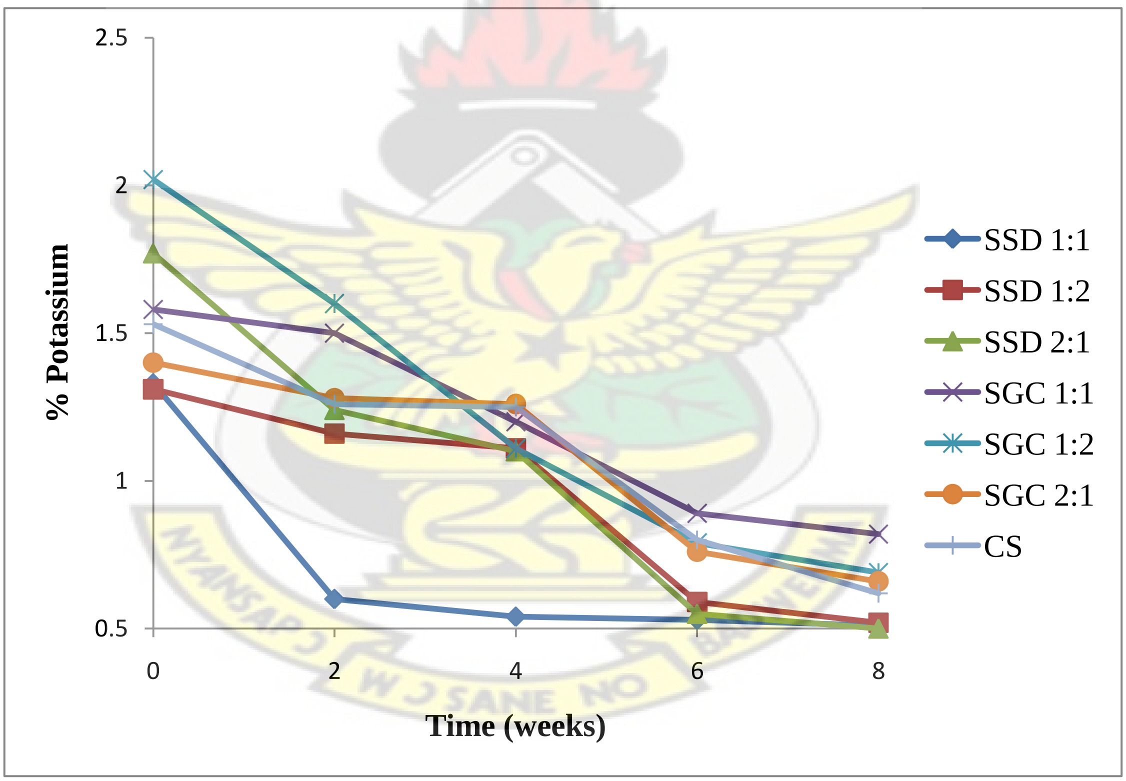

Fig 4.5: Mean fortnightly potassium content of both control and experimental treatments.

Fig 4.6 shows an increasing trend in ash content as organic matter decreased. The increase was from 10.5 %, 12.1 %, 9.8 %, 13.4 %, 19.3 %, 15.4 %, and 12.6 % to 39.1%, 41.1 %, 46 %, 53.2 %, 57.2 %, 56.5 %, and 64.5 % for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively as shown.

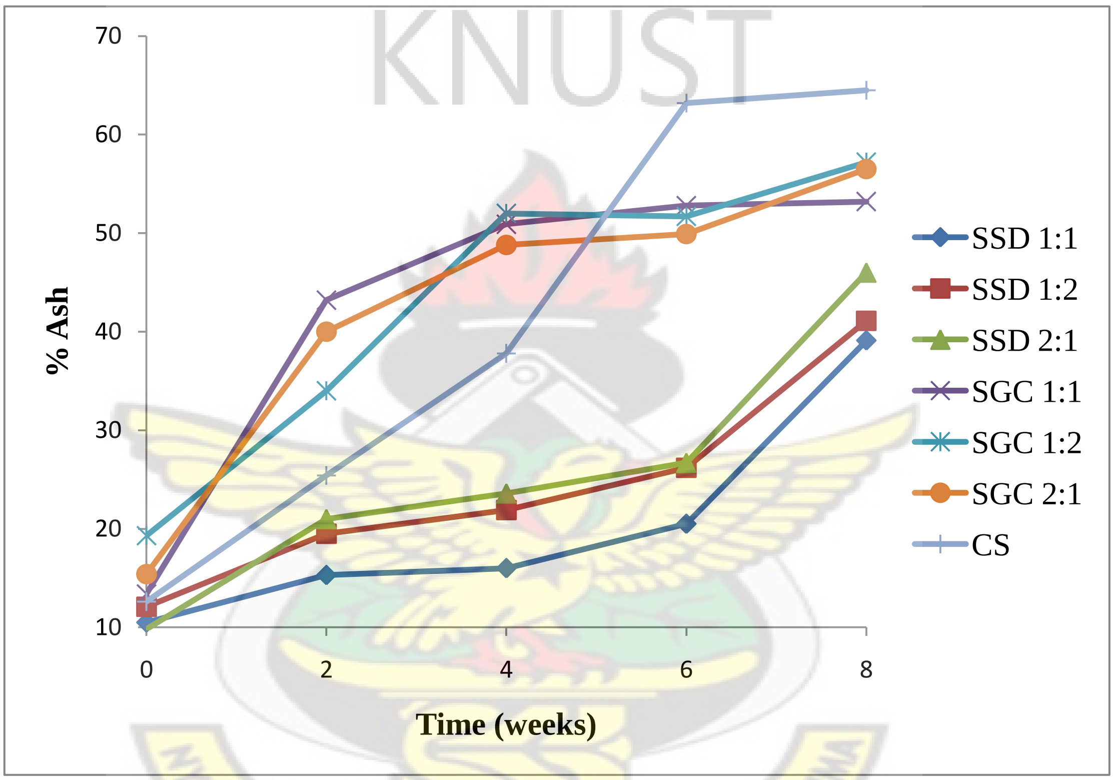

Fig 4.6: **Mean fortnightly Ash content of both control and experimental treatments.**

Fig 4.7 represents changes in percentage organic matter. Organic matter content decreased from means of 89.5 %, 87.9 %, 90.2 %, 86.6 %, 80.7 %, 84.6 % and 87.4 % to 60.9 %, 58.9 %, 54 %, 46.8 %, 42.8 %, 43.5 %, and 35.5 % for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

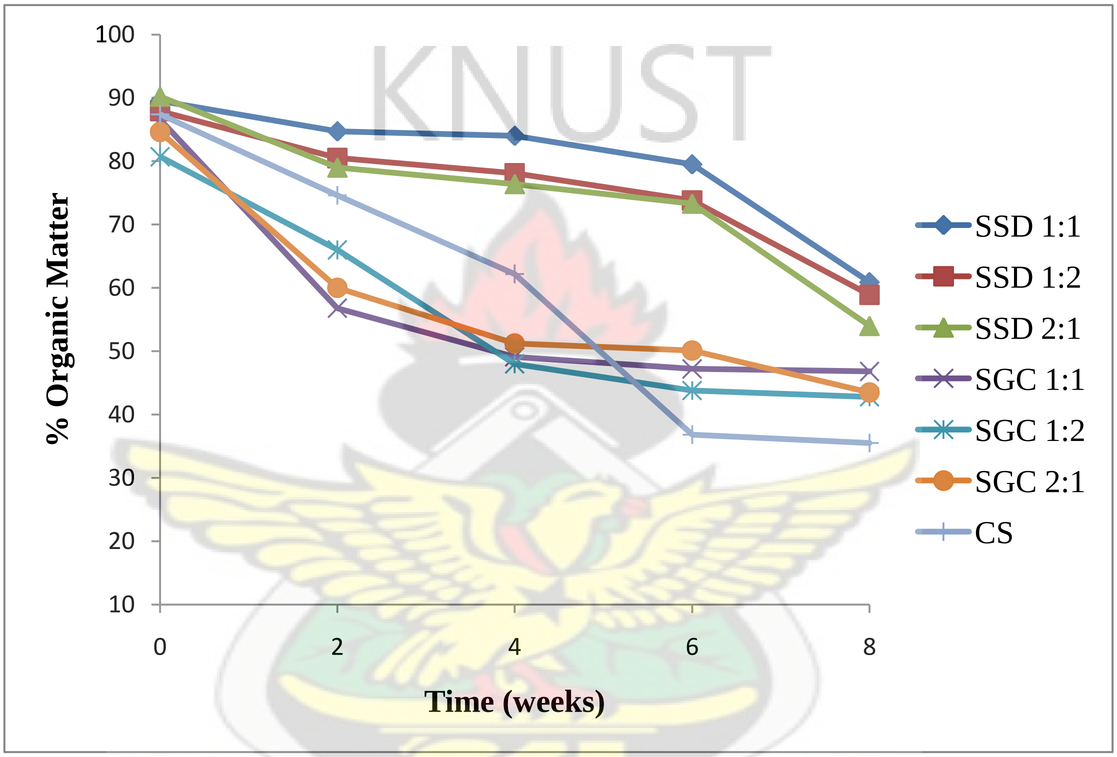

Fig 4.7: Mean fortnightly Organic matter content of both control and experimental treatments.

Fig 4.8 represents changes in pH during the whole period of composting. Initial pH of 7.3, 7.2, 7.4, 7.2, 7.4, 7.1, and 7.0 were recorded for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively. Final pH values recorded for the above treatments of SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS were 6.8, 6.7, 6.8, 6.9, 6.7, .6.8, and 6.9 respectively.

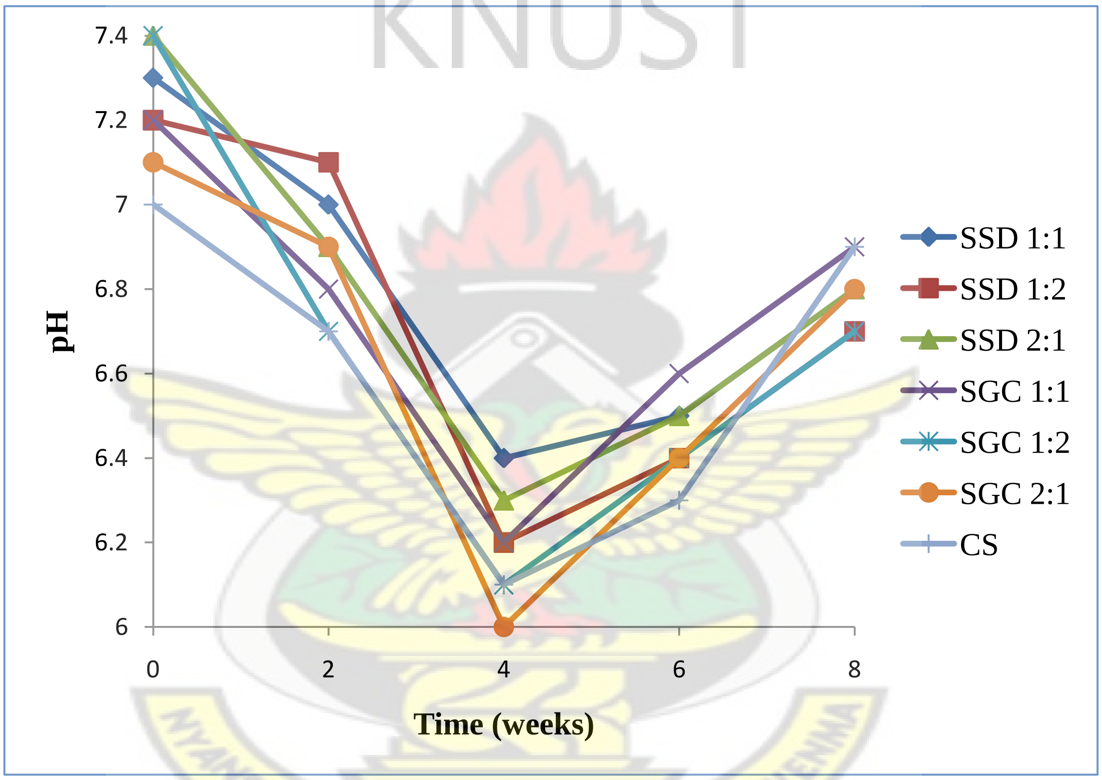

Fig 4.8: Mean fortnightly pH of both control and experimental treatments.

Again there was a gradual decrease in moisture content in the various treatments. This decreasing trend as illustrated in Fig 4.9 was from 59.18 %, 58.84 %, 57.49 %, 58.95 %, 57.57 %, 59.50 %, and 57.57 % to 34.42 %, 37.09 %, 20.06 %, 27.27 %, 32.87 %, 36.44% and 33.01 % for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

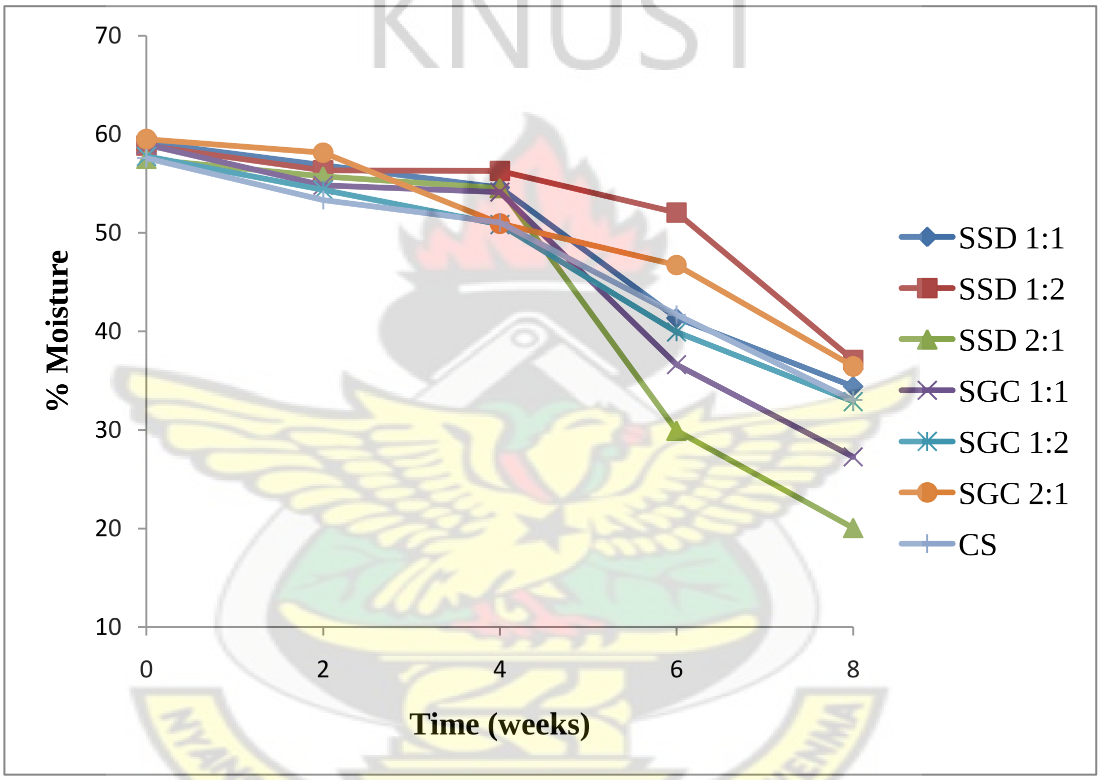

Fig 4.9: Mean fortnightly Moisture content of both control and experimental treatments.

Fig. 4.10 represents an increase in total solids from 40.82 %, 41.16 %, 42.51 %, 41.05%, 42.25 %, 40.50 %, and 42.43 % to 65.58 %, 62.91 %, 79.94 %, 72.73 %, 67.13 %, 63.56%, and 66.99 % for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

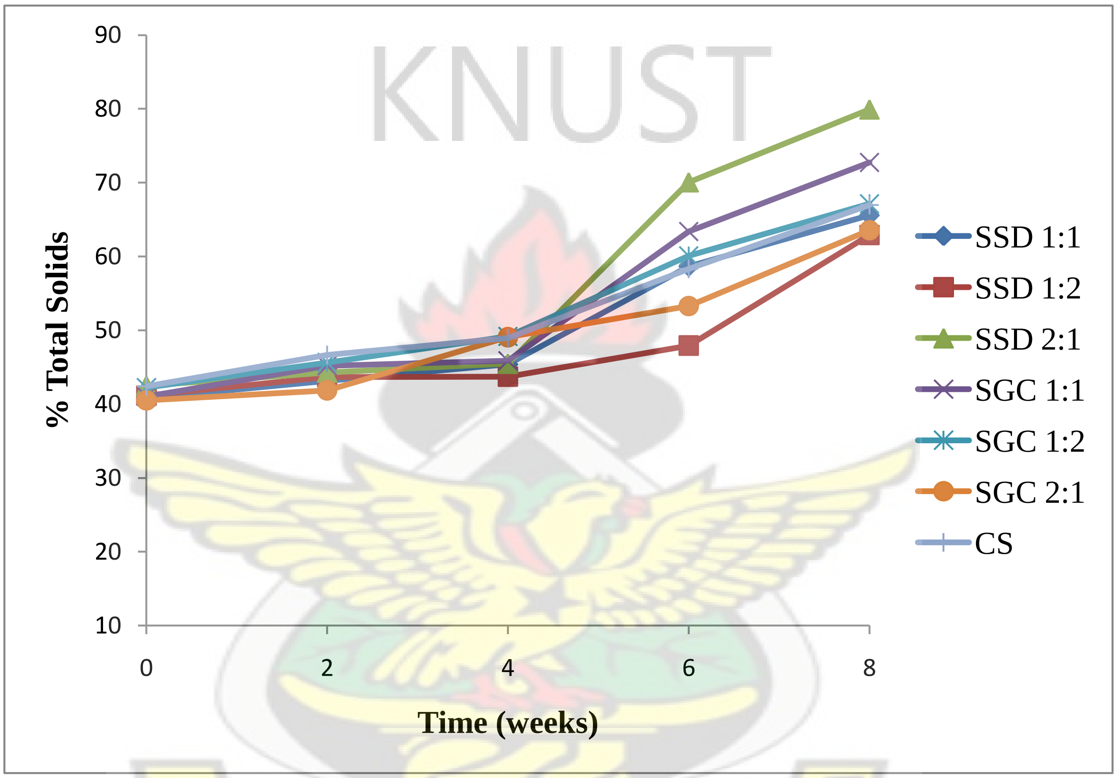

Fig 4.10: Mean fortnightly Total solids of both control and experimental treatments.

Fig. 4.11 represents the mean biweekly volume changes over the entire composting period from initial values of approximately 0.98 m^3 for all treatments reducing to final values of 0.39 m^3 0.25 m^3, 0.60 m^3, 0.21 m^3, 0.21 m^3, 0.20 m^3, and 0.22 m^3 for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

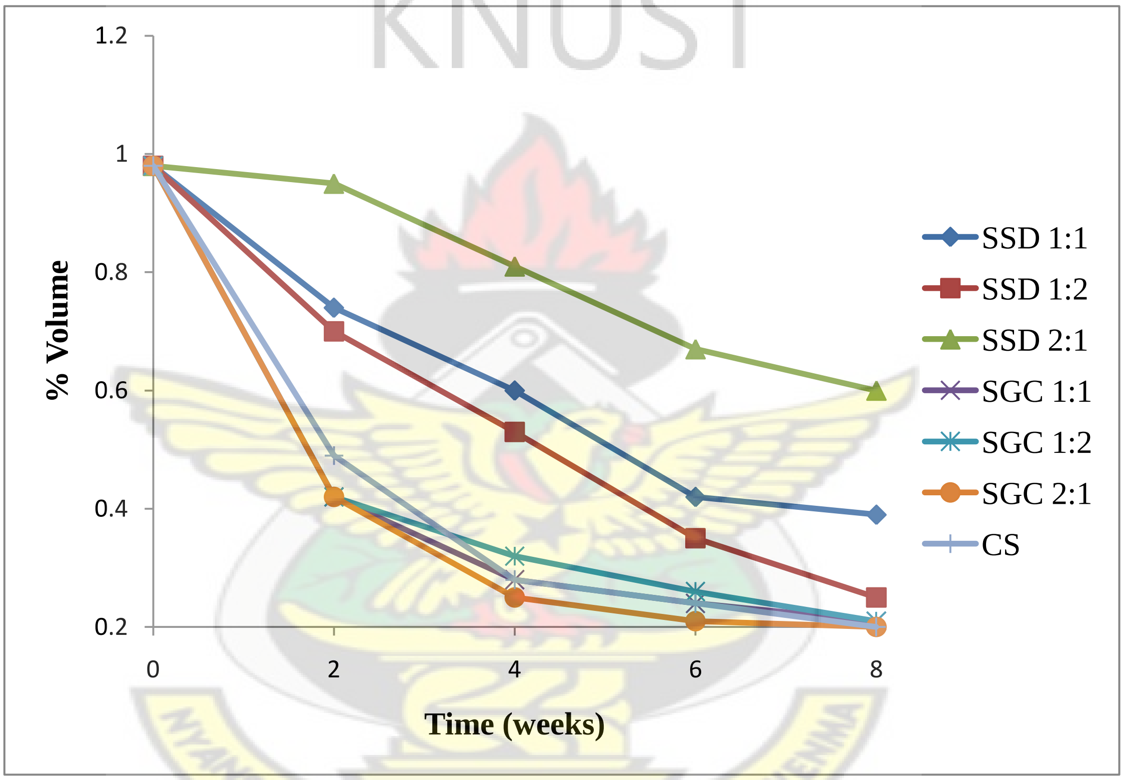

Fig 4.11: Mean fortnightly Volume of both control and experimental treatments.

Total coliforms levels determined during the period are shown in fig 4.12. In all seven treatments, pathogen levels reduced very significantly. Total coliforms reduced from the mean log values of 8.36, 7.36, 7.63, 8.63, 8.72, 8.98, and 6.36 to 2.36, 2.81, 2.63, 2.59, 2.72, 2.86, and 2.36 for the treatments SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

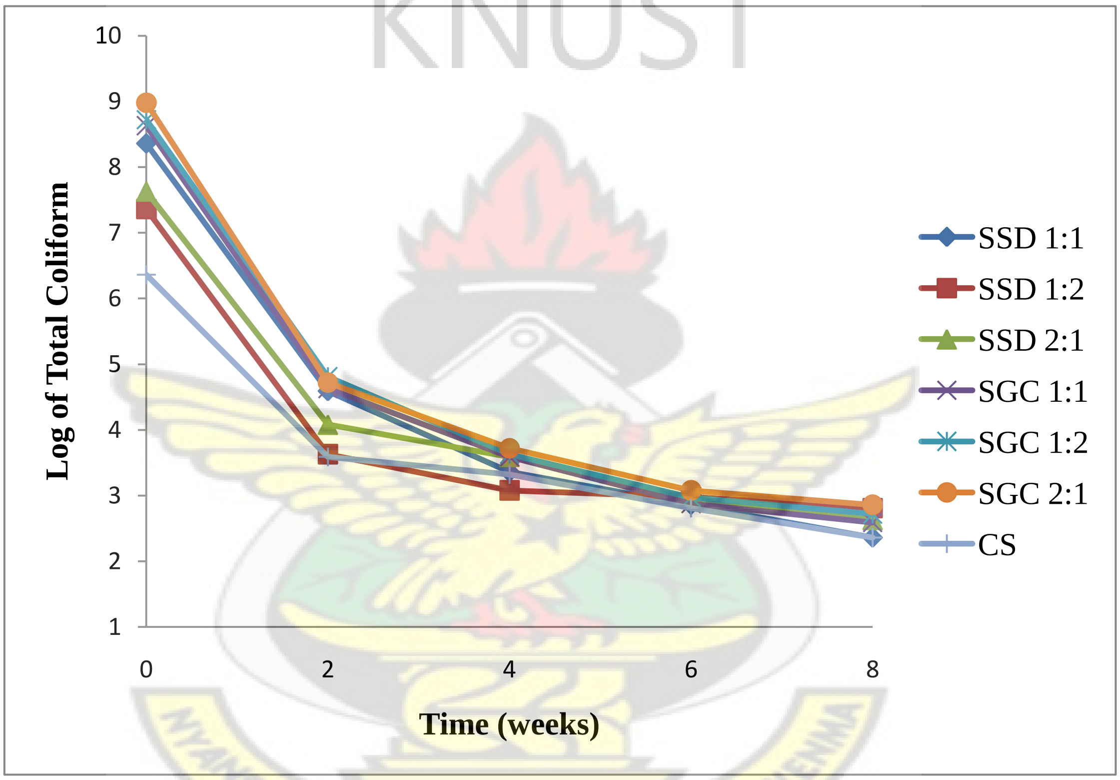

Fig 4.12: Mean fortnightly Total Coliform of both control and experimental treatments.

Faecal coliforms levels determined during the period are shown in fig 4.13. In all seven treatments, pathogen levels also reduced very significantly. Faecal coliforms also decreased from mean logs of 5.36, 4.38, 4.63, 5.59, 4.63, 5.72, and 3.36 to 2.04, 2.28, 2.04, 2.08, 2.11, 2.17, and 2.15 for the treatments ratio SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively. Results for all ratios were statistically significant.

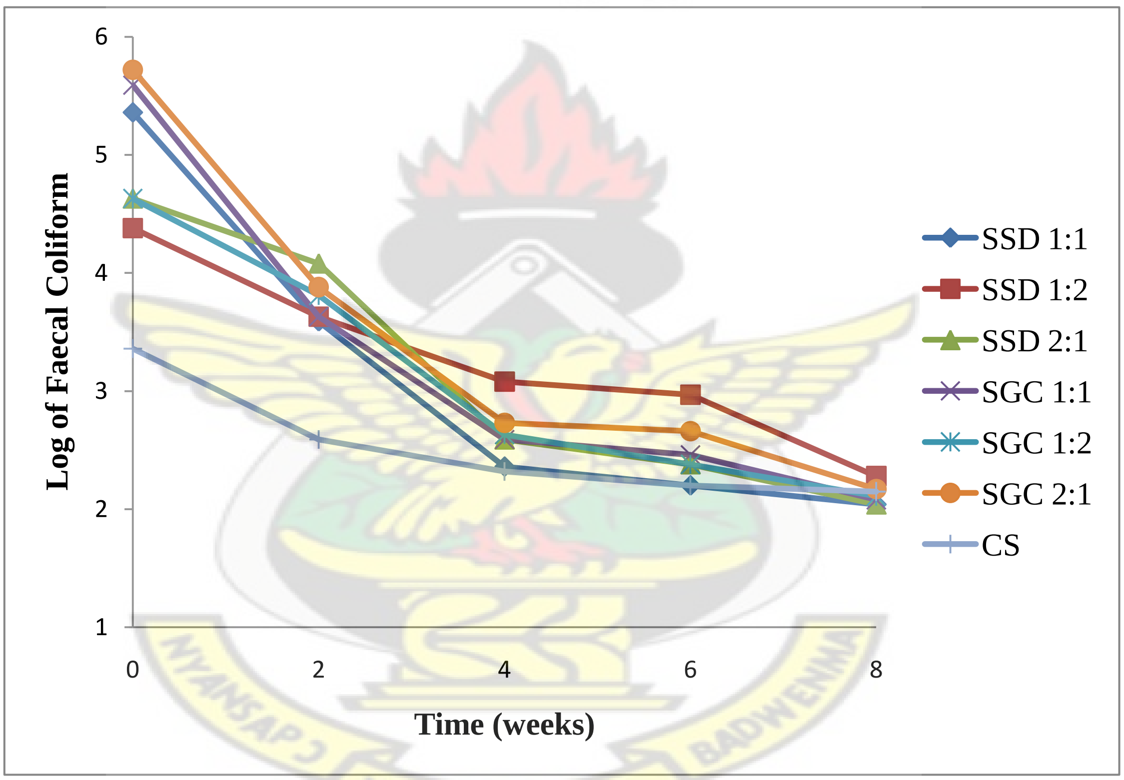

Fig 4.13: Mean fortnightly Faecal Coliform of both control and experimental treatments.

Temperature variation during the composting process and the ambient temperature is also shown in fig. 4.14. The figure shows the gradual rise of the process temperature from a near ambient temperature to a peak of around 53 °C and then dropping gradually to the ambient temperature which was around 28 °C to 30 °C. But getting to the end of the composting process period, the temperatures fell below the ambient temperature to as low as 25 °C.

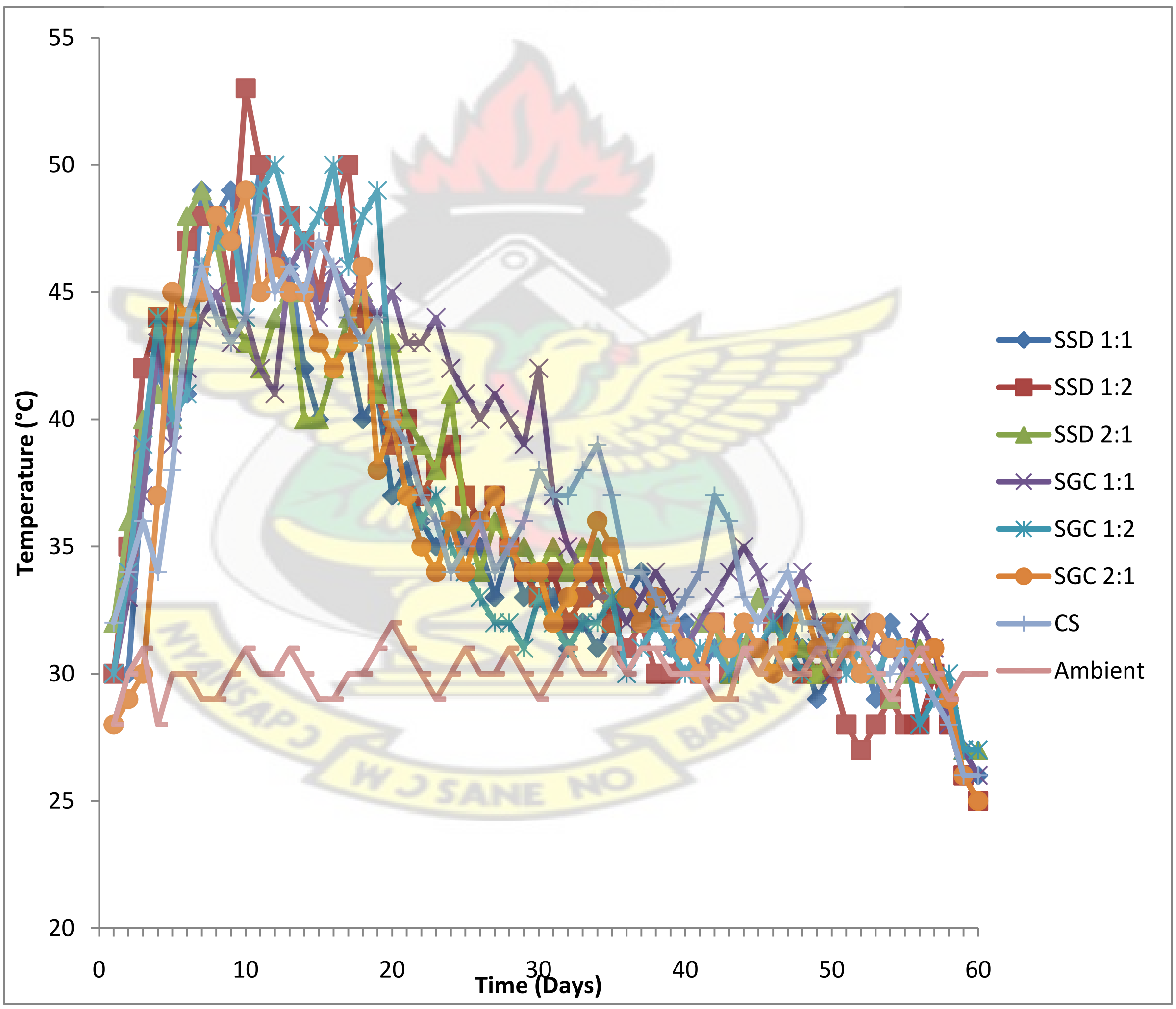

Fig 4.14: Mean daily temperature of both control and experimental treatments.

CHAPTER FIVE

5.0 DISCUSSION

5.1 CARBON, NITROGEN AND CARBON - NITROGEN RATIO

Organic material provides food for organisms in the form of carbon and nitrogen.

Bacteria use carbon for energy and nitrogen for protein to grow and reproduce. Carbon and nitrogen levels vary with each organic material.

Carbon-rich materials tend to be dry and brown such as leaves, straw, and wood chips. Nitrogen materials tend to be wet and green such as fresh grass clippings and food waste.

There was a steady decrease in carbon content, nitrogen content and C/N ratio for all the windrows.

SSD 1:1, SSD 1:2, and SSD 2:1 had the highest percentage carbon of 35.4 %, 31.4 %, and 31.4 % due to the presence of proportionate sawdust and proportionate food waste. This result led to the immobilization of the nitrogen in the mixture. Hence affected microbial activity in breaking down carbon into volatile carbon dioxide and water and thus slowed down decomposition.

Nitrogen decreased during the composting process and this could be as a result of nitrogen loss through the volatilization of gaseous ammonia. Wilson *et al*., (1983) also corroborated the decrease in nitrogen and indicated that the available nitrogen is usually converted into bacterial proteins and stored in the bodies of the microorganism during composting thus leading to a general decrease.

There was an increase however from an initial value of 2.0 %, 1.85 %, 1.9 %, and 1.7 % to 3.1 %, 2.85 %, 2.8 %, and 2.45 % for SGC 1:1, SGC 1:2, SGC 2:1, and CS during the first 13 days of composting.

Ajay and Kazmi, (2007) in their report also noticed an increase in total nitrogen contents after 20 days of composting period and indicated that it might have been due to the net loss of dry mass in terms of carbon dioxide, water loss by evaporation caused by heat evolved during oxidization of organic carbon, higher amount of food/vegetable waste used in the experiment and activities of nitrogen fixing bacteria.

The mean difference of nitrogen content in the final compost was however statistically significant (P = 0.319425), this implies that irrespective of the quantity of nitrogen in all seven windrows, all was adequately decomposed and transformed into stable compounds after composting.

Percentage nitrogen in all seven windrows was small but adequate for use as compost manure. This is corroborated by Gotass (1956) who set the standard at a range between 0.4 % - 3.5 % necessary for a mature compost. Too much nitrogen can also cause a rise in the pH level which is toxic to some microorganisms.

SGC 2:1 had 36.07 % loss of nitrogen which was the highest loss in all seven windrows. This was due to the fact that SGC 2:1 had a high proportion of nitrogen rich grass clipping in a 2:1 proportionate mixture with the food waste. The high loss of nitrogen in SGC 2:1 was corroborated by Douglas and Magdoff, (1991) who indicated that the percentage of total nitrogen lost increases as the initial nitrogen concentration of the feedstock material increases. This was evident in the case of SGC 2:1 which exhibited an increase from an initial content of 1.9 % to 2.8 % and this could be due to the fact that SGC 2:1 ratio contained more nitrogen-rich grass clippings to enhance the release of more nitrogen as decomposition progressed.

The mean difference of the C/N ratio in the final compost was not statistically significant (P = 0.511941). This also implies that irrespective of the C/N ratio in all seven windrows, all was adequately decomposed and transformed into stable compounds after composting.

C/N ratio in the final compost was highest in SSD 1:1 (32.18 %), SSD 1:2 (27.30 %) and SSD 2:1 (36.94 %) due to the high presence of carbon rich sawdust in both mixtures. The presence of carbon compounds (lignin and cellulose) could have had an effect due to their greater resistance to decomposition.

Again C/N ratio generally decreased because carbon was lost from the pile as a result of microbial activity releasing volatile carbon dioxide and water.

The C/N ratio does not need to be exact as carbon and nitrogen levels may vary with each organic material.

5.2 POTASSIUM AND PHOSPHOROUS

Although the nutrient content of compost is low compared to synthetic fertilizer products, compost is usually applied at greater rates and therefore nutrient contribution can be significant.

Phosphorus and potassium both showed a decreasing trend due to microbial activities. The mean difference of both phosphorus and potassium in the final compost were nevertheless statistically significant (P = 2.08E-08, P = 3.96E-08).

SSD 2:1 registered the highest phosphorus content of 0.31.

Much of the phosphorus in finished compost is not readily available for plant uptake since it is incorporated in organic matter.

SSD 2:1 registering the highest phosphorus might have been due to the fact that the mineralized phosphorus bound to the sawdust.

This was corroborated by the findings of Frossard *et al*., (2002) which indicated that only 2 to 16 % total phosphorus is rapidly exchangeable, and between 40 to 70 % as slowly exchangeable or not exchangeable.

There was also a gradual decrease in potassium content but not as low as that of phosphorus.

The percentage potassium in the final compost for all the seven windrows was adequate. They were found within the range of 0.5 % - 1.8 % set by Gotass, (1956).

This resulted in the availability of sufficient potassium in the compost mass to enable bacterial cells to absorb and regulate osmotic pressure.

Potassium in final compost was highest in SGC 1:1 (0.82 %) which made it an idle choice among all the ratios.

5.3 ORGANIC MATTER AND ASH CONTENT

Organic matter content in compost is an important characteristic for evaluating product quality. Organic matter is the measure of carbon based materials in the compost. High quality compost will usually have a minimum of 50 % organic matter based on dry weight.

Analysis of organic matter results revealed reduction in all windrows during the entire composting period.

There was 32 %, 33 %, 40.1 %, 46 %, 47 %, 48.6 %, and 59.4 % loss of organic matter for SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1, and CS respectively.

These results were nevertheless contrary to that of Fang *et al*., (1999) who reported only a 9 % loss in percentage organic matter in the composting of sewage sludge and sawdust-fly ash.

All windrows showed a statistical significance at the end of composting (P = 3.35E-05).

Organic matter decrease could be as a result of high microbial activity in the conversion of organic matter into volatile carbon dioxide and water.

Final percentage organic matter was highest in the final compost of SSD 1:1, SSD 1:2, and SSD 2:1. This could be due to the fact that the percentage reduction in the organic matter content was minimal in these three ratios, which in turn could be attributed to the presence of carbon compounds (lignin and cellulose) which has a greater resistance to decomposition. Schorth, (2003) indicated in his work how lignin reduces the bioavailability of other cell wall constituent, making them physically or chemically less accessible to decomposers during composting.

The ash content for all seven windrows however increased and also showed a statistical significance at the end of composting (P = 3.35E-05). Hence it was noticed that as organic matter decreased, ash content increased and as such both exhibited an inverse relationship.

This was due to the fact that organic matter being the organic fraction of the compost is degradable and lost as volatile carbon dioxide and water. On the other hand the ash content is the inorganic fraction of the compost and as such, as the organic fraction is decomposed, it leads to a corresponding increase of the inorganic fraction.

Hence it was noticed that the percentage ash in SGC 1:1, SGC 1:2, SGC 2:1, and CS were higher than that of SSD 1:1, SSD 1:2, and SSD 2:1 due to the fact that the percentage loss of organic matter was higher in the former than the latter and hence led to a bigger increase in the quantity of the inorganic fraction (percentage ash) in the former than the latter.

5.4 pH

pH is a numerical measure of the acidity or alkalinity of the soil. The pH scale ranges from 0 to 14 with a pH or 7 indicating neutrality. Most good compost has a pH of between 6 and 8 (Carr *et al.*, 1998).

From the results obtained, pH values decreased for all the experimental ratios, including that of the control.

There was pH drop of 6.85 %, 6.94 %, 8.11 %, 4.17 %, 9.46 %, 4.23 % and 1.43 % for the compost ratio SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS.

The drop in pH levels for all samples might have been due to changes in chemical composition such as the presence of organic carbon. This was corroborated by some researches FAO, (1987), and Meunchang *et al*., (2005) which indicated high organic carbon content, mineralization of organic acid by acid forming bacterial as well as the large quantities of carbon dioxide released during the composting process as being responsible for drops in pH levels.

Chen and Inbar, (1993) also indicated that the pH typically decreases as organic acids are produced.

Again, the pH for all the set up did not get too acidic and this finding was corroborated by Inckel *et al.*, (1990), who intimated that a compost heap which is properly constructed will seldom decrease in acidity (highly acidic). That is the composting pile will not be highly acidic.

The final rise in the pH values to near neutrality indicated maturity and was supported by the findings of Cherrington *et al*., (1991) who noted that the concentration of acids in compost is influenced by both production and consumption of the acids as most microorganisms utilize organic acids as a readily available substrate for aerobic oxidation.

The final pH values nevertheless fell within the optimum pH of 6.5 to 7.2 which according to Carr *et al*., (1998) was good to maintain a proper C/N ratio.

Henry (2003) also indicated that when the pH of compost pile reaches a range of 8 to 9, strong ammonia and amine related odors may be generated and this was not observed during the whole period of composting due to the fact that pH remained in the optimum range of 6.5 to 7.2.

5.5 MOISTURE CONTENT AND TOTAL SOLIDS

McCartney and Tingley, (1998) indicated that moisture content of the compost blend is an important environmental variable as it provides a medium for transport of dissolved nutrient required for the metabolic and physiological activities of microorganisms.

Decomposer organisms need water to live. Microbial activity occurs most rapidly in thin water films on the surface of organic materials.

The mean difference in the percentage moisture content of the final compost was statistically significant (P = 1.48E-12).

From the results, there was 41.8 %, 37 %, 65.2 %, 53.7 %, 43.09 %, 38.8 %, and 42.7% loss of moisture for SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1, and CS.

Obeng and Wright, (1987) however indicated a 12 to 15 % range as the lowest level at which bacterial activity could occur hence making the moisture content in SSD2:1 acceptable for microbial activity.

The high percentage moisture loss for SSD 2:1 although a right moisture content of 57.49 % being achieved at the beginning could be due to the fact that the high proportion of sawdust (having woodier, older and drier tissues) to food waste (2:1) led to the circumstance where the sawdust absorbed more water to make it moist and also partly to the rise in temperatures and turning of the heap.

Hence this situation led to the slowing down of microbial activities due to limitations encountered in transporting dissolved nutrients required for microbial metabolic and physiological activities and hence reducing the rate of decomposition.

From the results, total solids increased as moisture content decreased. Heaps with high percentage moisture loss had a higher percentage of total solids. Again SSD 2:1 had the highest percentage total solids due to the fact that it had the lowest percentage moisture content at the end of the composting process and this can be explained by the fact that percentage moisture and total solids have an inverse relationship.

The mean difference of the final compost was statistically significant (P = 1.48E-12).

This implies that irrespective of the moisture content in all seven windrows, all was adequately transformed into stable compounds after composting.

5.6 COMPOST VOLUME

The entire period of composting registered considerable reduction in compost volume for all the compost setup.

Results of the volume reduction were however statistically significant (P = 5.13E-08).

There was 59 %, 73 %, 38 %, 77 %, 77 %, 78 % and 76 % reduction in volume for SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS.

The results recorded were in agreement with that of Dao (1999) who reported of having registered over 50 % loss in volume when composting manure.

Considerable reduction in volume (over 50 %) was recorded for all except for SSD 2:1 which had quite a minimal reduction in volume (38 %) and also registered a slower rate of decomposition.

This result may be explained by the fact that SSD 2:1 contained a larger proportion of sawdust which is rich in carbon. Decomposition might have slowed because of the greater resistance to decomposition of remaining carbon compounds (lignin and cellulose) and also due to the minimal availability of moisture which slowed microbial activities and hence the rate of decomposition. Generally, the higher the lignin and polyphenolic content of organic materials, the slower their decomposition (Palm and Sanchez, 1991).

Carbon-rich materials tend to be brown, dry and older with woodier tissues and hence tend to decompose much slower. Again due to the small proportion of nitrogen containing food waste, the nitrogen in the mixture became immobilized and hence slowed the rate of decomposition.

SGC 1:1, SGC 1:2, SGC 2:1, and CS had high reduction in their volume and hence the highest rate of decomposition. This might be explained by the fact that there was enough nitrogen which was mineralized to affect a higher rate of decomposition.

5.7 COLIFORMS IN COMPOST

Finstein and Morris, (1975) indicated that during composting, microbial activities are diverse. Microbial stability can be very useful in assessment of compost's maturity.

There was a steady decrease in both total coliform and faecal coliform population in all seven windrows.

The mean difference of the final compost for all the windrows was found to be statistically significant ($P<0.05$) for both total coliform and faecal coliform.

There was a total coliform decrease of 71.8 %, 61.8 %, 65.5 %, 70 %, 68.8 %, 68.2 %, and 62.9 % for SSD 1:1, SSD 1:2, SSD 2:1, SGC 1:1, SGC 1:2, SGC 2:1 and CS respectively.

Again by the end of composting, faecal coliforms for all the windrows had reduced to levels even below the standard of less than 3.00log10 MPN/g (< 1000 MPN/g) as set by USEPA, (1994).

This drop could be attributed to the exhaustion of nutrients from the medium and/or to the temperature peak during the thermophilic phase, antagonistic organism, indigenous organisms, and time, all of which played unique roles in pathogen destruction.

These were corroborated by Wiley (1962), Himathongkham *et al*., (1999) and Golueke, (1983) who attributed coliforms drop to thermal kill, lack of nutrients and time respectively.

Again, the situation of low moisture leading to desiccation might have caused the death of cells and hence leading to a reduction in microorganism survival.

5.8 TEMPERATURE

Temperature is another important factor in the composting process and is related to proper air and moisture levels.

As the microorganisms work to decompose the compost, they give off heat which in turn increases pile temperatures. The process of aerobic composting can be divided into three major steps, a mesophilic-heating phase, a thermophilic phase and a cooling phase (Leton and Stentiford, 1990).

The composting process was accompanied by fluctuations in the temperature readings and also experienced the three major temperature phases being mesophilic phase, thermophilic phase, and a second mesophilic phase.

All the seven compost windrows experienced an initial temperature rise from between 28 °C and 40 °C for the first four days (Mesophilic phase 10 °C to 40 °C).

There was then a general increase in all compost windrows above 40 °C (Thermophilic phase) within 5 – 12 days to between 41 °C and 52 °C. This is because when active composting is taking place, microbial activity in the pile causes an increase in temperature in the center of the pile to about 52 °C to 60 °C because heat-loving (thermophilic) bacteria vigorously degrade organic material.

The temperatures for all compost windrows still remained in the thermophilic phase (above 40 °C) but fluctuating up and down until the 20^{th} day.

Chen and Inbar (1993) explained that the temperatures still remained in this range because decomposable materials were still available and that there was adequate oxygen for microbial activity.

The temperature readings then entered the second mesophilic phase of between 30 °C and 37 °C due to the depletion of food sources from about the 30th day and continued to fall till the final readings even fell towards the ambient temperature.

Rynk *et al*., (1992) indicated that when the compost pile temperature falls to that of the ambient air, the compost is ready for curing.

Maturation (curing) stage was supported by the fact that temperature readings for all compost windrows fell to between 25 °C and 29 °C below the ambient temperature of averagely 30 °C.

Stentiford (1996) intimated that temperature ranges of 35 °C-40 °C was needed to maximize microbial diversity whilst ranges of 45 °C-55 °C was needed to maximize the rate of biodegradation.

CHAPTER SIX

6.0 CONCLUSION

C/N ratio reduction occurred more in the grass clipping/food waste ratios than the sawdust/food waste ratios.

This showed better and more effective degradation in the grass clipping/food waste ratios than that of the sawdust/food waste.

Volume reduction amongst the grass clipping/food waste ratios was more effective in the 2:1 ratio which comprised of 2 parts of grass clipping to 1 part of the food waste.

The study however revealed that the finished compost for all the ratios of the two different bulking materials were of quality in terms of potassium content as they all had appreciable levels within the acceptable range of 0.5 % to 1.8 %.

Potassium content was highest in the SGC 1:1 ratio which had a percentage of 0.82 %.

Phosphorus content was highest in SSD 2:1 (0.31 %) as compared to that of SGC 1:1 (0.30 %), and SGC 2:1 (0.30 %).

Composting of sawdust/food waste and grass clipping/food waste was again much effective in reducing the pathogenic concentration to levels far below the acceptable standard of 1000MPN/g.

From the analysis, the grass clipping/food waste ratios decomposed faster than the sawdust/food waste ratios. This might also have affected the release of nutrients during decomposition.

Again the grass clipping/food waste ratios had C/N ratio levels below 20 which according to various researches is deemed matured for land or soil application whilst that of the sawdust/food waste ratios had C/N ratio levels above 20 which was due to the slow rate of decomposition.

6.1 RECOMMENDATION

From the analysis, it is recommended that;

- The grass clipping/food waste ratios after final analysis had favorable C/N ratios and at such can be applied as compost to soil to obtain high crop yield
- Further work should be carried out to compost sawdust and food waste with little adjustments to amount of sawdust and food waste so as to achieve Favorable C/N ratio.

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APPENDICES

APPENDIX A:

Mean carbon values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	52.3	49.3	48.9	46.1	35.7
SSD1:1B	51.7	49.1	48.7	46.3	35.1
Mean	52.0	49.2	48.8	46.2	35.4
SSD1:2A	51.2	47.2	46.7	45.8	31.3
SSD1:2B	51.0	47.6	46.9	46.2	31.5
Mean	51.1	47.4	46.8	46.0	31.4
SSD2:1A	52.3	45.9	44.7	42.8	31.6
SSD2:1B	52.5	45.9	44.1	42.4	31.2
Mean	52.4	45.9	44.4	42.6	31.4
SGC1:1A	50.2	42.3	33.0	30.9	26.4
SGC1:1B	50.4	42.1	33.0	30.9	27.0
Mean	50.3	42.2	33.0	30.9	26.7
SGC1:2A	46.9	44.7	38.2	33.2	27.2
SGC1:2B	46.9	44.3	38.6	33.4	27.0
Mean	46.9	44.5	38.4	33.3	27.1
SGC2:1A	49.3	47.3	34.7	32.6	27.0
SGC2:1B	49.1	47.7	35.1	33.2	26.6
Mean	49.2	47.5	34.9	32.9	26.8
CSA	51.0	46.9	43.2	39.1	25.9
CSB	50.6	466.9	43.4	39.5	25.5
Mean	50.8	46.9	43.3	39.3	25.7

APPENDIX B:

Mean nitrogen values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	1.30	1.39	1.34	1.30	1.11
SSD1:1B	1.50	1.35	1.36	1.28	1.13
Mean	1.40	1.37	1.35	1.29	1.12
SSD1:2A	1.70	1.59	1.57	1.59	1.14
SSD1:2B	1.68	1.61	1.61	1.55	1.16
Mean	1.69	1.60	1.59	1.57	1.15
SSD2:1A	1.32	1.17	1.11	1.10	0.83
SSD2:1B	1.30	1.13	1.13	1.10	0.87
Mean	1.31	1.15	1.12	1.10	0.85
SGC1:1A	2.20	3.05	2.50	2.55	2.32
SGC1:1B	1.80	3.15	2.70	2.55	2.10
Mean	2.00	3.10	2.60	2.55	2.21
SGC1:2A	1.84	2.81	2.50	2.46	2.17
SGC1:2B	1.86	2.89	2.58	2.52	2.21
Mean	1.85	2.85	2.54	2.49	2.19
SGC2:1A	1.83	3.00	2.70	2.46	1.77
SGC2:1B	1.97	2.60	2.78	2.66	1.81
Mean	1.90	2.80	2.74	2.56	1.79
CSA	1.73	2.43	2.33	2.17	1.60
CSB	1.67	2.47	2.43	2.21	1.80
Mean	1.70	2.45	2.38	2.19	1.70

APPENDIX C:

Mean carbon – to – nitrogen ratio values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	37.11	36.16	36.11	35.61	32.15
SSD1:1B	37.17	36.20	36.19	36.01	32.21
Mean	37.14	36.18	36.15	35.81	32.18
SSD1:2A	30.04	29.41	29.54	29.35	27.50
SSD1:2B	30.44	29.81	29.34	29.31	27.10
Mean	30.24	29.61	29.44	29.33	27.30
SSD2:1A	38.00	40.41	39.54	38.61	36.74
SSD2:1B	42.00	39.41	39.74	38.85	37.14
Mean	40.00	39.91	39.64	38.73	36.94
SGC1:1A	25.05	13.40	12.60	12.10	12.06
SGC1:1B	25.25	13.84	12.80	12.16	12.10
Mean	25.15	13.62	12.70	12.13	12.08
SGC1:2A	25.20	15.40	15.09	13.13	12.16
SGC1:2B	25.50	15.82	15.13	13.59	12.56
Mean	25.35	15.61	15.11	13.36	12.36
SGC2:1A	25.59	16.92	14.67	12.45	12.53
SGC2:1B	26.19	17.00	15.31	13.25	12.93
Mean	25.89	16.96	14.99	12.85	12.73
CSA	29.52	19.00	18.11	17.55	15.24
CSB	29.66	19.30	18.33	18.35	15.02
Mean	29.59	19.15	18.22	17.95	15.12

APPENDIX D:

Mean phosphorus values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	0.61	0.46	0.30	0.25	0.26
SSD1:1B	0.67	0.50	0.34	0.27	0.22
Mean	0.64	0.48	0.32	0.26	0.24
SSD1:2A	0.93	0.39	0.34	0.30	0.21
SSD1:2B	0.99	0.35	0.32	0.32	0.27
Mean	0.96	0.37	0.33	0.31	0.24
SSD2:1A	0.79	0.59	0.53	0.45	0.31
SSD2:1B	0.73	0.79	0.61	0.49	0.31
Mean	0.76	0.69	0.57	0.47	0.31
SGC1:1A	0.55	0.46	0.48	0.37	0.25
SGC1:1B	0.57	0.52	0.42	0.33	0.31
Mean	0.56	0.49	0.45	0.35	0.28
SGC1:2A	0.52	0.46	0.40	0.27	0.20
SGC1:2B	0.56	0.48	0.48	0.33	0.22
Mean	0.54	0.47	0.44	0.30	0.21
SGC2:1A	0.63	0.55	0.49	0.37	0.27
SGC2:1B	0.65	0.51	0.41	0.39	0.31
Mean	0.64	0.53	0.45	0.38	0.29
CSA	0.74	0.55	0.48	0.34	0.28
CSB	0.80	0.61	0.44	0.40	0.32
Mean	0.77	0.58	0.46	0.37	0.30

APPENDIX E:

Mean potassium values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	1.37	0.60	0.55	0.50	0.49
SSD1:1B	1.33	0.60	0.53	0.56	0.52
Mean	1.35	0.60	0.54	0.53	0.51
SSD1:2A	1.29	1.19	1.09	0.57	0.51
SSD1:2B	1.33	1.13	1.13	0.61	0.53
Mean	1.31	1.16	1.11	0.59	0.52
SSD2:1A	1.75	1.26	1.20	0.53	0.52
SSD2:1B	1.79	1.22	1.00	0.57	0.48
Mean	1.77	1.24	1.10	0.55	0.50
SGC1:1A	1.55	1.40	1.10	0.85	0.62
SGC1:1B	1.61	1.60	1.30	0.93	1.02
Mean	1.58	1.50	1.20	0.89	0.82
SGC1:2A	2.00	1.80	1.01	0.76	0.63
SGC1:2B	2.04	1.40	1.21	0.82	0.75
Mean	2.02	1.60	1.11	0.79	0.69
SGC2:1A	1.60	1.18	1.23	0.72	0.62
SGC2:1B	1.20	1.38	1.29	0.80	0.70
Mean	1.40	1.28	1.26	0.76	0.66
CSA	1.43	1.10	1.22	0.83	0.59
CSB	1.63	1.42	1.28	0.77	0.65
Mean	1.53	1.26	1.25	0.80	0.62

APPENDIX F:

Mean ash content values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	10.7	15.2	17.0	20.8	39.2
SSD1:1B	10.3	15.4	15.0	20.2	39.0
Mean	10.5	15.3	16.0	20.5	39.1
SSD1:2A	12.00	19.3	21.7	26.4	41.1
SSD1:2B	12.20	19.7	22.1	26.0	41.1
Mean	12.1	19.5	21.9	26.2	41.1
SSD2:1A	9.7	21.0	23.9	26.6	45.0
SSD2:1B	9.9	21.0	23.3	26.8	47.0
Mean	9.8	21.0	23.6	26.7	46
SGC1:1A	13.6	43.0	50.5	52.5	53.0
SGC1:1B	13.2	43.4	51.3	53.1	53.4
Mean	13.4	43.2	50.9	52.8	53.2
SGC1:2A	19.5	34.0	52.0	51.9	57.1
SGC1:2B	19.1	34.0	52.0	51.5	57.3
Mean	19.3	34.0	52.0	51.7	57.2
SGC2:1A	15.3	39.0	48.5	50.9	56.3
SGC2:1B	15.5	41.0	49.1	48.9	56.7
Mean	15.4	40.0	48.8	49.9	56.5
CSA	12.7	25.5	37.9	63.0	64.1
CSB	12.5	24.3	37.7	63.4	64.9
Mean	12.6	25.4	37.8	63.2	64.5

APPENDIX G:

Mean organic matter values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	98.7	84.2	85.0	79.6	61.4
SSD1:1B	89.3	85.2	83.0	79.4	60.4
Mean	89.5	84.7	84.0	79.5	60.9
SSD1:2A	87.5	80.3	78.2	73.7	58.6
SSD1:2B	88.3	80.7	78.0	73.9	59.2
Mean	87.9	80.5	78.1	73.8	58.9
SSD2:1A	90.0	78.0	76.1	73.5	54.0
SSD2:1B	90.4	80.0	76.7	73.1	54.0
Mean	90.2	79.0	76.4	73.3	54.0
SGC1:1A	86.3	56.4	48.1	47.4	46.7
SGC1:1B	86.9	57.2	50.1	47.0	46.9
Mean	86.6	56.8	49.1	47.2	46.8
SGC1:2A	80.4	65.8	47.3	48.1	43.3
SGC1:2B	81.0	66.2	48.7	48.5	42.3
Mean	80.7	66.0	48.0	48.3	42.8
SGC2:1A	84.4	60.0	50.4	49.2	42.5
SGC2:1B	84.8	60.0	52.0	51.0	44.5
Mean	84.6	60.0	51.2	50.1	43.5
CSA	87.3	74.2	62.1	36.3	35.0
CSB	87.5	75.0	62.3	37.3	36.0
Mean	87.4	74.6	62.2	36.8	35.5

APPENDIX H:

Mean pH values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	7.4	7.0	6.3	6.4	6.8
SSD1:1B	7.2	7.0	6.5	6.6	6.8
Mean	7.3	7.0	6.4	6.5	6.8
SSD1:2A	7.2	7.2	6.1	6.3	6.7
SSD1:2B	7.0	7.0	6.3	6.5	6.7
Mean	7.2	7.1	6.2	6.4	6.7
SSD2:1A	7.4	6.7	6.2	6.5	6.7
SSD2:1B	7.4	7.1	6.4	6.5	6.9
Mean	7.4	6.9	6.3	6.5	6.8
SGC1:1A	7.3	6.9	6.2	6.5	6.9
SGC1:1B	7.1	6.7	6.2	6.7	6.9
Mean	7.2	6.8	6.2	6.6	6.9
SGC1:2A	7.4	6.7	6.2	6.4	6.5
SGC1:2B	7.4	6.7	6.0	6.4	6.9
Mean	7.4	6.7	6.1	6.4	6.7
SGC2:1A	7.0	7.2	6.0	6.5	6.7
SGC2:1B	7.2	6.6	6.0	6.3	6.9
Mean	7.1	6.9	6.0	6.4	6.8
CSA	7.0	6.5	6.0	6.2	6.7
CSB	7.0	6.9	6.2	6.4	7.1
Mean	7.0	6.7	6.1	6.3	6.9

APPENDIX I:

Mean moisture content values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	59.19	56.66	54.60	41.31	34.40
SSD1:1B	59.17	57.06	54.60	41.39	34.44
Mean	59.18	56.86	54.60	41.35	34.42
SSD1:2A	58.63	56.30	56.17	52.07	37.00
SSD1:2B	59.05	56.36	56.37	52.05	37.18
Mean	58.84	56.33	56.27	52.06	37.09
SSD2:1A	57.45	55.62	54.50	29.91	20.03
SSD2:1B	57.53	55.82	54.56	29.95	20.09
Mean	57.49	55.72	54.53	29.93	20.06
SGC1:1A	58.85	54.91	54.03	36.43	27.07
SGC1:1B	59.05	54.71	54.23	36.83	27.47
Mean	58.95	54.81	54.13	36.63	27.27
SGC1:2A	57.73	54.06	50.81	39.90	32.85
SGC1:2B	57.77	54.66	50.85	39.96	32.89
Mean	57.75	54.36	50.83	39.93	32.87
SGC2:1A	59.30	58.10	50.90	46.62	36.43
SGC2:1B	59.70	58.16	50.96	46.82	36.45
Mean	59.50	58.13	50.93	46.72	36.44
CSA	57.37	53.23	51.00	41.66	33.00
CSB	57.77	53.43	51.08	41.72	33.02
Mean	57.57	53.33	51.04	41.69	33.01

APPENDIX J:

Mean total solids values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	40.72	43.12	45.30	58.63	65.38
SSD1:1B	40.92	43.16	45.50	58.67	65.78
Mean	40.82	43.14	45.40	58.65	65.58
SSD1:2A	41.14	43.57	43.70	47.91	62.40
SSD1:2B	41.18	43.77	43.76	47.99	63.42
Mean	41.16	43.67	43.73	47.94	62.91
SSD2:1A	42.31	44.27	45.37	70.02	79.92
SSD2:1B	42.71	44.29	45.57	70.12	79.96
Mean	42.51	44.28	45.47	70.07	79.94
SGC1:1A	41.03	45.15	45.37	63.17	72.43
SGC1:1B	41.07	45.23	46.37	63.57	73.03
Mean	41.05	45.19	45.87	63.37	72.73
SGC1:2A	42.15	45.44	49.07	60.03	67.10
SGC1:2B	42.35	45.84	49.27	60.11	67.16
Mean	42.25	45.64	49.17	60.07	67.13
SGC2:1A	40.30	41.85	49.00	53.24	63.54
SGC2:1B	40.70	41.89	49.14	53.32	63.58
Mean	40.50	41.87	49.07	53.28	63.56
CSA	42.23	46.47	48.76	58.11	66.77
CSB	42.63	46.87	49.16	58.51	67.21
Mean	42.43	46.67	48.96	58.31	66.99

APPENDIX K:

Mean volume values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	0.98	0.77	0.60	0.43	0.42
SSD1:1B	0.98	0.71	0.60	0.41	0.36
Mean	0.98	0.74	0.60	0.42	0.39
SSD1:2A	0.98	0.67	0.51	0.37	0.23
SSD1:2B	0.98	0.73	0.55	0.33	0.27
Mean	0.98	0.70	0.53	0.35	0.25
SSD2:1A	0.98	0.94	0.82	0.64	0.60
SSD2:1B	0.98	0.96	0.80	0.70	0.60
Mean	0.98	0.95	0.81	0.67	0.60
SGC1:1A	0.98	0.40	0.26	0.26	0.21
SGC1:1B	0.98	0.44	0.30	0.22	0.21
Mean	0.98	0.42	0.28	0.24	0.21
SGC1:2A	0.98	0.43	0.34	0.29	0.21
SGC1:2B	0.98	0.41	0.30	0.23	0.21
Mean	0.98	0.42	0.32	0.26	0.21
SGC2:1A	0.98	0.42	0.27	0.21	0.20
SGC2:1B	0.98	0.42	0.23	0.21	0.20
Mean	0.98	0.42	0.25	0.21	0.20
CSA	0.98	0.45	0.25	0.22	0.23
CSB	0.98	0.53	0.31	0.26	0.21
Mean	0.98	0.49	0.28	0.24	0.22

APPENDIX L:

Mean log total coliform values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	8.38	4.39	3.16	2.66	2.14
SSD1:1B	8.34	4.79	3.56	3.06	2.58
Mean	8.36	4.59	3.36	2.86	2.36
SSD1:2A	7.46	3.51	3.06	2.53	2.41
SSD1:2B	7.26	3.75	3.10	3.43	3.21
Mean	7.36	3.63	3.08	2.98	2.81
SSD2:1A	7.60	4.01	3.89	2.47	2.33
SSD2:1B	7.66	4.15	3.29	3.47	2.93
Mean	7.63	4.08	3.59	2.97	2.63
SGC1:1A	8.65	4.60	3.57	2.76	2.39
SGC1:1B	8.61	4.66	3.61	3.00	2.79
Mean	8.63	4.63	3.59	2.88	2.59
SGC1:2A	8.74	4.51	3.61	2.57	2.50
SGC1:2B	8.70	5.11	3.65	3.37	2.94
Mean	8.72	4.81	3.63	2.97	2.72
SGC2:1A	8.94	4.82	3.60	3.01	2.63
SGC2:1B	9.02	4.62	3.84	3.15	3.09
Mean	8.98	4.72	3.72	3.08	2.86
CSA	6.26	3.55	3.12	2.41	2.10
CSB	6.46	3.63	3.52	3.21	2.62
Mean	6.36	3.59	3.32	2.81	2.36

APPENDIX M:

Mean log faecal coliform values for the duplicates of the ratios in weeks

	Weeks				
Compost heap	**0**	**2**	**4**	**6**	**8**
SSD1:1A	5.22	3.17	2.25	2.10	2.05
SSD1:1B	5.50	3.91	2.47	2.30	2.03
Mean	5.36	3.59	2.36	2.20	2.04
SSD1:2A	4.26	3.61	3.03	2.74	2.16
SSD1:2B	4.50	3.65	3.13	3.20	2.40
Mean	4.38	3.63	3.08	2.97	2.28
SSD2:1A	4.51	4.05	2.48	2.37	2.07
SSD2:1B	4.75	4.11	2.70	2.39	2.01
Mean	4.63	4.08	2.59	2.38	2.04
SGC1:1A	5.36	3.52	2.29	2.59	2.11
SGC1:1B	5.82	3.74	2.89	2.33	2.05
Mean	5.59	3.63	2.59	2.46	2.08
SGC1:2A	4.41	3.70	2.50	2.44	2.07
SGC1:2B	4.85	3.92	2.76	2.32	2.15
Mean	4.63	3.81	2.63	2.38	2.11
SGC2:1A	5.50	3.56	2.55	3.00	2.14
SGC2:1B	5.94	4.20	2.91	2.32	2.20
Mean	5.72	3.88	2.73	2.66	2.17
CSA	3.14	2.45	2.43	2.15	2.10
CSB	3.58	2.73	2.11	2.25	2.20
Mean	3.36	2.59	2.32	2.20	2.15

APPENDIX N:

Analysis of Variance of the biweekly carbon content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1815.713	4	453.9281	22.83483	9.69E-09	2.689628
Within Groups	596.3629	30	19.87876			
Total	2412.075	34				

Significance at 5 %

APPENDIX O:

Analysis of Variance of the biweekly nitrogen content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.8082	4	0.45205	1.229208	0.319425	2.689628
Within Groups	11.03271	30	0.367757			
Total	12.84091	34				

Significance at 5 %

APPENDIX P:

Analysis of Variance of the biweekly C/N ratio of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	346.8355	4	86.70887	0.838042	0.511941	2.689628
Within Groups	3103.981	30	103.466			
Total	3450.816	34				

Significance at 5 %

APPENDIX Q:

Analysis of Variance of the biweekly phosphorus content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.76124	4	0.19031	21.29882	2.08E-08	2.689628
Within Groups	0.26805	30	0.008935			
Total	1.02929	34				

Significance at 5 %

APPENDIX R:

Analysis of Variance of the biweekly potassium content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.24396	4	1.06099	20.06122	3.96E-08	2.689628
Within Groups	1.586629	30	0.052888			
Total	5.830589	34				

Significance at 5 %

APPENDIX S:

Analysis of Variance of the biweekly Ash content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5692.298	4	1423.075	9.820861	3.35E-05	2.689628
Within Groups	4347.097	30	144.9032			
Total	10039.4	34				

Significance at 5 %

APPENDIX T:

Analysis of Variance of the biweekly Organic matter content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	5692.298	4	1423.075	9.820861	3.35E-05	2.689628
Within Groups	4347.097	30	144.9032			
Total	10039.4	34				

Significance at 5 %

APPENDIX U:

Analysis of Variance of the biweekly pH of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	4.544571	4	1.136143	71.86446	6.24E-15	2.689628
Within Groups	0.474286	30	0.01581			
Total	5.018857	34				

Significance at 5 %

APPENDIX V:

Analysis of Variance of the biweekly Moisture content of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3573.942	4	893.4856	47.45581	1.48E-12	2.689628
Within Groups	564.8322	30	18.82774			
Total	4138.775	34				

Significance at 5 %

APPENDIX W:

Analysis of Variance of the biweekly Total solids of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3573.94	4	893.4851	47.45583	1.48E-12	2.689628
Within Groups	564.831	30	18.82772			
Total	4138.77	34				

Significance at 5 %

APPENDIX X:

Analysis of Variance of the biweekly Volume of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.140246	4	0.535061	19.37625	5.73E-08	2.689628
Within Groups	0.828429	30	0.027614			
Total	2.968674	34				

Significance at 5 %

APPENDIX Y:

Analysis of Variance of the biweekly Total Coliform of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	133.7243	4	33.43107	134.3518	1.07E-18	2.689628
Within Groups	7.464971	30	0.248832			
Total	141.1893	34				

Significance at 5 %

APPENDIX Z:

Analysis of Variance of the biweekly Faecal Coliform of control and experimental bins

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	33.35491	4	8.338729	39.45522	1.53E-11	2.689628
Within Groups	6.3404	30	0.211347			
Total	39.69531	34				

Significance at 5 %