KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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CO-COMPOSTING ORGANIC SOLID WASTE WITH MORINGA OLEIFERA LEAVES, SAWDUST AND GRASS CLIPPINGS

BY

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CERTIFICATION

I hereby declare that this submission is my original work towards a Master of Science (Environmental Resource Management) 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

This study is dedicated to my father above for His guidance and protection. Also to Mr. Evans Adusei for his support and encouragement.

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I thank God for His grace and guidance throughout my academic journey. My profound gratitude goes to my supervisor Dr. Bernard Fei-Baffoe for his enormous contribution to my work.

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To my mother, my siblings and all loved ones, may God richly bless you for all the support and encouragement over the years.

ABSTRACT

Increase in eateries on KNUST campus and its environ to satisfy the ever increasing students population, has also increased the plight of waste management. Most of the waste produced out of these eateries are organic and can be treated to be reused. The use of composting as found to be the most cost effective and environmental friendly waste management was considered a better option to manage solid waste. The study therefore sought to investigate the quality of the compost obtained from co-composting organic solid waste with various bulking agents (moringa *oleifera* leaves, sawdust and grass clippings). A 12 week composting period was used for the study on KNUST campus. Waste was collected from various eateries on campus and mixed in different ratios of 1:1, 1:2 and 2:1 (v/v) ratio for solid waste/moringa leaves (SWM 1:1, SWM 1:2 AND SWM 2:1), solid waste/ sawdust (SWSD 1:1, SWSD 1:2 AND SWSD 2:1) and solid waste/grass clippings (SWGC 1:1, SWGC 1:2 AND SWGC 2:1), physico-chemical analysis of various parameters such as moisture, temperature, pH, organic matter, organic carbon, nitrogen, C/N ratio, phosphorus, potassium and ash were monitored, recorded and analyzed in the laboratory. Composites of the piles were taken to the laboratory every two weeks. Moisture and temperature were monitored daily. Turning was done every five days and the volume recorded. At the end of the study, the percentage content of nitrogen, phosphorus and potassium increased. *E.coli*, total coliform and faecal coliform population counts reduced. There was a decrease in C/N ratio and organic matter. There was an increase in ash content and pH. There was considerable reduction in volume for all compost piles. Moisture content showed percentage decrease as total solids increased. At the end of the 12 week period, SWM 1:2 showed the highest increase in all the three major plant nutrients (NPK) recommended in a good compost.

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LIST OF ABBREVIATION

MSW	Municipal solid waste
SWM	Solid waste/moringa leaves
SWGC	Solid waste/grass clippings
SWSD	Solid waste/sawdust
CS	Control (only solid waste, moringa, grass clippings and sawdust)
MDGs	Millennium development goals
ANOVA	Analysis of Variance
KNUST	Kwame Nkrumah University of Science and Technology
UNEP	United Nation Environmental Programme
EPA	Environmental protection agency
UDSUEP	Urban Development Sector Unit; East Asia and Pacific
FAO	Food and Agriculture Organization
Ca	Calcium
Mg	Magnesium
pH	Hydrogen ion concentration
N	Nitrogen
C	Carbon
P	Phosphorus
OM	Organic Matter
K	Potassium

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

Everyday thousands of tons of solid wastes are generated as a result of various daily activities. Most of these wastes find their way in the wetlands and open dump sites. The management of solid waste can be traced back to the ancient days where food scraps and other wastes from cities were simply thrown into the unpaved streets and left to accumulate. Around 320 B.C. in Athens, the first known law forbidding this practice was established and a system of waste removal began to evolve in several eastern Mediterranean cities (Kassa, 2008). As the cities grew, Municipal Solid Waste, combined with the even more serious problems of sewage disposal, became a problem (DeLong, 1993). Thus with the unset of industrialization which is characterized by urbanization and population growth, managing of waste became very difficult to control.

Urbanization has seen rapid population growth due to high migration rate from the rural to the urban communities. In most cases especially in developing countries, urbanization growth is unplanned bringing about congestions and demand for proper and healthy municipal services, with increased complexities of waste generation and its associated implications.

In developing countries waste management has become one of the burgeoning concerns facing governments in almost all countries, and this has been possible because of constraints related to economics, technology, education and qualified expertise. It is estimated that in 2006 the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tons, representing a 7% annual increase since 2003 (UNEP, 2009). The World Bank estimates that in developing countries, it is common for municipalities to spend 20-50 percent of their available budget on solid waste management even though 30-60 percent of all the urban solid wastes remain uncollected and less than 50 percent of the population is served. In low-income, mid-income and high-income countries, collection alone drains up 80-90%, 50-80% and less than 10% of municipal solid waste management budget respectively (UNEP, 2009). In urban areas of Asia, 760,000 tons of solid waste is generated annually and it is estimated that by 2025 this will rise to 1.8 million tons. In urban Asia for instance local governments spend about $25 billion annually on urban solid waste management alone (Hoornweg *et al.*, 1999).

Like many other developing countries, solid waste management in Ghana is a tough challenge facing the country. The government spends a lot of resources in trying to manage the country's waste especially in the most populated urbanized areas. According to Boadi and Kuitunen (2003), municipal solid waste management in Accra, is at present delivered in an unsustainable manner. This is due to uncontrolled urbanization and large quantities of daily waste generation, exerting much pressure on an already over stressed solid waste management system. And this is coupled with weak institutional capacity, and lack of resources, both human and capital. The way to a sustainable management is very crucial and requires appropriate policies and technologies as well as commitment on the side of both citizens and the government.

For its cost-effectiveness, biological treatments offer sustainable solution for urban organic wastes. And so in developing countries where technology use is at its barest minimum, composting is found to be very helpful to manage solid waste for reuse because of the high organic content of the generated waste.

Composting is defined as a process that transforms organic waste into a soil-like material called compost (Dickson *et al*., 1991). Apart from methods such as recycling, reduction at source, landfill, and incineration, composting bestows a tactic for coping high volumes of organic wastes in environmentally sound and desirable manners (Ahmed *et al.*, 2007). Not only does composting help in finding safe and economic ways to manage our solid waste but suitably prepared compost provide multiple benefits to our soils. Therefore over the years, a strong motivation for the development of composting systems has arisen as municipalities struggle to find safe and economical ways to handle their organic wastes (Hubbe *et al*., 2010).

Composting two or more materials together (co-composting) may accelerate the composting process, optimise C/N ratio, moisture content and particle size of the materials producing good quality soil amendment and conditioner (Ahmed *et al*., 2007). Therefore during composting, nitrogen and carbon rich materials such as sawdust, grass clipping, leaves etc, may be mixed with organic residues such as solid waste, manure solids, liquid waste and others to improve pile structure and porosity to increase aeration (Adhiraki *et al*., 2009). Hence the co-composting of solid waste with grass clippings, and sawdust and Moringa *Oliefera* leaves.

The study therefore, sought to evaluate the nutrient quality of compost obtained from co-composting organic solid waste with bulking agents (Moringa leaves, sawdust and grass clippings).

1.2 PROBLEM STATEMENT AND JUSTIFICATION

Inadequate solid waste management which was relatively bearable in Kumasi Municipality, especially on Kwame Nkrumah University of Science and Technology campus and its environs some years ago, has now become almost impossible to manage, especially with the growing student population and springing up of numerous hostel and accommodation buildings, eating places and other infrastructures. The proliferations of these eating places to satisfy the ever increasing population growth generate more waste than has been sustainably planned for. The content of the waste generated are mainly organic which can be composted for reuse. This waste when treated through composting can be used as soil amendments and plant nutrients supplement rather than being left to occupy space at refuse dumps or disposed off indiscriminately. Therefore composting which has been found as most safe and economical means of managing organic waste becomes appropriate for managing these wastes on the campus.

Moringa *Oleifera* popularly known as moringa in Ghana is a leafy vegetable tree which is grown basically in backyards as fence or hedges. Moringa in the world now is considered one of the most useful trees ever known, since almost every part of the tree has some beneficial property. It is an exceptionally nutritious vegetable tree with a variety of potential uses (Emmanuel *et al*., 2011). In Emmanuel *et al.* (2011), FAO studies on Moringa in 2010 revealed that Organic fertilizers derived from Moringa *Oliefera* seed processed with the right procedure can increase the soil aeration and richness of indigenous invertebrates, specialized endangered soil species, beneficial arthropods, earthworms, symbionts and microbes. Moringa with its high nutritional value is therefore co-composted along with sawdust and grass clippings with solid waste to produce organic fertilizer rich in soil nutrient for plant growth.

1.3 GENERAL OBJECTIVES

The main objective of the project was to determine the quality of compost from co-composting solid waste with moringa leaves, sawdust and grass clippings.

1.3.1 SPECIFIC OBJECTIVES

- To prepare compost piles using different mixing ratios of organic solid waste and moringa leaves, sawdust and grass clippings.
- To monitor composting process by measuring some specific physico-chemical parameters such as nitrogen, phosphorous, potassium, organic matter, total solids.
- To determine compost quality at the end of the process.

CHAPTER TWO

2.1 LITERATURE REVIEW

2.2 SOLID WASTE MANAGEMENT

In almost every second of our lives we generate waste in different forms. The general rise in population growth and economic development in urban areas due to urbanization over the years has compounded the plight of local governments in the management of these wastes produced.

It is estimated that, in 2006 the total amount of municipal solid waste (MSW) generated globally reached 2.02 billion tons, representing 7% of annual increase since 2003 (UNEP, 2009). In urban areas of Asia for instance, 760,000 tons of solid waste is generated annually and it is estimated to rise to 1.8 million tons by 2025 (Hoornweg *et al.*, 1999). In 2003 EPA reported that more than 208 million metric tons of municipal solid waste (MSW) was generated in 2000 in the U.S. and more than 40 billion dollars was spent on its management alone (Thorneloe *et al.*, 2005). Currently it is estimated that Ghana has an average daily waste generated per capital of 0.45 kg, equating to 3.0 million tons of solid waste annually (ICE Forum, 2011). A bigger portion of the government's budget for the day is basically invested in waste management all over the world. The World Bank estimates that, it is common for municipalities to spend 20%-50% of their available budget on solid waste management in developing countries, even though 30%-60% of all the urban solid wastes remain uncollected and less than 50% of the population is served. In the low, mid and high-income countries, collection alone drains up 80%-90%, 50%-80% and less than 10% of municipal solid waste management budget respectively (UNEP, 2009). In urban Asia for instance, the local governments spend about $25 billion annually on urban solid waste management (Hoornweg *et al.*, 1999). Ghana currently faces several environmental challenges especially with solid waste management. Solid waste management presents a challenge to many District Administrations across the country. The waste management problem is most deplorable in urban communities, which struggle with ever increasing populations due to urban-rural migration (The Chronicle, 2013).

The desire to control waste problems in our world sprouted up various environmental treaties and declarations such as the 1992 Rio Earth Summit, The Rio Declaration and Agenda 21, the recent 2000 Millennium Development Goals (MDGs) and many more (Khatib, 2011) to devise solutions to the ever rising waste management problems. In spite of these policies, environmental problems still persist especially in developing countries where technology is but very minimal.

2.3 SOLID WASTE MANAGEMENT AND ALTERNATIVE OPTIONS

Solid waste can be defined as any material which comes from domestic, commercial, and industrial sources arising from human activities which has no value to people who possess it and is discarded as useless (Akinwonmi *et al.*, 2012). Solid waste may consist of many materials that are combustible (debris, solid waste, wood, textiles etc) and non-combustibles (glass, leather, aluminium etc). Knowledge of the various characteristics of solid waste is important in evaluating alternative equipment needs, systems, management programs, plans and policies especially with respect to the implementation of disposal, resource and energy recovery options. The task of solid waste management however presents enormous complex technical challenges to managers all over the world.

Means of solid waste disposal and management may differ from developed and developing countries due to different lifestyles. For developing countries, due to poverty and paucity of environmental regulations and enforcement, waste disposal in many countries is still predominantly by open dumping, often with associated open burning (Cointreau, 2006). Accra and Kumasi, with a combined population of about 4 million and a floating population of 2.5 million generate over 3,000 tons of solid waste daily of which only 10% are properly disposed off mainly through landfill sites but options are rapidly depleting (ICE FORUM, 2011).

“The Waste Hierarchy” entails anticipated set options of desirable descending order of sustainable waste management technologies (DeLong, 1993). The structure includes; source reduction, recycling and recovery, composting, incineration, thermal destruction and sanitary landfill.

2.3.1 SOURCE REDUCTION

Reducing waste generation at the source can be said to be the best way of controlling waste. Waste can be reduced by using bulk items instead of packaged, which would mean eliminating excess packaging, avoiding certain products, or using products made of recycled or recyclable materials (DeLong, 1993). Source reduction has many environmental benefits such as prevention of emissions of many greenhouse gases, pollutants reduction, energy savings, resources conservations and reduction of need for new landfills and combustors (Akinwonmi *et al.*, 2012).

2.3.2 RECYCLING AND RECOVERY

Over the years, recycling has gained increasing attention as a means for managing waste. Recycling protect the environment by offering one of the most sensible solutions both economically and ecologically. Items such as glass bottles, aluminum cans, newspapers, and the many other recyclable materials do not take up space in landfills (DeLong, 1993). Recycling of waste results in saving natural resources, energy; reducing disposal costs; reducing harmful emissions to air and water; saving money and creating jobs. Yet many people do not recycle but always use new material. Over the years recycling has not been part of the life of the many Ghanaian populace despite all the benefits (Asuamah *et al.*, 2011).

2.3.3 COMPOSTING

This is the process where organic matter is transformed into soil-enriching humus (DeLong, 1993). It is found among the various methods as the most biological means of managing waste with little or no environmental effect. Composting is further detailed later in this review.

2.3.4 INCINERATION

Incineration is an efficient way to reduce the waste volume and demand for landfill space. Some types of waste, particularly paper and plastic, have energy value that can be recaptured through combustion (DeLong, 1993). Municipal solid waste (MSW) incineration plants however tend to be among the most expensive solid waste management options, and they require highly skilled personnel and careful maintenance. For these reasons, incineration tends to be a good choice only when other, simpler, and less expensive choices are not available (Haukohl *et al*., 1999).

2.3.5 THERMAL DESTRUCTION OF WASTE

This process is appropriate when a waste, albeit flammable, does not itself generate recoverable energy and requires additional fuel, or when high temperatures are needed to destroy toxic components (DeLong, 1993).

2.3.6 SANITARY LANDFILL

Sanitary landfill as the final disposal site for solid waste is given the least priority in an Integrated Waste Management approach (Akinwonmi *et al*., 2012). Even in a properly situated, constructed, and maintained disposal site, landfilling is at the bottom of the Waste Hierarchy (DeLong, 1993). Apart from the various health implications and emanating odors, landfills occupy large areas for operation; require huge capital investment and expertise for its engineering and maintenance. Over the years however, sanitary landfills still remain the recommended choice for solid waste management for metropolitan and municipal areas because of its capacity to contain large volumes of the generated waste (Mensah and Larbi, 2005).

2.3 THE COMPOSTING PROCESS

Among the various waste management methods comes along an effective way of transforming organic waste into a useful soil amendment known as compost. Compost is considered to be the most environmentally friendly, agronomically advantageous, and a relatively cheap organic amendment which stimulates soil microbial activity and crop growth (Ros *et al.*, 2006). Composting can be defined as a biological decomposition process where organic materials are transformed into a soil-like material called compost (Dickson *et al.,* 1991*).* In simple term Hasanimehr *et al.* (2011), also defined composting as an environmentally friendly technology to treat and recycle organic wastes.

The composting process involves a diverse population of predominantly aerobic micro-organisms that decompose organic materials in order to grow and reproduce (Graves and Hattemer, 2000). The composting process is controlled by several natural factors and environmental conditions such as right organisms, moisture, aerobic conditions, feed material and nutrients for microbial growth. The process occurs naturally provided these factors are available in the right quantities and condition. Effective controlling of these factors enhances the composting process and causes it to occur at a much faster rate. However the availability of the above materials do not ensure efficient composting process, since the process can also be affected by other conditions such as pH, and substrate characteristics such as C/N ratios, particles size, and nutrient contents.

The composting process creates stable, soil-enriching humus and concentrates of Nitrogen (N), Phosphorous (P), Potassium (K), Calcium (Ca) and Magnesium (Mg) contents (Balasundaran, 2009). Compost in any form provided it is devoid of all pathogens is a reliable source of organic matter to enrich and amend cultivated soils. A study by Ros *et al*. (2006), on the long-term effect of applying different composts on soil showed increased levels of organic carbon and total nitrogen content in soils.

At the end of a composting process, a finished compost is expected to be odorless, fine-textured, with low-moisture and it can be bagged and sold for use in gardens, or nurseries or used as fertilizer on croplands (Eghball, 1997). The compost quality mostly depends on the waste being composted. The presence of high nitrogen, phosphorus, and potassium contents in the organic waste facilitates production of high-quality manure after composting. A properly managed composting process produces compost that is high in nitrogen, phosphorus, and potassium content. Also it increases the rate of natural decomposition and generates sufficient heat to destroy weed seeds, pathogens, and fly larvae (Graves and Hattemer., 2000).

2.4 THE COMPOSTING MOTIVATION

Recent adoption of composting by many countries around the world has been realized due to the growing realization that land dumping or incineration is not offering real solution to the perpetual increasing problems of solid waste quantities accompanied by decreasing land availability for waste disposal, as compared to composting which provides a sustainable rich soil amendment facility for agronomy. Composting has gained interest as a suitable option for treatment of waste with economic and environmental profits, although it cannot be considered a new technology among other waste management strategies (Abd-El-Kader *et al.*, 2012).

In developing countries where technology use is at its barest minimum, biological treatments offer sustainable solution for urban organic wastes. In practice, it is the main biological process applied for solid waste. And even though there are many technologies of managing solid waste, composting offers the most environmentally friendly, cost effective and efficient means. Suitably prepared compost provides multiple benefits to our soils. According to Mitchell, (2001), composting redirects organic waste from landfills and transforms the waste into a product useful in landscaping, gardening, maintaining the structure and fertility of agricultural land, slope stabilization, and even brownfield remediation. Hence over the years strong motivation for the development of composting systems has arisen as municipalities struggle to find safe and economical ways to handle their organic wastes (Hubbe *et al*., 2010).

2.5 PRINCIPLES OF COMPOSTING

The composting process is carried out by a diverse population of predominantly aerobic micro-organisms who decompose organic material in order to grow and reproduce. Their activity is encouraged through management of the carbon to nitrogen (C/N) ratio, oxygen supply, moisture content, temperature, and pH of the compost pile (Graves and Hattemer, 2000).

The two principal composting methods can be classified as aerobic and anaerobic decomposition.

2.5.1 AEROBIC DECOMPOSITION

Aerobic composting process involves a biological decomposition and stabilization of organic substrates under conditions that allow reproduction and activity of thermophilic microorganisms as a result of biologically produced heat, to produce a final product that is stable, free of pathogens, pests and plant seeds, useful in agriculture and forestry as manure (Balasundaran, 2009). Under aerobic composting, decomposition occurs with adequate supply of oxygen. The process starts with the formation of the compost pile. Mesophilic organism firstly multiply rapidly on the readily available sugars and amino acids and generate heat by their own metabolism and raise the temperature to a point where their own activities become suppressed (optimum growth temperature range = 20-45 °C). Several thermophilic fungi and bacteria (optimum growth temperature range = 50-70 °C) continue the process, raising the temperature of the material to 65 °C or higher. The peak heating phase is important for the compost quality as it kills pathogens and weed seeds. The pile temperature gradually decreases to an ambient temperature allowing the mesophilic microbes to dominate the process again. A curing process immediately follows the active composting stage. The start of the curing phase is identified when turning no longer reheats the pile. Curing of the compost provides a safety net against the risks of using immature compost.

By the time aerobic composting is completed, the pile becomes more uniform and less active biologically although mesophilic organisms recolonize the compost. The material becomes dark brown to black in colour. The particles reduce in size and become consistent and soil-like in texture. In the process, the amount of humus increases, the ratio of carbon to nitrogen (C/N) decreases, pH neutralizes, and the exchange capacity of the material increases. Aerobic composting is the most efficient form of decomposition and produces finished compost in the shortest time (Cooperband, 2000).

2.5.2 ANAEROBIC COMPOSTING

In anaerobic composting, organic materials are filled in pits and allowed to remain for several months without allowing fresh air into the organic matter. Anaerobic composting is characterized by the production of foul smelling gases and the process proceeds at a slower rate by the action of anaerobic microorganisms (Balasundaran, 2009).

In anaerobic composting, decomposition occurs with little or no oxygen supply. Anaerobic micro-organisms dominate and develop intermediate compounds including methane, organic acids, hydrogen sulphide and other substances. Anaerobic composting is a low-temperature process; it therefore leaves weed seeds and pathogens intact. Nutrient loss is minimal and requires relatively little work compared to aerobic decomposition. Anaerobic composting usually takes longer than aerobic composting.

In nature anaerobic process takes place in the decomposition of the organic muds at the bottom of marshes and in buried organic material to which oxygen does not have access. The marsh gas which rises is largely CH_4 (Kriengkasem, 2002).

Due to the bulkiness and heterogeneity of composting materials, there always exists ‘anaerobic’ conditions, which are little in ‘aerobic’ composting but abundant in ‘anaerobic’ composting; and vice-versa (Kriengkasem, 2002).

However, between the two decomposition processes, aerobic composting is more advantageous than anaerobic composting because of its high microbial activity resulting in rapid decomposition and the absence of foul smelling gases (Balasundaran, 2009).

2.6 TYPES OF COMPOSTING

Vermicomposting - It is the biological degradation and stabilization of organic waste by earthworms and microorganisms to form a compost. It has been recognized that the work of earthworms is of tremendous agricultural importance. And so vermicomposting forms an essential part in organic farming today. Earthworms along with other micro-organisms play an important role in regulating soil processes, maintaining soil fertility and in bringing about nutrient cycling (Ansari, 2009).

Windrows - This method involves placing a mixture of organic waste materials into long, narrow piles approximately six feet high by twelve feet wide and as long as is necessary. The compost process is accelerated by frequent turning of the windrow with a front-end loader or custom designed machinery built for this purpose. Turning fluffs the pile and increases porosity of the mixture, which helps to improve the introduction of ambient air into the windrow (Ahmed, 2007).

***Passive composting piles* -** The passive composting pile method involves forming the mix of raw material into a pile. This method is often used to compost leaves. Porosity in the pile is periodically rebuilt by turning. Aeration is accomplished through the passive movement of air through the pile. This requires that the pile be small enough to allow for passive air movement, too large piles may form anaerobic zones. Special attention is required during the mixing of raw material to maintain the necessary porosity and structure for adequate aeration throughout the entire composting period. The passive composting method requires minimal labor and equipment. Because aeration is passive, this method is slow and thus has potential for development of anaerobic conditions as well as odor problems (Graves and Hattemer, 2000).

In-Vessel Composting - It involves confining the compost process to a variety of containers or vessels. Different in-vessel systems use a variety of methods to accelerate the composting process. These systems usually include provisions for aeration, mixing, temperature control, and containment of odors. In-vessel systems generally are the most costly of the technologies because of its high construction costs. Most of these are proprietary systems that also require greater operation and maintenance expenses and a higher skill level to operate (Ahmed, 2007).

Examples of this method include;

- ***Bin composting***

Bin composting uses either constructed wooden bins, unused storage bins, or other appropriate vessels either with or without a roof to compost. The material in non-aerated bins must be turned regularly to maintain aerobic composting (Graves and Hattemer, 2000).

- ***Rectangular agitated bed***

The rectangular agitated bed method uses long, narrow beds to compost with an automated turner for periodic turning. The turner is supported on rails that are mounted on either side of the bed for its whole length. As the turner moves along the bed, the compost is turned and moved a set distance until it is ejected at the end of the bed. In some systems blowers are also used to force air into the beds (Graves and Hattemer, 2000). The duration of this composting process is determined by the length of the bed and the turning frequency. Generally an extended curing period is required.

- ***Silo composting***

The silo method is a rapid composting method that requires a prolonged curing stage. Compost material is loaded into the silo at the top and removed from the bottom using an auger. Aeration is provided through the base of the silo so that air is forced upward through the compost material. Outlet air can be collected from the top and directed to an odor treatment system, such as a biofilter (Graves and Hattemer, 2000).

- ***Rotating tube***

The rotating tube is a method that can be used where small amounts of waste require composting. The compost mix is loaded in the upper part of the tube. The mix rests on the first baffle plate. When the tube has filled from the first baffle plate to the top of the tube, it is rotated to aerate the compost mix and empty the tube above the first baffle plate. This allows additional compost mix to be loaded in the tube (Graves and Hattemer, 2000).

Aerated Static Pile - This system involves supply of ambient air through mechanic means and requires no turning of the organic mixture once the pile is formed. By controlling air mechanically, this process allows the use of larger piles. For composting under this method, an air plenum is constructed and the organic mixture is placed in piles on top of the air plenum. Piles are built as high as the equipment allows, normally it is kept eight to twelve feet high. Aerated static piles can be constructed individually or in extended piles.

Individual piles, constructed all at once, allow the composting to occur in batches. Extended piles consist of a series of cells created over the course of many days and stacked against each other to form one long rectangular pile. A temperature sensor placed within the pile works in conjunction with the blower to control temperature and oxygen concentration (Ahmed, 2007). The technology is commonly used for treatment of municipal sewage sludge. Active composting period may range between three to five weeks (Misra and Roy, 2003).

Turned Windrows - This composting method has been in use with the large farms especially in the developed parts of the world. The windrows are periodically turned using a bucket loader or special turning machine, commonly available on the farms. The turning operation mixes the composting materials, enhances passive aeration and provides conditions congenial for aerobic decomposition. Composting operations may take up to eight weeks (Misra and Roy, 2003).

Passively Aerated Windrows - This composting method eliminates the need for turning by providing air to the materials via pipes, which serve as air ducts. Thus aeration is accomplished solely through the passive movement of air through perforated pipes embedded in the base layer of the pile. Initial construction of this type of windrow requires more labor than other windrow methods. However once the windrow is formed the labor requirement is primarily that necessary to monitor the temperature and porosity of the pile. This method requires not too high piles as with the other windrow method (Graves and Hattemer, 2000). Active composting period could range between ten to twelve weeks (Misra and Roy, 2003).

All these technologies are designed to accelerate the decomposition process of organic materials. However the management levels of these processes have the potential of either speeding up or slowing down the decomposition process, ultimately influencing the quality and cost of the product (Ahmed, 2007).

2.7 CONDITIONS FOR AEROBIC COMPOSTING

A sure way of enhancing degradation in the compost pile is to provide favourable conditions for microorganism in the pile. During decomposition, the most important process variables that must be considered include moisture content, temperature and total oxygen requirement (Cooperband, 2000). This is because the composting process is mediated by microbial activity and all physical and chemical environment impacts inside the compost pile affecting the activities which include temperature, aeration, moisture content, C/N ratio and pH (Balasundaran, 2009).

2.7.1 TEMPERATURE

Temperature has been a key important parameter used in determining the success of a composting process as it is directly proportional to the biological activity within the composting system. It is the most common indicator of progress in composting process (Eghball, 1997). The composting process occur basically in three different phases which can be conventionally defined in terms of the kinds of micro-organism population that thrive in different temperature ranges, i.e. psychrophilic (optimum at 13ºC), mesophilic (at 21-48ºC), and thermophilic (at 45-68ºC) (Hubbe *et al.*, 2010). The initial stage of composting is marked by either psychrophilic or mesophilic temperatures depending on the ambient temperature and the temperatures of the compost mix materials (Graves and Hattemer, 2000). Mesophilic bacteria consume the most readily decomposable carbohydrates and proteins right at the start of the composting process (Maynard, 2000). The mesophilic phase is succeeded by the thermophilic phase, where heat loving bacteria dominate the compost and initially decompose proteins and non-cellulose carbohydrates and eventually attack the lipid and hemicellulose fractions if any in the compost (Maynard, 2000). The thermophilic phase is an indicator of vigorous microbial activities since thermophilic bacteria use up too much of the degradable materials to sustain their population for any length of time during the composting process (Smith and Friend, 2013). It also destroys pathogens and eliminates weed seeds and all other unwanted materials. A study of composting municipal solid waste, in Kuo *et al*. (2013), observed that high temperature during thermophilic degradation phase caused a marked change in bacterial community. *E.coli* and faecal *Streptococci*, as well as yeasts and filamentous fungi, populations decreased sharply. As the thermophilic bacteria decline and the temperature of the pile gradually cools off, the mesophilic bacteria again dominate the composting process into the curing phase. The mesophilic bacteria consume all other remaining organic material with the help of other organisms to ensure further decomposition of the product of the thermophilic phase (Graves and Hattemer, 2000).

Defining the temperature ranges does not mean micro-organisms found in one phase during the composting process are not found in the other. Rather, these ranges are defined to make a rough delineation between temperatures at which certain classes of micro-organisms have peak growth rates and efficiencies (Graves and Hattemer, 2000).

Heat generation occurs in the pile when microbial population begins to degrade the most readily degradable materials and increase, the heat produced by these activities are trapped by the self-insulating compost material. As the heat within the pile accumulates, the temperature of the compost continuously begins to rise steadily through the phases as microbial population increases and diversifies (Graves and Hattemer, 2000). Unless a pile is constantly fed with new materials and turned at strategic times, the high range temperatures typically last no more than three to five days. Turnings and aeration can be used to regulate temperature. The drop in compost pile temperature is not a sign that composting is complete, but rather an indication that the compost pile is entering into another phase of the composting process (Smith and Friend, 2013). High temperatures vaporize ammonia, produced when the C/N ratio is low. However any small nitrogen loss due to high temperature is outweighed by the advantages of destroying pathogenic organisms and weed seeds, controlling flies, and providing better decomposition of the compost (Lineberger, 2009).

Cooperband, (2000), indicated that, as the active composting phase subsides, temperature gradually declines to around 38°C where mesophilic organisms recolonize the pile, and the "curing" phase begins. During the curing phase, rate of oxygen consumption declines to where compost can be stockpiled without turning. At this phase organic materials however continue to decompose and are converted to biologically stable humic substances or mature finished compost.

Depending on the ambient temperature, a complete composting process may take two to six months (Eghball, 1997). Temperature should be frequently monitored using a thermometer and adjusted as needed throughout the composting process (Chen *et al.*, 2011).

2.7.2 AERATION

Micro- organisms in a compost require oxygen to produce energy, grow quickly and consume more materials to enhance degradation. A study by Hubbe *et al.* (2010), revealed that increased aeration favoured the action of white-rot fungi in the degradation of lignocellulosic waste. Aerobic composting as compared to anaerobic composting requires large amounts of oxygen, particularly at the initial stage. Aeration is the source of oxygen, and, thus, indispensable for aerobic composting. Aeration in composting removes excessive heat, water vapor and other gases trapped in the pile (Smith and Friend, 2013).Where the supply of oxygen is insufficient, the growth of micro-organisms is limited, resulting in slower decomposition rate. Without sufficient oxygen, the composting process will become anaerobic and produce undesirable odors. In a compost pile, while oxygen concentrations of more than 10% are considered optimal, aerobic microbes can survive at oxygen concentration as low as 5% (Chen *et al.*, 2011).

Compost turning is critical for a rapid degradation and high quality compost particularly for solid waste composting (Kuo *et al.*, 2013). Studies by Hubbe *et al.*, (2010), showed that turning overcomes charring, drying, caking, and air channeling. However the frequency of turning may also pose an issue; since every turning result in at least a temporary reduction in temperature of the compost. Some researchers recommend turning frequency of once or twice a week, while others recommend once a week with suggestion that more frequent turning may not be a good investment of time and energy. Hubbe *et al.* (2010), discovered that turning a mixture of swine manure and sawdust every two or four days yielded faster composting, compared to weekly turning. It was also observed that turning increased decomposition rate, but did not greatly change the end results of composting of cattle slurry. The same study showed conclusively that covering of a compost pile with polyethylene adversely affected the process.

Some basic factors such as porosity, moisture and wind can affect aeration of compost. Controlling the pile size, the physical quality of the composting materials such as particle size and moisture content, and also by ensuring adequate frequency of turning enhance the aeration process of compost (Smith and Friend, 2013).

2.7.3 MOISTURE

Moisture is necessary to support the metabolic activity of the micro-organisms in compost. Microbial activity occurs most rapidly in thin water films on the surface of organic materials (Smith and Friend, 2013). Proper moisture encourages the growth of microorganisms that break down organic matter into humus (McLaurin and Wade, 2012). The recommended optimum moisture for efficient composting is given between 40 % and 60 % by weight (Troy *et al.*, 2012). Most literature also recommends a moisture content of 50%-60% by weight for optimal composting conditions (Trautmann and Richard, 1996). However the ideal moisture content of a compost pile varies with pile materials (Chen *et al.*, 2011). Where the pile is too dry, micro- organisms become dormant and composting occurs more slowly, while moisture content in excess of 65 percent may suffocate decomposers, developing anaerobic condition which may produce unpleasant odors. Chen *et al*. (2011), also indicates that too low of a moisture content deprives microbes of water needed for their metabolism and inhibit their activities, resulting in slower composting. However too high of moisture content fill pore spaces with water rather than air, leading to anaerobic conditions. According to Kuo *et al.* (2013), anaerobic conditions occur because increasing water content, result in decreasing O_2 diffusion rate. And as O_2 becomes insufficient to meet the metabolic demand, the composting process slows down and decrease decomposition rate.

A moisture level of 40 to 60% by weight is recommended to be maintained throughout the composting period and finishing about 30% (Kuo *et al.*, 2013). At a minimum content of 12% to 15% moisture, bacterial activity is believed to take place but not efficient. Kuo *et al.* (2013) indicated that microbial activity is severely restricted at 15% moisture level. However, ideal moisture percentage of a compost may vary depending on the organic material's structure. Materials with different moisture contents can be blended to achieve an ideal moisture content (Chen *et al., 2011*). Carbon-rich materials like sawdust and straw may require more moisture than leaves, while solid waste or grass clippings (nitrogen-rich materials) are likely to need little additional moisture. Moisture plays a very significant role in regulating pile temperature. Drier piles tend to heat up and cool down more rapidly than wetter pile (Chen *et al*., 2011). Hence an adequate moisture level is expected to be maintained for microbial growth through the composting process (Mitchell, 2001). Moisture content generally decreases as composting proceeds; therefore, additional water is recommended as when necessary (Pace *et al.*, 1995).

A general rule of thumb is to wet or the squeeze method may be used to measure moisture. Material should feel damp to the touch, with just a drop or two of liquid expelled when squeezed in hand. Carbon- rich material may be added dry to very wet compost to reduce moisture (Smith and Friend, 2013).

2.7.4 pH VALUE

The pH value of a compost pile gives the measure of the acidity or alkalinity of the compost. A pH of 7.0 is neutral in reaction; pH less than 7.0 designates an acidic condition, while a greater value than 7.0 is an alkaline condition. Studies have recommended initial pH values of compost to range from 4.2 to 7.2 or 7.0 to 7.5, (Chen *et al.,* 2011). However according to Ahmed *et al. (*2007), there is no specific pH required for composting, as different organic materials suitable for composting have a range of pH from 5.0 to 12.0.

Various metabolic composting activities affect pH levels of the compost. An extreme pH level where pH is highly acidic or highly alkaline creates unfavorable conditions for microbial growth, inhibiting their activities thereby slowing down decomposition. When a pH value exceeds 7.5, gaseous losses of ammonia are more likely to occur because nitrogen gets converted to NH_3, resulting in nitrogen loss from the compost (Hubbe *et al.*, 2010). The formation of ammonia, not only reduce nitrogen reserve but also slows the process (Graves and Hattemer., 2000). However a study conducted by Li *et al.,* (2013), using organic household waste (consisting mainly solid waste and other kitchen waste) for composting experiment observed that, the process had the highest degradation rate when the pH level was at the range of 6 to 8. Expected pH levels in a finished compost is recommended at 6.5 to 7.5 and between 7.5 and 8.0 in (Chen *et al,* 2011, Graves and Hattemer., 2000) respectively. However Chazirakis *et al.* (2011) had pH values between 7.5 and 8.2 for finished compost in his study.

Initial pH level of a compost is expected to drop after few days into composting. According to Graves and Hattemer. (2000), pH levels drop to 4 - 5 during the first few days of active composting period because of organic acid formation in anaerobic zones or accumulation of organic acid intermediates resulting from abundance of carbonaceous substrate. This drop is a reflection of the synthesis of organic acids which serve as substrates for succeeding microbial population. Later in the thermophilic phase, pH can rise to 9 promoting release of ammonia and usually returning back to near-neutral condition as compost matures (Hubbe *et al*., 2010). However a study by Chazirakis *et al.* (2011), had a different opinion with his study. The study observed no drop in pH levels during first few days but rather slight increase. Explanation was that, the first weeks of intense microbial activity and organic matter degradation led to formation of ammonium and hence an increase in pH. At the end of the study pH recorded values between 7.5 and 8.2 in all piles. Another research in the study however advocated use of well controlled amounts of green liquor dregs to minimize pH drop often observed at onset of composting (Hubbe *et al.*, 2010).

The pH levels of a compost vary throughout the pile and during the composting process. This is because there is variation in pH levels of raw materials used for a compost mix. However these variations do not impact significantly on the composting process because different micro-organisms thrive at different pH levels of the compost. Although various studies have given ideal range for microbial activity between 6.5 and 8.0, Graves and Hattemer. (2000), intimate that composting is possible at the extremes of 5.0 and 9.0, though at a slower decomposition rate. In cases where materials to be composted is very acidic, small amount of lime or fly-ash (Hubbe *et al.,* 2010) may be added to the compost. Caution is however required since excessively alkaline conditions can promote release of ammonia gas. Acidic material such as aluminum sulfate can be added to compost of high pH level of 8.5 to 9.0 to counter ammonia gas formation (Hubbe *et al*., 2010). Composts with very low pH (<4.0) should be used with caution since the low pH can be an indication of poor composting practices which result in the formation of potentially toxic organic acids (Darlington, 2001). Benito *et al.* (2005) in their study obtained higher pH value for pruning waste compost as compared to the other treatments. It was suggested that taking into account the high pH value of the compost was to be mixed with other materials when to be used with plants sensitive to alkaline conditions. Controlling pH levels within an optimal range is very difficult and generally not attempted (Chen *et al*., 2011).

It should be noted however that, pH varies and this variation affects composting performance (Li *et al*., 2013).

2.7.5 THE NUTRIENT FACTOR

Micro-organisms in a compost feed on the organic substrate to produce heat and energy for their metabolism. The micro-organisms use carbon for energy and protein to grow and reproduce. Carbon-rich materials tend to be dry and brown such as leaves, straw, sawdust and wood chips, etc whilst nitrogen-rich materials tend to be wet and green such as fresh grass clippings and solid waste (Smith and Friend, 2013). Fruit and vegetable wastes are easily degraded because they contain mostly simple carbohydrates (sugar and starches). In contrast, leaves, stems, nutshells, bark, and trees decompose more slowly because they contain cellulose, hemicelluloses, and lignin (Chen *et al.*, 2011). Of the many elements required for microbial decomposition, carbon and nitrogen are the most critical, their presence play a major role in the composting process. (Chen *et al*, 2011).

CARBON NITROGEN RATIO

Important nutrients are contained in compost which are grouped into macro-nutrients such as nitrogen, phosphorus, potassium, calcium and micro-nutrients such as manganese, iron, zinc, copper (Watson, 2002). All organic matter is made up of substantial amounts of carbon combined with lesser amounts of nitrogen. A very good balance of carbon and nitrogen in a system makes up the C/N ratio. Micro-organisms with the correct supply of carbon and nitrogen proportion, obtain energy and protein for growth and production for optimal performance. Micro-organisms require carbon (C), nitrogen (N), phosphorus (P) and potassium (K) as their primary nutrients for survival (Hubbe *et al.*, 2010).

Recommended optimal C/N ratio of raw materials is between 25:1 and 30:1 although ratios between 20:1 and 40:1 are also acceptable. Where C/N ratio is higher than 40:1, the growth of micro-organisms is limited; heat production is also reduced resulting in a longer composting time and slower composting process. On the other hand, a C/N ratio of less than 20:1 may lead to underutilization of nitrogen, where excess nitrogen may be lost to the atmosphere as ammonia or nitrous oxide, and also create odour problems. This is corroborated in (Smith and Friend, 2013), that pile with high carbon content such as leaves, sawdust or wood chips may sit for a year or more without much apparent decay. While excessive nitrogen in piles is also likely to cause release of excess nitrogen as smelly ammonia gas and also cause a rise in the pH level which is toxic to some micro-organisms. However, research studies by Li *et al*. (2013), revealed that sound composting reactions can also be expected when the C/N ratios are also lower than 25:1. It must be noted that many ingredients used for composting do not have the ideal ratio of 25-30:1. As a result, most must be mixed to create the perfect compost recipe .

Given the wide range of density, particle size, and lignin content of different lignocellulosic materials, attaining the above ratio range may be difficult to define in general (Hubbe *et al*., 2010). Richard and Trautmann (1996), indicated that, although the usual recommended range for C/N ratios at the start of a composting process should be about 30:1, depending on the bioavailability of the carbon and nitrogen, this recommendation may vary.

Nitrogen-rich materials are basically found in green and wet materials such as grass clippings, solid waste, green leaves whereas dried and brown materials like sawdust, wood straw etc, are known to be carbon-rich materials. The nitrogen content of composts varies according to the source material and how it is composted (Mangan *et al.,* 2013). Generally nitrogen-rich materials undergo rapid decomposition due to its low lignin content.

Nitrogen is usually lost to the atmosphere as ammonia when decomposing organisms do not have the proper diet of carbon (McLaurin and Wade, 2012). A finished compost has little ammonium, as it is oxidized to nitrate during composting and curing, and any nitrate that is produced could be leached or lost to the air, or consumed by the organisms performing the composting. High pH values (8.5 or higher) often result in nitrogen loss from the compost thereby reducing nitrogen reserve of the compost and may even cause odor problem (Hubbe *et al.*, 2010). A total nitrogen level between 0.75% and 2.5% is normal for a finished compost (Mangan et al., 2013) Bueno *et al.* (2008) in Hubbe *et al.* (2010) also defined "acceptable chemical properties" as a Kjeldahl nitrogen content of at least 3.2%.

The loss of nitrogen as ammonium gas during composting process and also its soil fixation issues still remains key issue of concern. However researches so far have shown that, conditions to avoid such loss can include use of a long composting time, low particle size, medium moisture content and medium to low aeration level (Hubbe *et al.*, 2010). However the Kjeldahl-N content evolution in a study was found to be much more sensitive to changes in aeration and time than in the other independent variables. The study also advised that the use of high aeration level, low particle size and longtime composting periods are necessary for producing composts with high nitrogen content (>3%) (Bueno *et al.*, 2008).

It is expected that as composting proceeds to maturity, the C/N ratio gradually decreases from around 30:1 to 10-15:1 for a finished compost. According to Chen *et al.* (2011), this occurs because each time organic compounds are consumed by micro-organisms, two-thirds of the carbon is converted and given off as CO_2. The remaining third is incorporated along with nitrogen into microbial cells and then later released for further use once those cells die. According to Hubbe *et al*. (2010), the fall of C/N ratio during composting and in its final value can even be used as one criterion of relative maturity of the product. However Chazirakis *et al.* (2011) indicated that it is necessary that caution is taken before using C/N ratio as criteria of relative maturity since not all carbon is available for microbial use.

Table 2.1 Estimated C/N ratio for some materials

High carbon materials-browns	High nitrogen materials-greens	C/N Ratio for Browns	C/N Ratio for Greens
Ashes, wood	Alfalfa	25:1	12:1
Cardboard, shredded	Clover	350:1	23:1
Corn stalks	Coffee grounds	75:1	20:1
Fruit waste	Solid waste	35:1	20:1
Leaves	Garden waste	60:1	30:1
Newspaper, shredded	Grass clippings	175:1	20:1
Peanut shells	Hay	35:1	25:1
Pine needles	Manures	80:1	15:1
Sawdust	Seaweed	325:1	19:1
Straw	Vegetable scraps	75:1	25:1
Wood chips	Weeds	400:1	30:1

Source: Composting 101, 2006

2.7.6 COMPOST VOLUME

The volume of a compost is a factor in retaining heat in a pile, it is therefore an important factor to consider during composting (Smith and Friend, 2013). Too large piles create anaerobic zones near its center, which slows the composting process. On the other hand, smaller piles tend to lose heat quickly and may not achieve a temperature high enough to evaporate moisture and kill pathogens. In both cases decomposition rate is generally decreased. When considering optimal size for compost piles or windrows, parameters such as the physical property (porosity) of the materials and ways of forming piles should be considered. Climate may also be an important factor when considering pile volume.

2.7.7 LIGNIN CONTENT

Lignin forms one of the main constituents of plant cell walls, and its complex chemical structure makes it highly resistant to microbial degradation. Because lignin is the most difficult component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate (Richard, 1996).

2.7.8 PARTICLE SIZE

The particle size of organic wastes for composting is important for microbial activity and aeration in the compost pile. Most materials that make up the organic fraction of solid waste have irregular shapes and sizes. Smaller particles have more surface area per unit volume; therefore, microbes have greater access to their substrate. However, if particles are also too small, airflow and oxygen availability within the compost pile will be restricted, resulting in anaerobic conditions (Cooperband, 2000). In Hubbe *et al*. (2010), research recommend particles between about 2.5 and 7.2 cm in size. However various researches showed best results obtained when materials were cut to about 1 cm, another also could discern effects on biodegradability attributable to chemical differences, another also observed reduced resistance to biodegradation when materials were grinded.

In Kriengkasem (2002), a study on composting with water hyacinth revealed that, the increase in the reaction rate of degradation depends on the size of the water hyacinth. The finely grinded one could increase the decomposition rate to 60% in 7 to 10 days, and in 14 days if the particle size were about 2 cm to 3 cm.

Particle size is found to have impact on nitrogen losses in a compost. A study by Bueno *et al.* (2008) showed that using high particle size could cause high contents of nitrogen losses. An empirical relationship was found between free air space (related with the particle size) and ammonium emissions.

2.7.9 TIME

Time can also be used as an independent variable with respect to deciding on the point the compost is ready. Depending on how and what a compost is to be used may determine its readiness. Research by Hubbe *et al*. (2010), established that at 56 days composted cattle slurry was suitable for field application, while 254 days of composting was needed before it was suitable for use in greenhouses with sensitive plants.

It is important to note that, when composting processes are not carried out under optimized conditions as described earlier, there is then a risk that pathogens originating from plant and food residues can remain in the compost, which may be carried into agricultural products and food supply (Hubbe *et al.*, 2010).

Table 2.2 Recommended Conditions for Rapid Composting

Condition	Reasonable Range	Preferred Range
Carbon to Nitrogen Ratio	20:1 – 40:1	25:1 - 30:1
Water Content	40 – 65%	50 – 60%
Oxygen Concentration	5%	5 – 15%
Particle Size (diameter)	1/8 – ½ inch	Depends on Material
Ph	5.5 – 9.0	6.5 – 8.0
Temperature	43 – 65 ºC	54 – 60 ºC

Source: Eghball, 1997.

2.8 THE MICRO-ORGANISMS AND PATHOGENS IN COMPOST

In every compost pile, there are numerous types of micro-organisms that degrade the organic substrate through their biological activities. The microbial diversity of a compost may vary during different phase of the composting process (Ahmad *et al.,* 2007). They decompose organic materials of the compost and causes dramatic rise in temperature from their body heat. Micro-organisms such as ants, millipedes, centipedes, sow bugs, spiders and earthworm are mostly the larger microbes found in the compost. Bacteria, actinomycetes, protozoa and fungi also form the smaller microbes in the compost.

Psychrophilics are bacteria that initiate work in the lowest temperature range and have an optimum temperature of about 13ºC (Dickson *et al.*, 1991). While mesophilic bacteria, fungi, actinomycetes, and protozoa also function at temperature between 10°C and 45°C

(Cooperband, 2011). Mesophilic bacteria rapidly decompose organic matter, producing acids, carbon dioxide and heat at temperature range of generally between 21º to 38ºC. When the pile temperature rises above 38ºC, mesophilic bacteria begin to die off or move to the outer part of the heap (Smith and Friend, 2013). This allows heat loving bacteria (thermophilic bacteria) that thrive in a range between 45º – 68º C to then dominate the compost (Dickson *et al.*, 1991). A decrease in the temperature of the pile or a sharp change in its acidity can render bacteria inactive or kill them (Smith and Friend, 2013).

Pathogens in a compost may result from pathogens that are normally found in the raw waste used for the piles. It is expected that a composting process undergo a decreasing trend in pathogen population. Decrease in pathogen growth in a compost is as a result of high temperatures generated in the compost. Hoffmeister *et al.* (2005), in their work did not record a fall in the number of total and faecal coliform count as compared to other authors who had decrease in their faecal coliform from 2.0×10^7 to 3.1×10^3 cells/g. The drop in coliform counts for the waste under composting was ascribed to the high temperatures in the thermophilic phase or to the loss of humidity from within the compost respectively. Other studies also recommend over 50ºC as a basic requirement for pathogen elimination (Dincer *et al.*, 2003).

Although it is necessary that finished compost be freed from all pathogens, Watson (2002), indicates that, pathogens are rarely found in compost at concentrations that would cause problems in using the compost, provided the composting process is correctly completed.

2.9 COMPOSTING MATURITY AND QUALITY

2.9.1 COMPOST MATURITY

A mature compost is defined as a thermophilic converted product with high humus content that can be used as a soil amendment and can prevent or remediate pollutants in soil, air, and storm water run-off (EPA, 2000). A compost is considered mature when the energy and nutrient-containing materials have been combined into a stable organic mass. The composting process results in a dark brown material in which the initial constituents are no longer recognizable and further degradation is not noticeable except for some woody pieces (Mangan *et al.*, 2013, Smith and Friend, 2013). Thus matured compost has little resemblance in physical form to the original biodegradable from which it is made (Darlington, 2001). A stable compost on the other hand is considered when the temperature within a static pile remains near ambient for several days, assuming there is sufficient moisture and oxygen (Mangan *et al.*, 2013).

Testing for compost maturity can be done in various ways. According to Ofosu-Budu *et al.* (2010), these can be broadly categorized into different groups as physical (odour, temperature), chemical (C/N ratio, cation exchange capacity, nitrification), biological (plant bioassay–germination test), microbiological (respiration analysis), spectroscopic (NMR and infrared methods), humification (humic/fulvic acid content) and chromatographic (sephadex fractionation). Other biological means may also involve seed germination and root length, since immature composts may contain phytotoxic substances such as phenolic acids and volatile fatty acids that may inhibit germination (Bernal *et al.,* 1997). The use of seed germination as the most practical test of compost maturity emerged as an approach in the early 1980s (Bardos, 2004).

There is also the use of microbial stability test to assess compost maturity. This can be determined by measuring the microbial biomass count, its metabolic activity and the concentration of easily biodegradable constituents. Laboratory methods for evaluating stability through latent metabolism include oxygen consumption or respiration activity, and heat production, both of which are indicative of the amount of degradable organic matter still present and which is inversely related to stabilization (Bernal *et al.,* 1997).

Respirometric study is also another means of determining compost maturity. This study determines the oxygen consumption or carbon dioxide production caused by mineralization of the compost organic matter. It has been carried out in pure compost and mixed compost with soil in a proportion compatible with agricultural use. Immature compost has a strong demand for oxygen and high carbon dioxide production rates due to intense development of microorganisms as a consequence of the abundance of easily biodegradable compounds in the raw material. For this reason, oxygen consumption or carbon dioxide production are indicative of compost stability and maturity (Bernal *et al.,* 1997).

The length of the time needed to achieve finished compost vary with many factors and can take anywhere from a couple of weeks to over a year. Making sure that a compost is finished before adding it to the soil is very important. Application of an unfinished or a carbonaceous compost could adversely affect plant growth since the compost may have its own demand for nutrients as the breakdown to maturity continues in the soil. In addition, immature composts made from nitrogen-rich feedstocks are often high in ammonium which can be toxic to plant growth (Mangan *et al*., 2013).

C/N ratio is one of the most important parameters that determine the extent of composting and degree of compost maturity (Shyamala and Belagali, 2012). However, the C/N ratio is an indicator of compost stability only up to a point. A compost with a high C/N ratio prevents the uptake of nitrogen by the plants because of the competition between compost micro-organisms and plants for nitrogen. A low C/N ratio, however, is not necessarily an indicator of stability, particularly if the original C/N ratio is low as well. A reduced C/N ratio generally indicates that at least some decomposition and stabilization have occurred (Graves and Hattemer., 2000).

Among all these tests Graves and Hattemer. (2000), established that the best test of compost stability is to observe its effect on plants. Phytotoxicity (poisonous to plants) can result from high levels of heavy metals, toxic compounds, and organic acids as well as problems with oxygen demand of the compost.

2.9.2 COMPOST QUALITY

Compost quality reflects the chemical makeup of a given compost. A compost can be matured or fully composted, but may be of poor quality due to low nutrient levels. Compost quality is determined by its physical, chemical, and biological characteristics.

The physical characteristics used to determine compost quality, may include particle size, texture, color appearance, and absence of non-compostable debris since they are important indicators of the quality of commercially produced compost. According to Graves and Hattemer. (2000), a compost texture at the matured stage should be soil-like and dark brown to black color. The difference in color between composts is often used as the deciding factor for users.

The chemical characteristics of the compost are also important to determine its value as fertilizer or a soil amendment, its potential toxicity to plants, and its ease of incorporation. The chemical characteristics of interest include organic matter content, moisture content, pH, metals, nutrients, and soluble salts (Graves and Hattemer., 2000).

- ***PHOSPHORUS***

Phosphorus is always an important nutrient for plant growth (Shyamala and Belagali, 2012). It is found to be one of the most required macro nutrients for plant growth. However similar to nitrogen much of the phosphorus in finished compost is not readily available for plant uptake since it is incorporated in organic matter. Not all mineralized phosphorus from organic matter are available for crop uptake, because some of the phosphorus released from organic matter by microbial and chemical action are quickly made unavailable by binding with other elements in the soil.

In some studies where plants have been grown with compost as the sole source of fertility added have shown phosphorus deficiency more readily than nitrogen or potassium deficiencies (Mangan *et al.,* 2013).

A good compost is expected to have a good phosphorus concentration. During their studies, Shyamala and Belagali, (2012), had the total phosphorous concentration varying from 1.43 to13.871 mg/kg. In comparison with recommended standards, the total phosphorous content was found to be higher in all the samples. And this was because, total phosphorous content gradually increased during composting process and water solubility of phosphorous decreases with humification, so that, phosphorous solubility during the decomposition was subjected to further immobilization factor.

POTASSIUM

Potassium in finished compost is much more available for plant uptake than nitrogen and phosphorus since potassium is not incorporated into organic matter. However, much of the potassium can be leached from the compost since it is water soluble. In one study, potassium levels were reduced by 25% when a compost finished under cover was left uncovered in the open over a winter period (Mangan *et al.,* 2013).

- ***ORGANIC MATTER CONTENT***

Organic matter content of a compost gives a measure of all carbon based materials in the compost. Compost is valued for its organic matter content (Darlington, 2001). The recommended organic matter content in a compost is given between 30% to 50% of dry weight, with the remainder being minerals (Mitchell, 2001). Good quality compost is expected to contain a minimum of 50 percent organic matter content since compost users find organic matter content as a major component in a compost. High organic matter content in a compost implies high amount of carbon content and reduced organic matter content shows low carbon content. During vigorous microbial activity, organic matter is converted into volatile carbon dioxide and water resulting in reduction in content. Generally carbon-rich materials have high organic matter content whilst nitrogen–rich materials contain low organic matter content. Reduction in organic matter gives an indication of increased rate of microbial activity. The total loss of organic matter in a compost can be used as an indicator of compost degradation (Troy *et al.*, 2012). The addition of organic matter to soil improves soil structure condition, workability, water holding and fertility of the soil (Bardos, 2004).

- ***TOTAL SOLIDS***

The total solids of a compost is a measure of all the amount of solid materials in the compost. It is found to be the converse of the moisture content of a compost. Usually the quantity of solids in a compost is expressed as a percentage of the sample weight, oven-dried at 70±5°C to a constant weight. Moisture content value of a compost is obtained from subtracting the percent solids obtained from 100%. Total solids however do not have a recommended range. It is expected that, the higher the amount of the total solid content in a compost, the lower the moisture content of the compost (Watson, 2002).

These methods differ in simplicity, duration and approach and because some of these characteristics are somewhat subjective, there is no set method of determining compost quality. However the degree of compost quality required may be dependent on the end use of the product. Compost maturity among other conditions such as method of composting, source and type of organic material depicts the effectiveness of the compost (Adebayo *et al.*, 2011).

2.11 THE BENEFITS OF COMPOST

As more and more compost is produced and utilized, and as the body of end-use related research grows, the benefits of using compost have become more evident and measurable. Compost is extremely versatile and beneficial to many applications (Ron, 2001). Composting basically create an opportunity to recycle back into the soil, the plant and animal left overs. Compost may be applied for many purposes such as;

2.11.1 AGRICULTURAL PURPOSES

SOIL AMENDMENT

Stable and mature compost can be applied to soil as an organic amendment to improve plant growth and soil fertility, as well as enhancing the function of soil for carbon sequestration (Guo *et al.*, 2012).

Compost provide a ready source of carbon and nitrogen for microorganisms in the soil, improve its structure, reduce erosion and lower the temperature at the soil surface and also aid in seed germination and increase its water holding capacity (Adebayo *et al.*, 2011). When used in sufficient quantities, addition of compost has both an immediate and long-term positive impact on soil structure. In fine-textured (clay, clay loam) soils, compost addition reduces bulk density, improve friability and porosity whilst improving soil aggregation and water holding capacity in coarse-textured (sandy) soil (Ron, 2001). In Adebayo *et al*. (2011) studies showed that compost and other organic manures serve as soil amendments to improve soil nutrient status.

MOISTURE MANAGEMENT

The addition of compost provides greater drought resistance and more efficient water utilization ability. Recent research suggests that the addition of compost in sandy soils can facilitate moisture dispersion by allowing water to move more readily laterally from its point of application (Ron, 2001).

PROVISION OF ESSENTIAL PLANT NUTRIENTS

Compost has the ability to provide a continuous supply of nutrients to plant growth and increase the soil's ability to retain essential minerals. Compared with raw organic wastes, mature compost provides a stabilized form of organic matter and has the potential to enhance nutrient release in the soil (Adebayo et al, 2011). Compost has the ability to release nutrient over time, making it useful throughout the growing season.

A field experiment carried out to evaluate the growth of *Brassica chinensis* and *Zea mays* proof that, addition of manure compost increased total organic matter, macro-nutrients (N, P, Mg, Na, Ca and K) and micro-nutrients (Cu, Zn and Mn) in the amended soils according to the rate of compost application. It also improved soil physical properties with a significant increase in soil porosity and hydraulic conductivity, but a decrease in bulk density. The dry weight yields of both plant species were higher in soils receiving manure compost amendment and plots with 50 and 25 tonnes ha^{-1} compost had the highest yields of *Z. mays* and *B. chinensis*, respectively. An increase in dry weight yields indicated a better nutrient status in compost-amended soil which was supported by the higher tissue nutrient contents of N, P and K of plants grown in soil with manure compost amendment (Wong *et al*., 1999).

SLOW NUTRIENT RELEASER

All composts work as a 'slow release fertilizer' whereas chemical fertilizers release their nutrients rather quickly in soil and soon get depleted (Sinha, 2009). Compared to some chemical fertilizers which release nutrients so quickly that rain can leach them away even before plants derive benefit in compost, most of the nitrogen and phosphorus are held in organic form and released slowly. The nutrients in compost are therefore available throughout the growing season (Dickson *et al*., 1991).

2.11.2 LAND AND LANDFILL APPLICATION

The recycling of compost to land is considered as a way of maintaining or restoring the quality of soils, mainly because of the fertilizing or improving properties of the organic matter contained in them. Composting helps to optimize nutrient management of the soil, contributes to the carbon sequestration and partially replaces peat and fertilizers. Its land application process completes a circle whereby nutrients and organic matter which have been removed during harvesting of produce are replaced. Compost application to agricultural land needs to be carried out in a manner that ensures sustainable development (Tweib *et al*., 2011).

Compost is used to restore landfill sites and improve landfill covers. It is also used as daily cover material (Bardos, 2004).

BINDS CONTAMINANTS

Compost has the ability to bind heavy metals and other contaminants, reducing their leachability and absorption by plants. The same binding effect also allows it to be used as a filter media for storm water treatment and has been shown to minimize leaching of pesticides in soil systems (Ron, 2001).

WETLAND RESTORATION

Compost has also been used for the restoration of native wetlands. Rich in organic matter and microbial population, compost and soil/compost blends can closely simulate the characteristics of wetland soils, thereby encouraging the re-establishment of native plant species (Ron, 2001).

2.11.3 ENVIRONMENTAL FRIENDLY

The advantage of readily available materials for compost preparation, gradual release of plant nutrients without being wasted through leaching or erosion, destruction of harmful weed and toxic materials during preparation and environmental friendliness have made organic amendments, particularly composted manure popular among farmers (Adebayo *et al.*, 2011).

2.11.4 SOIL-BORNE DISEASES SUPPRESSANT

Compost functions as a disease suppressant by increasing the microbial activity in the soil. The increased number and diversity of soil micro-organisms give beneficial organisms a competitive edge over pathogens (Graves and Hattemer, 2000).

In Dickson *et al*. (1991), current research conducted by several pathologists indicates that incorporation of specific types of compost into soil suppresses several soil-borne diseases on crops such as turf grass, peas, beans and apples.

In Sinha (2009), research corroborated that mean root disease was reduced from 82% to 18% in tomato and from 98% to 26% in capsicum in soils amended with compost.

The use of compost for its disease suppressive quality has been emphasized in container media and nurseries. In Graves and Hattemer (2000), a study discovered that composted separated manure was effective as a peat substitute in container media and was suppressive to soil-borne pathogens, such as *Pythium, Rizoctonia*,and *Fusarium.*

2.11.5 ROOT GROWTH STIMULANT

The changes in the soil brought about by the addition of compost stimulate root growth. An increased root system makes a plant more drought resistant because it is able to obtain more water from the soil. The increased root system also allows the plant to increase its nutrient uptake. Leaching is reduced because of increased water and nutrient retention capacities of the soil resulting from increased organic matter provided by the compost (Graves and Hattemer, 2000).

CHAPTER THREE

3.0 METHODOLOGY

3.1 STUDY AREA

The area for the study was the Kwame Nkrumah University of Science and Technology, located in Kumasi – Ashanti region, Ghana. The University campus, which is about seven square miles in area, is located about eight miles (13 km) to the east of Kumasi, the Ashanti region has coordinates 06º41'5.67''N and 01º34'13.87''W. The students population is about 21,285 and 2,306 of undergraduates and postgraduates respectively. There are six halls of residence namely Africa Hall, Independence Hall, Queens Hall, University Hall, Republic Hall and Unity Hall. About 60% of the student populations are non-resident of these halls. In view of this problem, there are large numbers of private hostels around the campus and its environs to accommodate students who are not admitted to these residential facilities (http://en.wikipedia.org/wiki/Kwame_Nkrumah_University_of_Science_and_Technology#Student_accommodation).

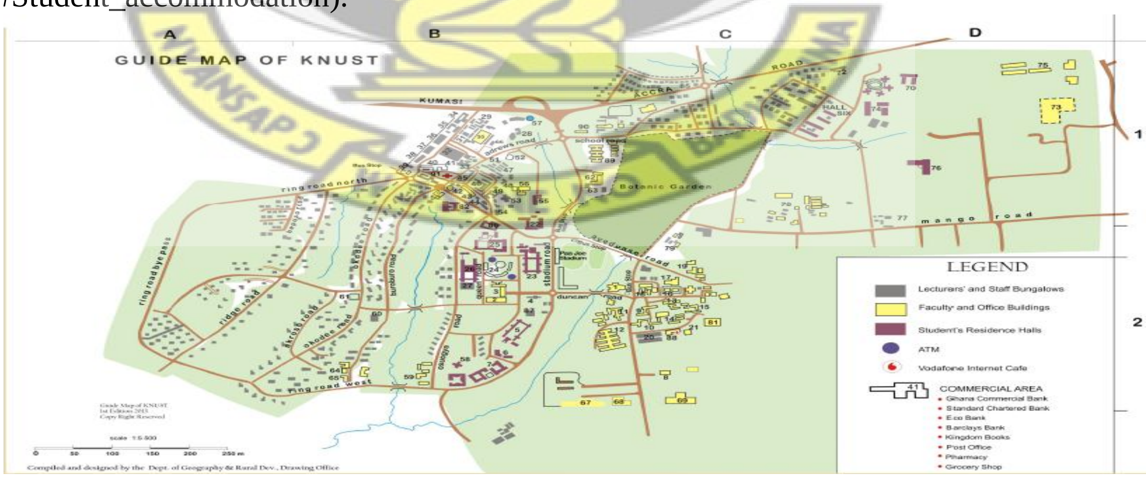

Fig 3.1 GUIDE MAP OF KNUST

3.1.1 SHED PREPARATION AND WASTE COLLECTION

The project was done under a shed structure constructed behind the Department of Theoretical and Applied Biology, KNUST. This was done to protect the composting processes from extreme weather conditions such as rain and sunshine. Solid waste was collected from various eateries in the halls of residence and Ayeduase gate daily for five days in sacks. Moringa *Oliefera* leaves were collected from the farm of the Faculty of Agriculture for two days. Sawdust was collected in sacks from a carpentry shop at Ayeduase gate. Grass clippings were collected from mowed lawns on campus. Sawdust and grass clippings were collected in a day.

	
Plate 3.1 Collected Solid waste and Moringa Leaves in Sacks	**Plate 3.2 Collected Solid waste Poured On the Ground**

3.1.2 WASTE SORTING AND MIXING

Solid wastes collected included wasted vegetables, fruits, plantain peels, rice, kenkey and fufu leftovers, yam peel etc. Sorting was done both at collection point and during pouring. All non-biodegradable materials such as polythene bags and rubbers, food wrappers, broken bottles etc were taken out of the waste during pouring from sacks. To attain a homogeneous mixture, collected solid waste was cut into smaller pieces with a cutlass and shovel. After cutting, the solid waste was then mixed together to obtain a homogeneous mixture.

3.1.3 THE COMPOSTING PROCEDURE

Basically the study sought to investigate the nutrient content of compost obtained, when solid waste is mixed in different ratios of moringa leaves, sawdust and grass clippings. The compost materials therefore consisted of solid waste, moringa leaves, grass clippings and sawdust. The passive composting method was used for the process. To ensure accuracy, compost piles were prepared with each ratio having a replicate.

The ratios for the mixing of solid waste / moringa leaves, solid waste/ grass clipping and solid waste/ sawdust were 1:1 (one part of solid waste to one part of moringa leaves/ grass clipping/ sawdust), 1:2 (one part of solid waste to two parts of moringa leaves/ grass clipping/ sawdust), and 2:1 (two parts of solid waste to one part of moringa leaves/ grass clipping/ sawdust) all measured by volume by volume.

For the mixing of solid waste/ moringa leaves 1:1, 1:2 and 2:1 ratio; one part of solid waste to one part of moringa leaves (i.e.30 L: 30 L), one part of solid waste to two parts of moringa leaves (i.e. 30 L: 60 L) and two parts of solid waste to one part of moringa leaves (i.e. 60 L: 30 L) all measured in volume by volume respectively.

For the mixing of solid waste/sawdust 1:1, 1:2 and 2:1 ratios, one part of solid waste to one part of sawdust (i.e. 30 L: 30 L), one part of solid waste to two parts of sawdust (i.e. 30 L: 60 L) and two parts of solidwaste to one part of sawdust (i.e. 60 L: 30 L) all measured in volume by volume respectively.

For the mixing of solid waste/grass clippings 1:1, 1:2 and 2:1 ratios, one part of solid waste to one part of grass clippings (i.e. 30 L: 30 L), one part of solid waste to two parts of grass clippings (i.e. 30 L: 60 L) and two parts of solid waste to one part of grass clippings (i.e. 60 L: 30 L) all measured in volume by volume respectively..

The piles were labeled as SWM 1:1, SWM 1:2 and SWM 2:1 for the ratios of solid waste/ moringa leaves. The ratios of solid waste/ sawdust were labeled as SWSD 1:1, SWSD 1:2 and SWSD 2:1. And the solid waste/ grass clipping ratios were labeled as SWGC 1:1, SWGC 1:2 and SWGC 2:1. In total with the replicate and the control piles (moringa leaves only, sawdust only and grass clippings only) without replicates, there were twenty two piles in all. All the preliminary results of other elements were put in tables.

Plate 3.3 Freshly Prepared Compost Piles	**Plate 3.4** Compost Piles After Eighth Week

3.2 COMPOST MONITORING

3.2.1. TURNING OF COMPOST

Turning was done initially using a shovel and after three weeks when pile volume was reduced due to decomposition, hands were used for turning to ensure efficiency. After turning, piles were neatly heaped back into a conical shaped structure.

Plate 3.5 Turning of Compost Piles with hands

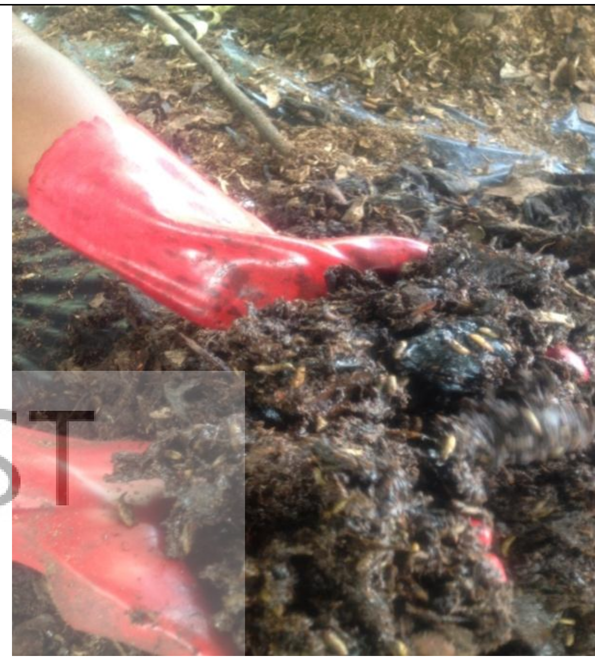

Plate 3.6 Fetched Compost with Micro-organisms

Plate 3.7 A moist fetched compost

Plate 3.8 A compost at Eleventh week

3.2.2 TEMPERATURE MEASUREMENT

A "Mercury in glass" thermometer with a temperature range of 0ºC to 100ºC was carefully inserted into the piles to read temperature. The thermometer was inserted into the pile at different angles; one in the middle and the other two at different sides of the pile. This was to ensure that daily average temperature in the pile was taken throughout the composting period. Temperature measurement was taken once daily in the afternoons.

3.2.3 MEASUREMENT OF PILE VOLUME

The initial pile volume for all the piles were taken after pile preparation on the first day. A tape measure was used to measure the circumference of the compost pile. A rod of about 60 cm tall was used to measure the height of the pile. The rod was inserted into the middle part of the pile. A white chalk was used to mark the part of the rod that was just outside the pile. The height was then measured with a measuring tape when the rod is pulled out from the pile. Volume of pile was taken every five days after compost turning. The pile volume was calculated by the formula;

$V=\frac{1}{3}\pi r^2 h$, $r=c/2\pi$

Where V= Volume, h= height, r= radius, c=circumference

3.3 LABORATORY ANALYSIS

After the pile preparation, composites of about 60 g of each pile were sampled and taken to the laboratory for analytical determination of some physico-chemical and biological parameters. Some of the physico-chemical and biological analyses included moisture content, C/N ratio, phosphorus, potassium, organic matter, faecal and total coliform, pH, ash and nitrogen contents.

3.3.1 DETERMINATION OF MOISTURE CONTENT

A compost sample of 100 g was weighed using an electronic precision balance. The samples were oven dried at a temperature of 105ºC for 24 hours and reweighed. Difference in weight showed the water content of the samples.

Percentage moisture content was calculated using the formula;

$$\left(\frac{\text{Initial Weight (W1)} - \text{Dry Weight (W2)} \times 100}{\text{Initial Weight (W1)}} \right)$$

(Motsara and Roy, 2008)

3.3.2 CARBON CONTENT DETERMMINATION

After heating at a temperature of 550ºC, organic and inorganic carbon was burnt off and percentage carbon was calculated as;

$$\% \text{ carbon} = \frac{(100 - \% \text{ Ash})}{1.72}$$

3.3.3 DETERMINATION OF ORGANIC MATTER AND ASH CONTENT

Compost sample (5 g) was put into a dry porcelain crucible and dried for 24 hours at 105ºC. Samples were then transferred into an ignition furnace where the temperature was gradually increased to 550ºC and then maintained for four 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;

Ash was calculated as

$$\% \text{ ash} = \frac{W3 - W1}{W2 - W1} \times 100\%$$

% organic matter = 100 - % ash

Where W1 = weight of empty, dry crucible;

W2 = weight of dry crucible containing compost before ignition

W3 = weight of dry crucible containing compost after ignition

(Motsara and Roy, 2008)

3.3.4 DETERMINING TOTAL SOLIDS

Determination of total dry solids was attained by weighing (100 g) of each sample into a petri dish and designated W1, oven dried for 24 hours at 105ºC and then reweighed, W2.

The percentage of total dry solid was then calculated using the formula;

%Total solids = $\underline{W2}$ X 100%

W1

Thus, % Total Solids = (100 - % Moisture)

3.3.5 DETERMINATION OF pH

Compost sample (10 g) was placed into a 100 ml beaker, and 50 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 2 minutes, and then recordings of the pH were taken by immersing the pH electrode in the suspension (Motsara and Roy, 2008).

3.3.6 DETERMINATION OF TOTAL NITROGEN BY KJELDAHL'S METHOD

DIGESTION – 2 g of dried compost sample of each composite was weighed into a 500 ml long-necked Kjeldahl flask with a 10 ml concentrated sulphuric acid, a tablet of catalyst mixture. The mixture was heated in the digester for a period of two hours until the solution was clear. The samples were allowed to cool to the ambient temperature, then the fluid was decanted into a 100 ml volumetric flask and made up to the mark with distilled water.

DISTILLATION - A 10 ml aliquot of fluid from the digested sample by means of a pipette was transfered into Kjeldahl distillation flask. Then 90 ml of distilled water was added to the distillation flask. 20 ml of 40% NaOH was dispensed to the content of the distillation flask. Distillate was collected over 10 ml of 4% boric acid with 3 drops of mixed indicator in a 200 ml conical flask. The presence of nitrogen gave a light blue colour.

TITRATION – 100 ml of collected distillate was titrated with 0.1N HCL till the blue colour changed to grey and then suddenly flashes to pink. A blank determination was carried out without a compost sample.

CALCULATION - Weight of sample used, considering the dilution and the aliquot taken for distillation in the calculation was determined as follows:

%N = 14X (A-B) X NX 100/(1000 x 0.2)

Where,

A = volume of standard HCL used in sample titration

B = volume of standard HCL used in blank titration

N = normality of standard HCL

% Crude Protein (CP) = % Total Nitrogen (NT), X 6.25 (protein factor).

3.3.7 C / N RATIO

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

The C/N was calculated using the formula;

$$\text{C/N Ratio} = \frac{\text{Carbon Content}}{\text{Nitrogen content}}$$

3.3.8 DETERMINATION OF PHOSPHORUS

Phosphorus was estimated 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. 10 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 absorbance recorded.

Compost sample of 1 g was taken and digested as per the wet digestion (di-acid digestion with a mixture of HNO_3 and $HCLO_4$ in a ratio of 9:4). In this method, 1 g of ground compost sample was taken and placed in a 100 ml volumetric flask, and 10 ml of acid was added and swirled. The flask was then heated to a temperature between 90ºC and 150ºC until the production of red NO_2 fumes ceased. The contents were heated further until there was a volume reduction and the content 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 acid-washed filter paper. The solution was then used for phosphorus estimation. 5 ml of digestate was then taken and put in a 50ml volumetric flask after which 10 ml of vanadomolbdate reagent was added. The digestate 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 the determined from the standard curve. P was calculated by the formula

P content (µg) in 1.0 g of sample = Average Reading x 58.625 x 0.04

3.3.9 POTASSIUM DETERMINATION

A standard solution of KCL was prepared by dissolving 1.908 g of KCl in 1liter of distilled water. An aliquot of 100 ml of the 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. A gram of each sample was acid-digested (di-acid digestion with a mixture of HNO_3 and $HClO_4$ in a ratio of 9:4) and made up to 100 ml. The samples were kept for estimation in the range of 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 Atomic Absorption spectrophotometer. The concentration of K for absorbance of each sample was used to determine the K content as below

Percentage K = Average Reading x 0.205 x 0.04

3.3.10 TOTAL COLIFORMS AND FAECAL COLIFORMS

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-10} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. A milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth with inverted Durham tubes and incubated at 35ºC for total coliforms and 44ºC faecal coliforms for 24 hours. Tubes showing colour change from purple to yellow and after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.3.11 *E.COLI* (THERMOTOLERANT COLIFORMS)

The most probable method was employed in the determination of *E. coli* in the compost sample. From each of the positive tubes identified a drop was transferred into a 5ml test tube of trypton water and incubated at 44ºC for 24 hours. A drop of Kovacs' reagent was then added to the water. All tubes showing a red ring colour development after gentle agitation denoted the presence of indole and recorded as presumptive for thermotolerant coliforms (E.*coli*). Counts per 100 ml were calculated from Most Probable Number (MPN) tables (Obiri-Danso *et al.*, 2005).

3.4 STATISTICAL ANALYSIS

The GraphPad Prism software was use to run the "one-way analysis of variance" ANOVA. The ANOVA was used in making comparisons for all ratios and compost piles. The analyses also run the TUKEY'S TEST to show between exactly which piles there were differences and exactly where the differences occurred. All graphs were drawn with the Microsoft Excel.

CHAPTER FOUR

4.0 RESULT

Results recorded from monitoring physico-chemical and biological parameters which were used to indicate the quality and rate of decomposition of compost pile ratios are represented in tables and graphs. Monitored parameters include; C/N ratio,organic carbon, nitrogen, potassium, phosphorus, pH, organic matter, ash content, total solids, moisture, volume, Ecoli, total coliform, faecal coliform and temperature.

Table 4.1 represents the percentage initial mean values for the different ratios of compost piles. This prelude reading helped determine optimum readings before composting process.

Table 4.1: Initial mean values for various parameters for the different ratios of waste

Compost Heap	Initial mean values of various parameters											
	Parameters											
	OC %	N %	C/N%	P %	K %	PH %	ASH %	MC%	OM%	TS%	TC/100ml Cfu. 35/37°C	FC/100ml Cfu. 44°C	*E.coli*/100 ml Cfu. 44°C
SWM 1:1	9.33	1.89	4.94	0.07	0.98	8.68	21.80	37.16	16.08	62.84	4.15×10^{11}	2.35×10^{9}	9.15×10^{7}
SWM 1:2	8.78	1.61	5.46	0.11	1.00	9.32	17.05	47.14	15.16	52.86	9.15×10^{10}	4.15×10^{8}	2.35×10^{6}
SWM 2:1	10.39	1.12	9.27	0.04	0.98	9.28	16.26	35.13	17.12	64.87	9.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:1	11.18	0.70	15.98	0.05	1.12	7.25	13.70	35.21	19.27	64.79	4.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:2	10.13	0.56	18.08	0.05	0.72	7.32	12.60	31.81	17.46	68.19	2.35×10^{11}	9.15×10^{8}	2.20×10^{7}
SWSD 2:1	14.62	0.63	23.41	0.03	0.59	7.48	11.90	31.35	25.20	68.65	2.35×10^{10}	9.15×10^{8}	4.15×10^{7}
SWGC 1:1	14.56	1.12	13.14	0.06	0.86	7.84	20.60	40.01	25.11	59.99	9.15×10^{11}	4.15×10^{9}	9.15×10^{7}
SWGC 1:2	14.40	1.19	12.11	0.08	0.43	7.21	21.20	59.26	24.83	40.74	4.15×10^{10}	9.15×10^{8}	9.15×10^{6}
SWGC 2:1	10.48	1.40	7.50	0.05	0.56	8.16	13.40	38.05	18.07	61.95	2.35×10^{11}	4.15×10^{8}	4.15×10^{6}
SW	10.06	0.54	18.62	0.02	0.38	7.20	11.16	56.91	17.34	43.09	9.3×10^{8}	9.15×10^{8}	2.3×10^{5}
SD	8.69	0.52	16.71	0.03	0.45	7.21	11.03	23.68	14.99	76.32	4.15×10^{6}	2.10×10^{6}	4.0×10^{4}
M	8.71	3.43	2.54	0.49	1.34	5.93	6.52	80.08	15.01	19.92	2.3×10^{5}	Nil	Nil
GC	10.61	1.42	7.47	0.12	1.05	7.16	10.01	82.01	18.29	17.99	2.35×10^{6}	4.0×10^{-4}	Nil

Table 4.2: Final mean readings for various parameters at the end of the composting process. These readings were used to determine the compost quality at the end of the experiment.

Table 4.2: Final mean values for various parameters for the different ratios of waste

Compost Heap	Final mean values of various parameters												
	Parameters												
	OC%	N%	C/N	P%	K%	pH	ASH %	MC%	OM%	TS%	TC/100ml Cfu. 35/37°C	FC/100ml Cfu. 44°C	*E.coli*/100ml Cfu.44°C
SWM 1:1	5.17	2.41	2.14	0.54	1.82	8.95	53.00	21.40	8.91	78.60	2.10×10^{10}	2.35×10^{7}	2.3×10^{5}
SWM 1:2	6.22	2.80	2.22	0.60	2.91	10.0	45.50	17.76	10.72	82.24	4.15×10^{10}	1.50×10^{6}	4.0×10^{5}
SWM 2:1	5.16	2.31	2.24	0.48	2.25	9.89	50.40	14.17	8.90	85.83	2.35×10^{10}	9.15×10^{7}	3.0×10^{5}
SWSD 1:1	8.91	2.03	4.39	0.20	1.23	8.40	28.20	21.24	15.36	78.76	9.15×10^{9}	2.10×10^{7}	9.0×10^{5}
SWSD 1:2	9.21	1.82	5.06	0.14	0.95	9.07	28.00	18.30	15.89	83.15	9.15×10^{10}	4.15×10^{7}	2.3×10^{6}
SWSD 2:1	7.62	2.10	3.63	0.30	1.62	9.20	29.40	19.20	13.14	80.80	2.10×10^{9}	2.35×10^{7}	4.0×10^{5}
SWGC1:1	6.82	2.07	3.29	0.38	2.55	9.87	38.60	16.85	11.76	83.15	1.50×10^{10}	2.10×10^{7}	2.3×10^{6}
SWGC1:2	4.46	2.12	2.13	0.32	1.83	9.08	42.20	15.81	10.69	84.19	9.15×10^{9}	4.15×10^{7}	9.0×10^{5}
SWGC2:1	7.23	2.45	2.95	0.37	2.61	9.70	38.60	16.60	12.46	83.40	1.15×10^{10}	4.15×10^{7}	2.3×10^{5}
SW	8.67	1.83	4.74	0.09	0.84	9.09	26.60	34.26	14.94	65.74	9.1×10^{8}	1.9×10^{6}	2.8×10^{4}
SD	5.53	1.70	3.25	0.11	0.89	8.37	27.67	21.52	9.54	78.48	3.2×10^{6}	8.9×10^{4}	3.8×10^{3}
M	7.01	2.42	2.90	0.34	1.15	6.56	24.96	64.96	12.08	35.04	9.9×10^{4}	Nil	Nil
GC	7.02	1.25	5.62	0.11	1.02	8.33	27.82	79.49	12.10	20.51	2.1×10^{6}	4.15×10^{-5}	Nil

4.1 MOISTURE CONTENT

Fig 4.1 gives a graph of the moisture content trend of the composting process for the 12-week period. Moisture content of the compost generally experienced downward trend.

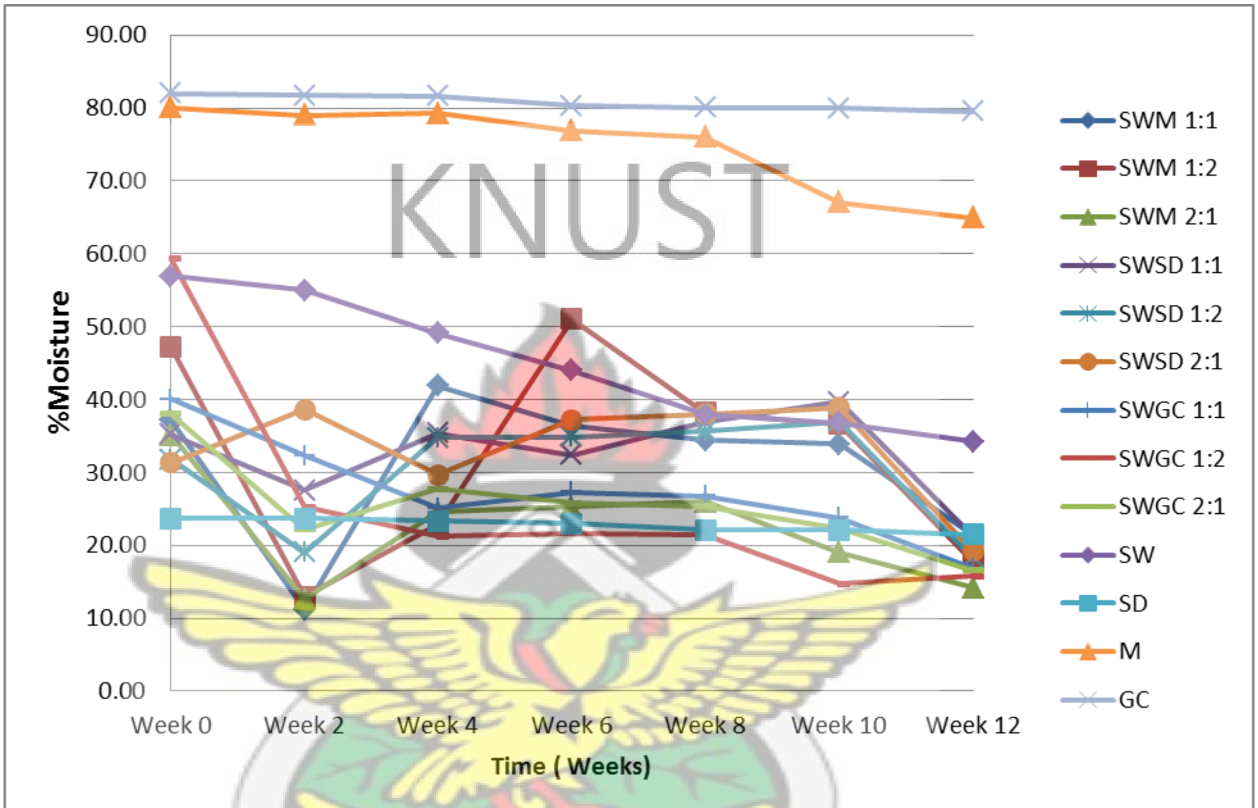

Fig 4.1: Mean bi-weekly moisture content for compost piles

Moisture content (%) for the compost heaps started from 59.26% as highest and 31.35 lowest for SWGC 1:2 and SWSD 2:1 respectively. The first fortnight mean percentage values showed a relatively drastic decrease in moisture content from 37.16%, 47.14%, 35.13%, 31.35%, 40.01%, 59.26% and 38.05% to 11.25%, 12.99%, 12.65%, 27.58%, 19.06%, 38.60%, 32.30%, 25.28% and 22.22% for all piles except SWSD 2:1 which recorded an increase from 31.35% to 38.60%.

SWM 1:1 and SWSD 1:1 finished the composting process with the highest moisture content at 21.40% and 21.24% respectively and with SWM 2:1 recording the lowest moisture content at 14.17%. M and GC recorded the highest moisture content both before and after composting process at 80.08% and 82.01% and 64.96% and 79.49% respectively. SD recorded the lowest moisture content at 23.68% and ended at 21.52% as shown in Fig 4.1

4.2 TOTAL SOLIDS

Figure 4.2 shows the total solid content trend for the compost piles of the composting process for the 12-week period. There was a general increasing trend for the total solid content for all piles at the end of the composting process. SWM 2:1 recorded the highest total solid content value at 85.83% with SWM 1:1 recording the lowest value at 78.60% in the finished compost.

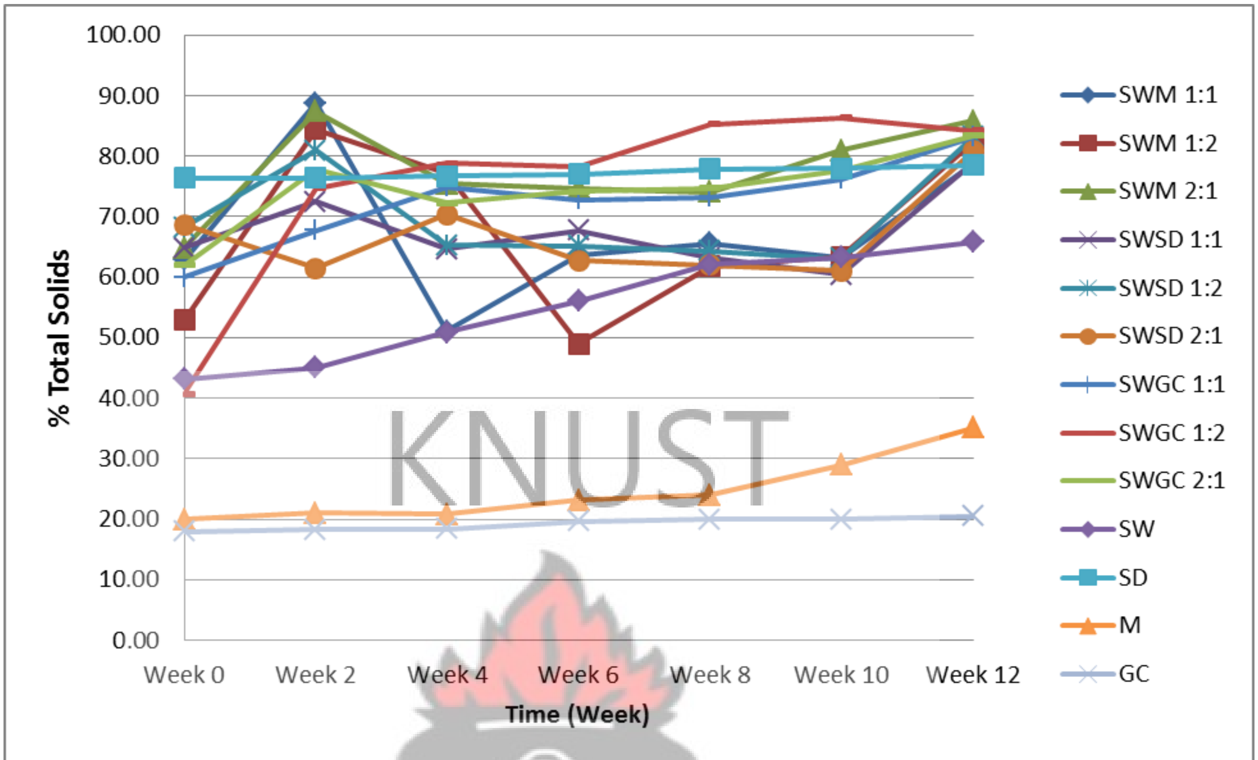

Fig 4.2: Mean bi-weekly total solid content for compost piles

Bi-weekly measurement of total solid content recorded initial highest value at 68.65%, and lowest at 52.86% for SWSD 2:1 and SWGC 1:2 respectively. Generally, the values showed inconsistent increasing and decreasing trends except for SWGC 1:1, SWGC 1:2 and SWGC 2:1 which had consistent increasing trend. Highest and lowest final percentage values were recorded at 85.83% and 78.76% for SWM 2:1 and SWSD 1:1 respectively. Controls showed increased values throughout the composting process as shown in Fig 4.2.

4.3 TEMPERATURE

Figure 4.3 shows the temperature trend for the composting process of the various compost piles for the 12-week period. There was a general decreasing trend of temperature for all piles at the end of the composting process. Optimum temperature range recorded was 40˚C to 46˚C with finished compost reaching ambient temperature of 23˚C to 24˚C.

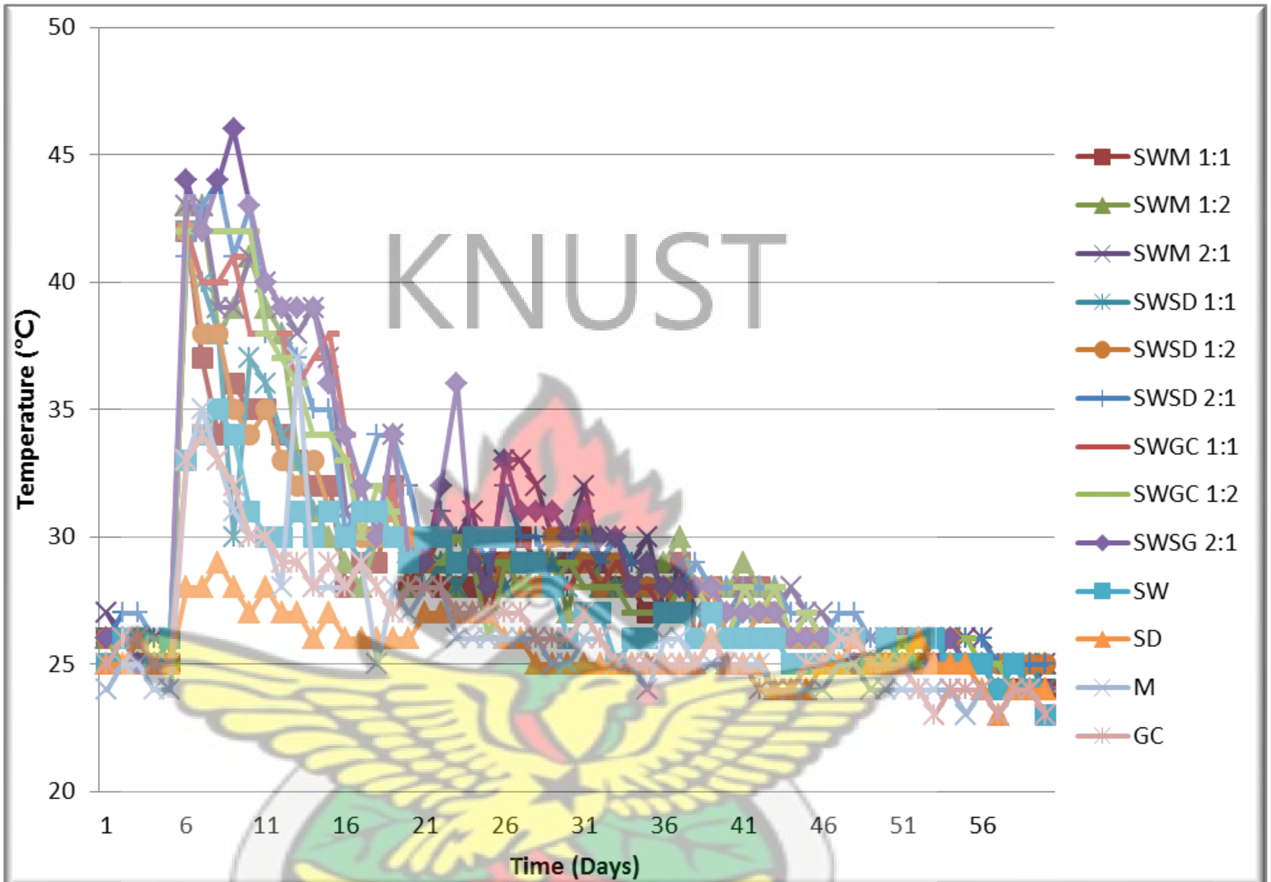

Fig 4.3: Daily mean temperature for compost pile

Fig 4.3 shows daily mean recorded temperature variations for all compost piles including controls during the composting period. The figure shows composting process started with an ambient temperature of around 24ºC to 27ºC. All compost piles experience initial fluctuating temperatures from between 25ºC to 27ºC for the first five days (Mesophilic phase). Temperature build up was observed on the 6th day and persisted for six days with temperature ranges from between 34ºC and 46ºC (Thermophilic phase). The optimum temperature value was recorded at 46ºC. The temperature then remained fluctuating between 28ºC and 39ºC until around day 37. The temperature finally dropped to 27ºC approaching ambient temperature of 24ºC (mesophilic phase) between day 45 and 60. Composting process finished with final temperature drop to ambient temperature of 24ºC.

Comparing the piles, SWGC 2:1 and SWSD 2:1 were observed to have recorded the highest temperature at 46ºC and 44ºC respectively during the thermophilic phase, whilst SWGC 1:2 maintained stabilized temperature at 42ºC for five days of the thermophilic phase. Initial lowest temperature was recorded at 25ºC on day 2 by SWGC 1:1 and SWGC 1:2 with lowest final temperature recorded at 24ºC for SWM 1:1, SWSD 1:1, SWGC 1:1, SWGC 1:2 and SWGC 2:1 respectively.

The controls started with a temperature range of 24ºC to 26ºC for the first 6 days. Optimum temperature for the controls was recorded at 35ºC for SW and M on day 9 and 8 respectively. The final temperature range for the finished compost of the controls was recorded around 24ºC to 23ºC.

4.4 VOLUME

Table 4.3: bi-weekly mean volume for compost piles. General reduction in volume was observed for all piles.

Table 4.3: bi-weekly mean volume values of compost piles.

Compost Heaps	Weeks						
	0	2	4	6	8	10	12
SWM 1:1	0.88	0.000745	0.000546	0.000427	0.000275	0.000278	0.000253
SWM 1:2	0.23	0.00087	0.000883	0.000584	0.000482	0.000428	0.000401
SWM 2:1	0.35	0.00148	0.001	0.000105	0.000697	0.000619	0.000536
SWSD 1:1	0.26	0.00146	0.00143	0.00116	0.0012	0.0011	0.000843
SWSD 1:2	0.38	0.00278	0.00262	0.00214	0.00222	0.00202	0.00191
SWSD 2:1	0.4	0.00199	0.00185	0.00163	0.00152	0.00139	0.00121
SWGC 1:1	0.19	0.00102	0.000734	0.000584	0.000483	0.000412	0.000344
SWGC 1:2	0.28	0.0011	0.000639	0.00069	0.000529	0.000477	0.000445
SWGC 2:1	0.34	0.00167	0.00114	0.000885	0.000719	0.000733	0.000654
SW	0.000537	0.00029	0.000196	0.000168	0.000101	0.0000916	0.0000878
SD	0.000896	0.000846	0.000821	0.000812	0.000788	0.000736	0.000107
M	0.0215	0.0000308	0.000041	0.0000328	0.0000316	0.0000287	0.0000245
GC	0.000502	0.000383	0.000287	0.000312	0.000217	0.000225	0.000176

4.5 *E.COLI*, TOTAL COLIFORM AND FAECAL COLIFORM

Table 4.4: initial mean readings for *Ecoli*, Total Coliform and Faecal Coliform values at the start of the composting process. These readings were used to determine the population count of compost at the end of the experiment.

Table 4.4: Initial *Ecoli*, Total Coliform and Feacal Coliform Values

Compost Heap	Total Coliforms/100ml cfu. 35/37ºc	Feacal Coliform/100ml cfu. 44ºc	*Ecoli*/100 ml cfu 44º
SWM 1:1	4.15×10^{11}	2.35×10^{9}	9.15×10^{7}
SWM 1:2	9.15×10^{10}	4.15×10^{8}	2.35×10^{6}
SWM 2:1	9.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:1	4.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:2	2.35×10^{11}	9.15×10^{8}	2.2×10^{7}
SWSD 2:1	2.35×10^{10}	9.15×10^{8}	4.15×10^{7}
SWGC 1:1 Rep 1	9.15×10^{11}	4.15×10^{9}	9.15×10^{7}
SWGC 1:2 Rep 1	4.15×10^{10}	9.15×10^{8}	9.15×10^{6}
SWGC 2:1 Rep 2	2.35×10^{11}	4.15×10^{8}	4.15×10^{6}
SW	9.3×10^{8}	9.15×10^{8}	2.3×10^{5}
SD	4.15×10^{6}	2.10×10^{6}	4.0×10^{4}
M	2.3×10^{5}	Nil	Nil
GC	2.35×10^{6}	4.0×10^{-4}	Nil

Table 4.5: final mean readings for *Ecoli*, Total Coliform and Faecal Coliform values at the end of the composting process. These readings were used to determine the population count fall of compost at the end of the experiment.

Table 4.5: Final *Ecoli*, Total Coliform and Faecal Coliform Values

Compost Heap	Total Coliforms/ 100ml cfu. 35/37ºc	Faecal Coliform / 100ml cfu. 44ºc	*Ecoli* / 100 ml cfu. 44º
SWM 1:1	2.10×10^{10}	2.35×10^{7}	2.3×10^{5}
SWM 1:2	4.15×10^{10}	1.50×10^{6}	4.00×10^{5}
SWM 2:1	2.35×10^{10}	9.15×10^{7}	3.00×10^{5}
SWSD 1:1	9.15×10^{9}	2.10×10^{7}	9.00×10^{5}
SWSD 1:2	9.15×10^{10}	4.15×10^{7}	2.30×10^{6}
SWSD 2:1	2.10×10^{9}	2.35×10^{7}	4.00×10^{5}
SWGC 1:1	1.50×10^{10}	2.10×10^{7}	2.30×10^{6}
SWGC 1:2	9.15×10^{9}	4.15×10^{7}	9.00×10^{5}
SWGC 2:1	1.15×10^{10}	4.15×10^{7}	2.30×10^{5}
SW	9.1×10^{8}	1.9×10^{6}	2.8×10^{4}
SD	3.2×10^{6}	8.9×10^{4}	3.8×10^{3}
M	9.9×10^{4}	Nil	Nil
GC	2.1×10^{6}	4.15×10^{-5}	Nil

4.6 ORGANIC CARBON

Figure 4.4 shows the organic carbon trend for the compost piles of the composting process for the 12-week period. There was a general decreasing trend for the organic carbon content for all piles at the end of the composting process.

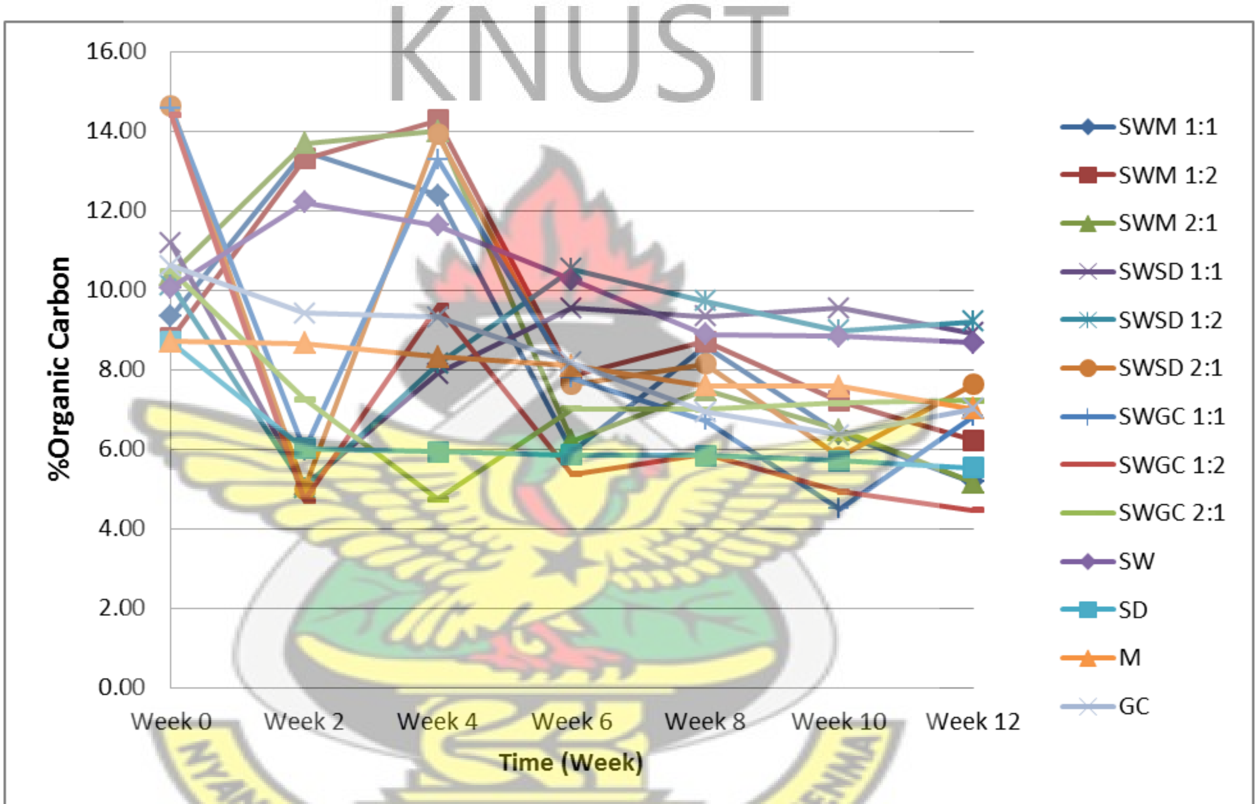

Fig 4.4: Mean bi-weekly organic carbon content for compost piles

Percentage organic carbon content recorded highest initial and final values at 14.62% and 9.21% for SWSD 2:1 and SWSD 1:2 respectively. SWGC 1:2 recorded the lowest organic carbon value at 4.46% in finished compost. The controls recorded highest initial and finished values at 10.61% and 8.67 for GC and SW respectively.

4.7 NITROGEN

Figure 4.5 shows a graph of the nitrogen content trend of the composting process for the 12-week period. Nitrogen content of the compost generally experienced an increasing trend. SWM 1:2 recorded the highest value at 2.80% with SWSD 1:2 recording the lowest at 1.82% in the finished compost.

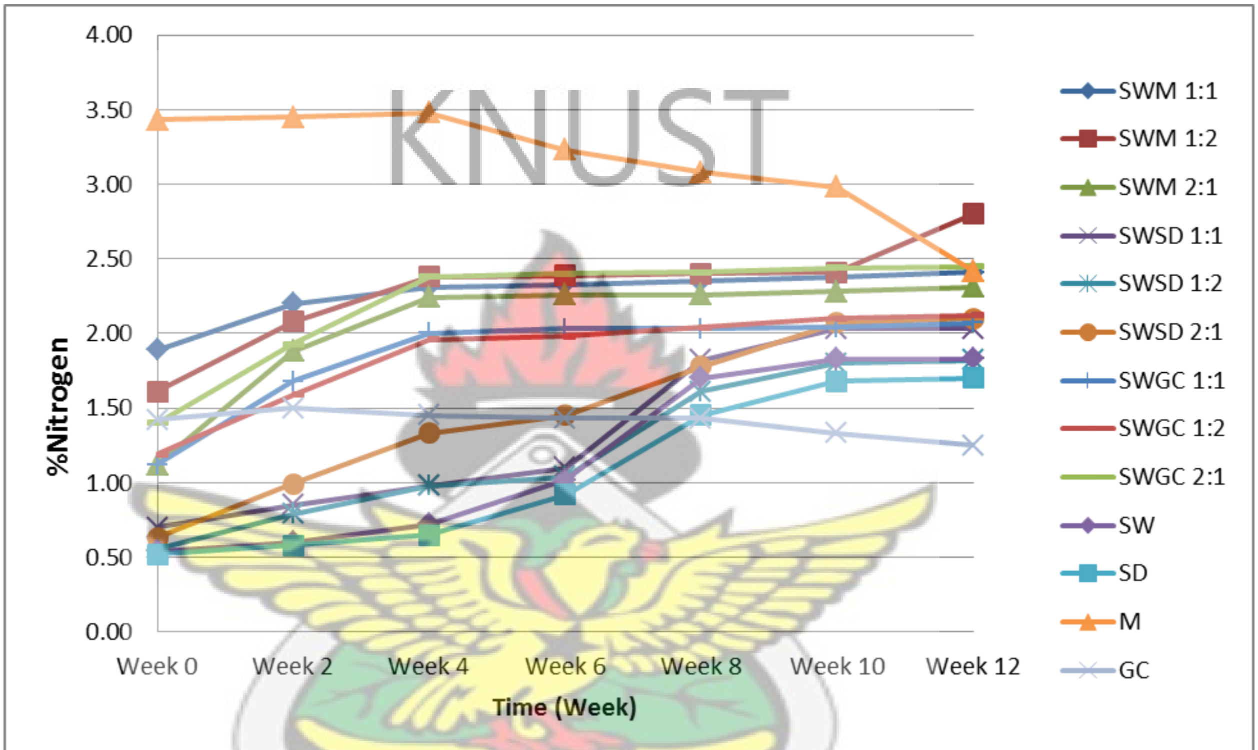

Fig 4.5: Mean bi-weekly nitrogen content for compost piles

Bi-weekly mean values recorded for nitrogen shows gradual increase. A highest and lowest initial percentage value was recorded of 1.89% and 0.56% for SWM 1:1 and SWSD 1:2 respectively. Nitrogen content values for controls showed slight increase in values. M recorded increase for the first 6weeks and afterwards recorded constant decrease for subsequent weeks from 3.23% to 2.42%.

4.8 CARBON TO NITROGEN RATIO

Figure 4.6 shows the carbon to nitrogen ratio trend for the compost piles of the composting process for the 12-week period. Generally, the carbon to nitrogen ratio of the compost experienced downward trend at the end of the process. At the end of the process SWSD 1:2 recorded the highest C/N ratio of 5.06 with SWGC 1:2 recording the lowest C/N ratio of 2.13.

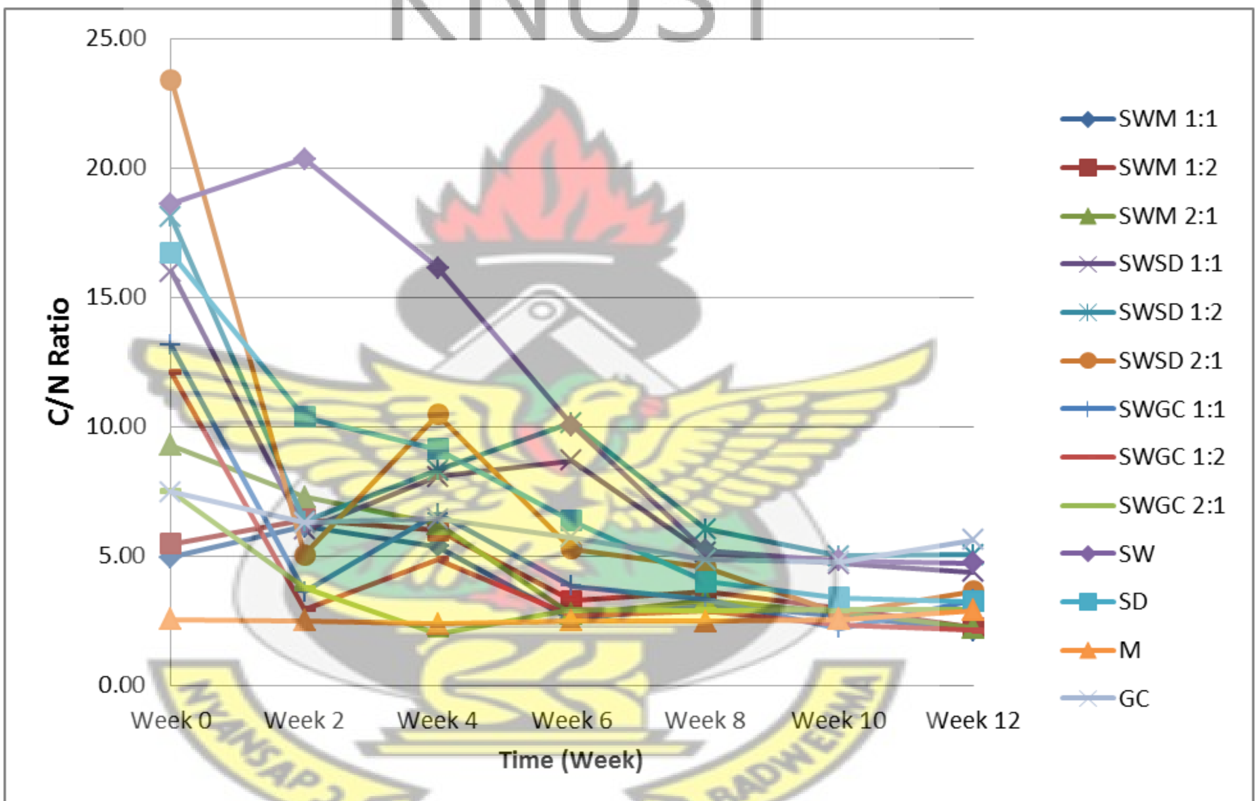

Fig 4.6: Mean bi-weekly C/N ratio for compost piles

Initial mean C/N ratio values were recorded for SWM 1:1, SWM 1:2, SWM 2:1, SWSD 1:1, SWSD 1:2, SWSD 2:1, SWGC 1:1, SWGC 1:2 and SWGC 2:1 respectively. SWSD 2:1 recorded highest initial C/N ratios at 23.41 with SWM 1:1 recording the least at 4.94 as shown in Fig 4.6. The final C/N ratio values recorded highest and lowest of 5.0 and 2.13 with SWGC 1:2 respectively. The controls recorded highest initial value for SW of

18.62. M recorded the lowest C/N ratio value for both initial and final composting process.

4.9 pH

Figure 4.7 shows the pH trend for the compost piles of the composting process for the 12-week period. Composting process started with SWM 1:1, SWM 1:2 and SWM 2:1 recording relatively high pH compared to the other piles. Final pH for all piles was relatively high as compared to recommended ranges.

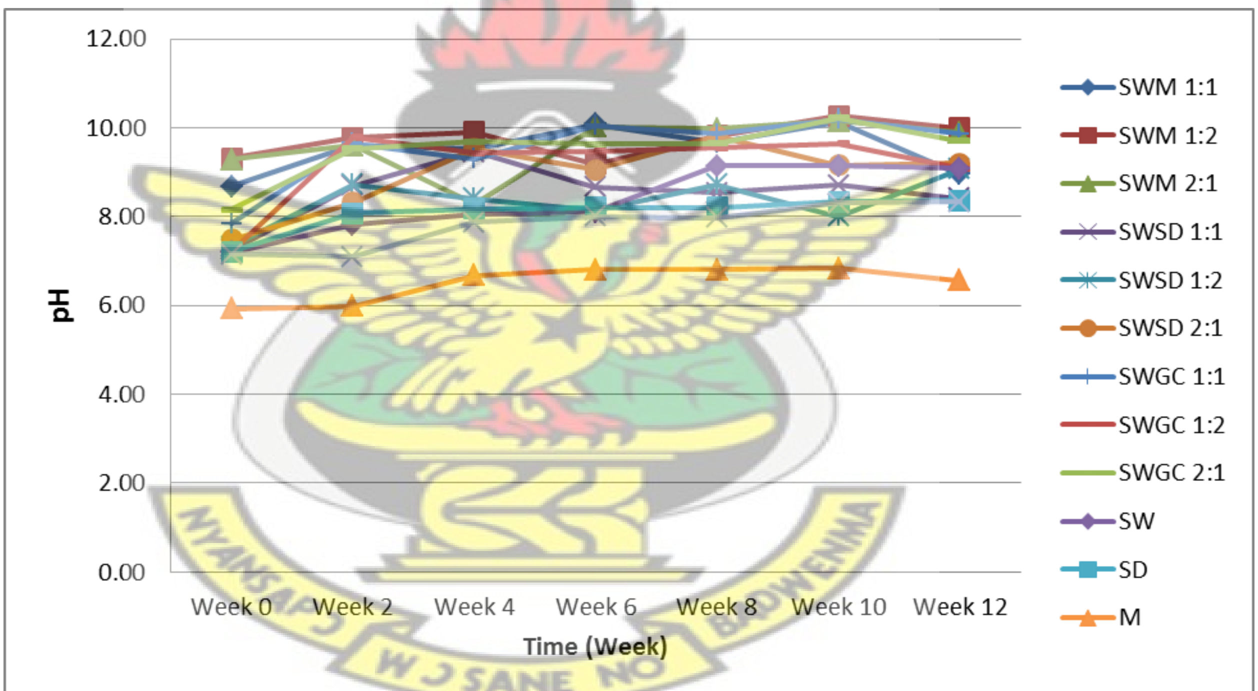

Fig 4.7: Mean bi-weekly pH for compost piles

Bi-weekly mean pH values recorded shows initial pH levels of 8.68, 9.32 and 9.28 for SWM 1:1, SWM 1:2, and SWM 2:1, and 7.25, 7.32 and 7.48 for SWSD 1:1, SWSD 1:2, SWSD 2:1, and 7.84, 7.21 and 8.16 for SWGC 1:1, SWGC 1:2 and SWGC 2:1 respectively as shown in Fig 4.7. pH values recorded highest at both week 6 and week 10 for SWM 1:1 at 10.08 and 10.14, SWM 2:1 at 10.02 and 10.15, SWGC 1:1 at 10.05 and 10.20 respectively. Week 10 also recorded highest pH value for both SWM 1:2 and SWGC 2:1 at 10.26 and 10.23 respectively. Final pH values were recorded with SWM 1:2, SWM 2:1, SWGC 1:1, SWGC 2:1, SWSD 2:1, SWGC 1:2 and SWSD 1:2 recording high pH values of 10.00, 9.89, 9.87, 9.70, 9.20, 9.08 and 9.07, followed by SWM 1:1 and SWSD 1:1 recording relatively low pH values of 8.95 and 8.40 respectively. Bi-weekly mean pH values for the controls recorded highest initial and final values of 7.20 and 9.09 for SW.

4.10 ORGANIC MATTER

Figure 4.8 shows the trend for the organic matter content of the compost piles for the 12-week period. There was a general decreasing trend for the organic matter content for all piles at the end of the composting process. SWM 2:1 recorded the least reduced organic matter content value at 8.90% in the finished compost.

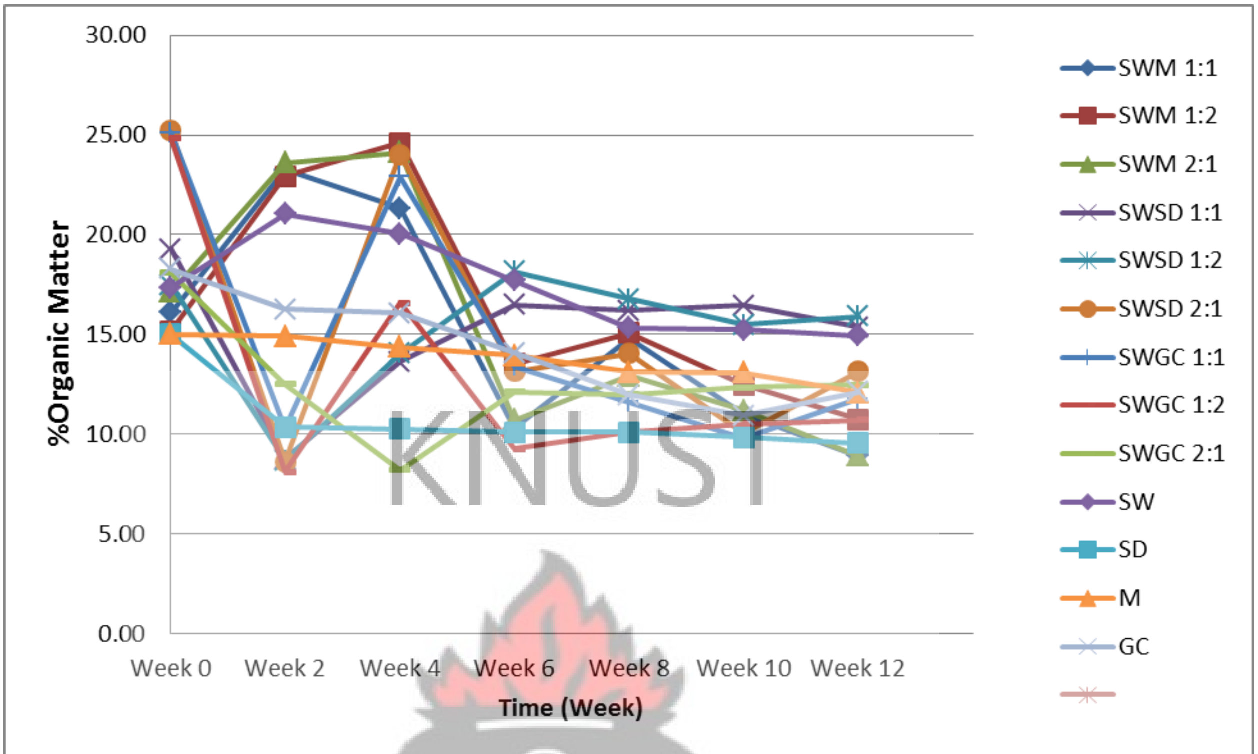

Fig 4.8: Mean bi-weekly organic matter content for compost piles

Initial mean percentage values of organic matter content from the result recorded highest value of 25.20% for SWSD 2:1. Finished compost had highest and lowest organic matter content of 15.89% and 8.90% for SWSD1:2 and SWM respectively. Percentage organic matter content for the controls recorded 18.29% and 14.94% for highest initial and final values for GC and SW respectively. All controls showed decrease values throughout the composting process with SD showing lowest decreased organic matter value.

4.11 ASH CONTENT

Figure 4.9 shows the trend of ash content for the compost piles of the composting process for the 12-week period. There was a general increasing trend for the ash content for all piles during the composting process. SWM 1:1 recorded the highest ash content value of 53.00% with SWSD 1:2 recording the lowest value of 28.00% in the finished compost.

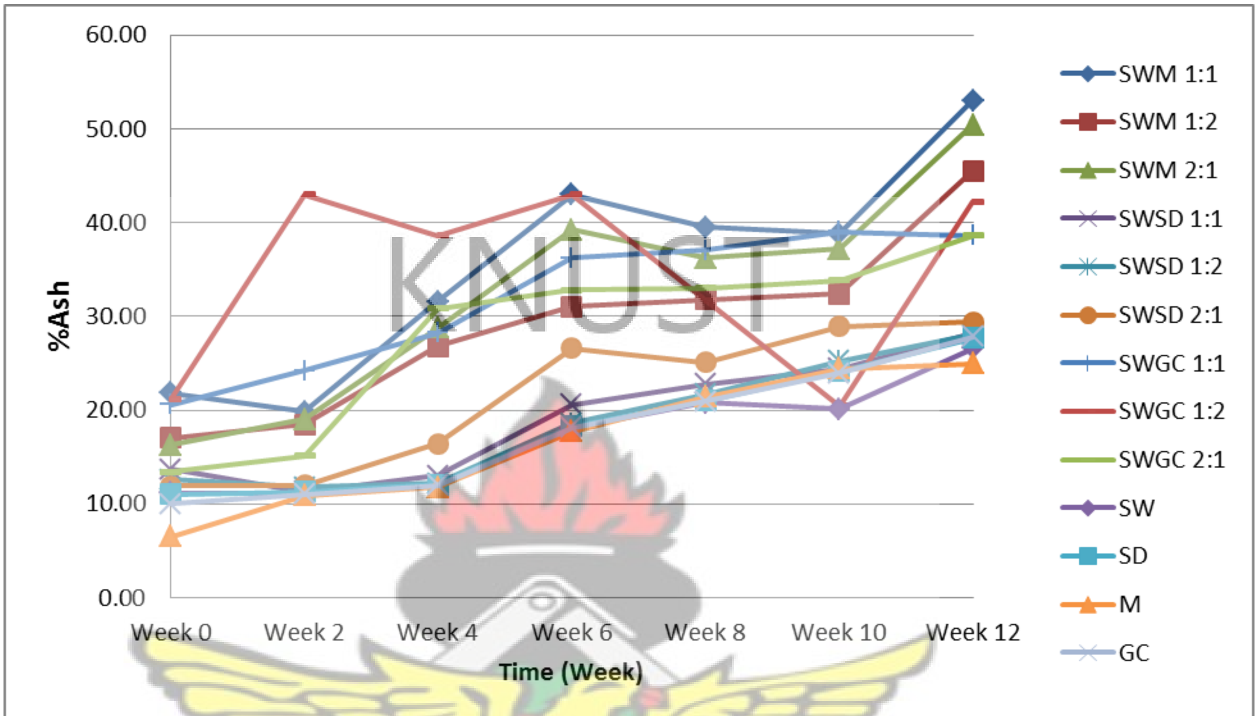

Fig 4.9: Mean bi-weekly ash content for compost piles

Percentage ash content recorded highest initial and lowest value of 21.80% and 11.90%, for SWM 1:1and SWSD 2:1 respectively. SWM 1:1, SWM 2:1 and SWM 1:2 recorded highest values of 53.00, 50.40 and 45.50 in finished compost. SWSD 2:1, SWSD 1:1 and SWSD 1:2 recorded lowest ash content values of 29.40, 28.20 and 28.00 in finished compost respectively. Percentage ash content value for the controls recorded highest and lowest initial values of 11.16 and 6.52 for SW and M respectively. GC and M recorded highest and lowest values of 27.82 and 24.96 in finished compost respectively. Controls generally recorded increasing trend from initial to final values.

4.12 POTASSIUM

Figure 4.10 shows the potassium trend for the compost piles of the composting process for the 12-week period. There was a general increasing trend for the potassium content for all piles at the end of the process. SWM 1:2 recorded the highest potassium value of 2.91% in the finished compost.

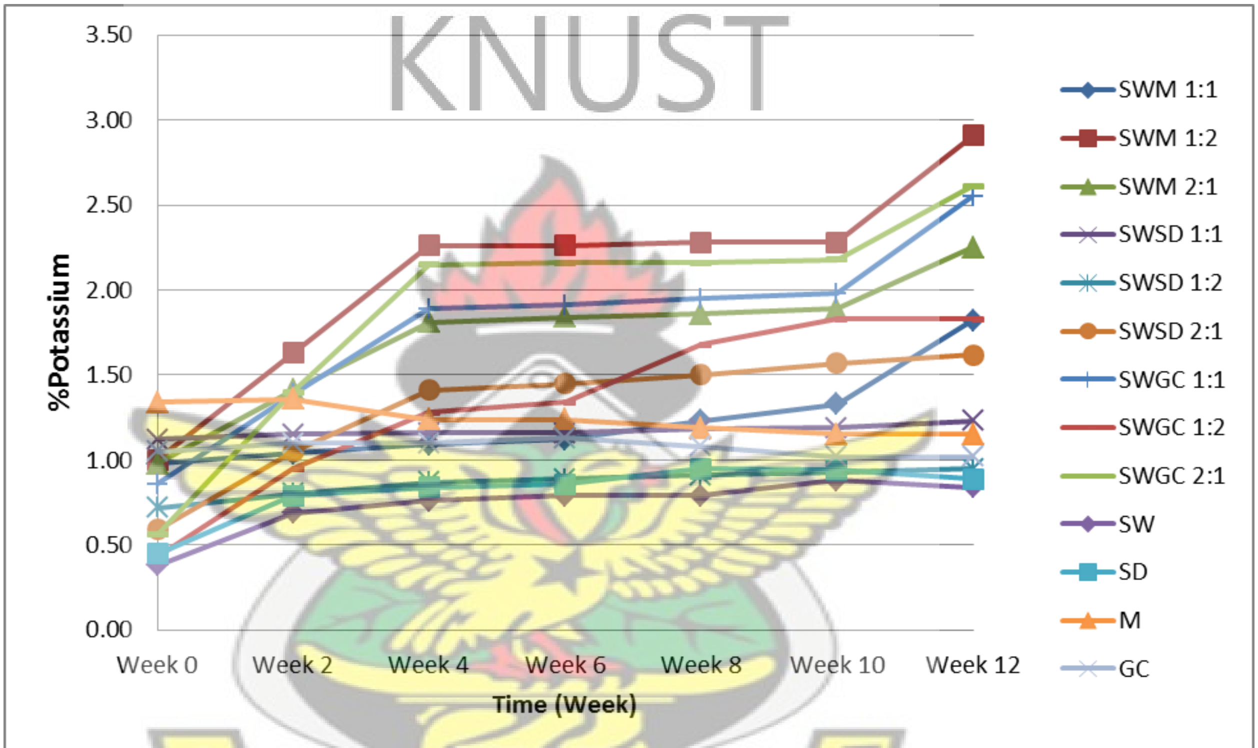

Fig 4.10: **Mean bi-weekly potassium content for compost piles**

Potassium content of the compost heaps recorded highest and lowest initial mean values of 1.12% and 0.43% for SWSD 1:1 and SWGC 1:2 respectively. Highest potassium content was recorded for SWM 1:2, of 2.91 with SWSD 1:2 recording the lowest mean value of 0.95% respectively as shown at Fig 4.10. Bi-weekly mean values for the controls also recorded highest and lowest initial values of 1.34% and 0.38% for M and SW respectively.

4.13 PHOSPHORUS

Figure 4.11 shows the trend of phosphorus for the compost piles of the composting process for the 12-week period. There was a general increasing trend for the phosphorus content for all piles during the process. SWM 1:2 recorded the highest phosphorus value of 0.60% with SWSD 1:2 recording the lowest value of 0.14% in the finished compost.

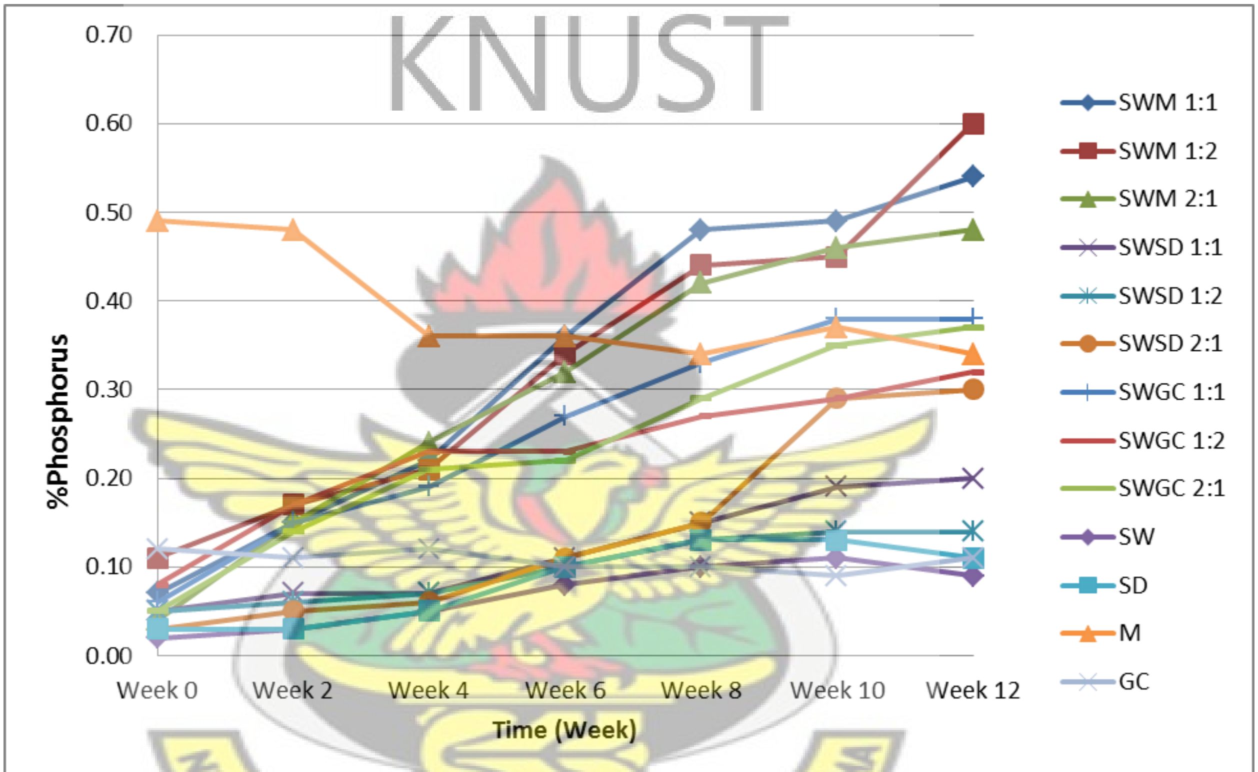

Fig 4.11: Mean bi-weekly phosphorus content for compost piles

Fig 4.11 above shows initial percentage values of phosphorus recorded highest and lowest values of 0.11% and 0.03% for SWM 1:2 and SWSD 2:1 respectively. Phosphorous value showed gradual increase throughout the composting process with SWM 1:2, SWM 1:1, SWM 2:1, recording the highest phosphorus values of 0.60%, 0.54% and 0.48%, with SWSD 1:1 SWSD 2:1 and SWGC 1:2, recording relatively low phosphorus values of 0.20%, 0.30%, and 0.32% respectively. The controls also recorded highest and lowest initial phosphorus values of 49% and 0.02% for M and SW respectively. M recorded high phosphorus value of 0.34 in finished compost.

CHAPTER FIVE

5.0 DISCUSSION

5.1 PHYSICO – CHEMICAL ANALYSIS

5.1.1 MOISTURE CONTENT

Moisture is necessary to support the metabolic activities of the micro-organisms in a compost. Adequate moisture is essential for microbial activity hence a balanced moisture content encourages the growth of microorganisms that break down the organic matter into humus (McLaurin and Wade, 2012). The optimum moisture content for efficient composting is recommended between 40% and 60% (Troy *et al.*, 2012). But most literature recommends a moisture content of 50%-60% for optimal composting condition (Trautmann and Richard, 1996). The initial moisture content of the compost piles recorded adequate moisture content for effective composting. High initial moisture content recorded with SWGC 1:2 and SWM 1:2 were due to the presence of proportionate solid waste combined with grass clippings and proportionate solid waste combined with moringa leaves. SWSDs recorded low moisture content due to high carbon content of the sawdust. This was stated by Smith and Friend (2013), that carbon –rich materials naturally tend to be dry with low moisture content.

Initial mean percentage values of moisture of the compost piles were below the recommended optimal range of 50%-60%. Chen *et al*. (2011), indicated that although optimal moisture content for composting is recommended between 50% and 60% the ideal moisture content of a compost pile may vary depending on the structure of the organic materials since compost pile varies with pile materials. However adjustments can be made by adding water to ensure compost piles attain optimum moisture for efficient decomposition.

Moisture content generally decreases as composting proceeds; hence the need to add additional water to the compost (Pace *et al.*, 1995). Mean percentage values throughout the composting period showed a declining trend in moisture content. The first fortnight mean percentage values showed a relatively drastic decrease in moisture content for all piles except SWSDs. The drastic decline in moisture may have occurred due to rapid decomposition by microbial activities during the first few weeks. Thermophilic micro-organisms dominate pile for active microbial activity few days after composting. Micro-organisms need water for their survival and to support their microbial activities. Hence during the first few weeks of composting where vigorous microbial activity took place, water absorption was high thereby decreasing the moisture content of the compost although adjustments were made when necessary. Moisture content generally decreases as composting proceeds (Pace *et al.*, 1995). Hence final mean percentage values showed decline in moisture content of the finished compost.

The controls however recorded high mean percentage moisture values. Nitrogen- rich materials moringa and grass clippings recorded highest moisture content as compared to the carbon-rich materials. The controls did not show much decline in moisture values although they recorded steady declining trend throughout the composting process. This is indicative of low decomposition rate due to decreased microbial activities of micro-organisms. Moisture content in excess of 65% suffocates decomposers, thereby inhibiting their growth and metabolic activities. Chen *et al*. (2011), confirmed this by indicating that higher moisture content fill pore spaces in a compost causing decrease oxygen diffusion and supply for metabolic activity thereby slowing down composting process and causing anaerobic condition in the compost (Kuo *et al.*,2013). This also explains the observed severe unpleasant odor that emanated from moringa and solid waste few days after composting

The mean difference in moisture content of the final compost was statistically significant ($P < 0.0001$). This implies that moisture content in the compost piles though initially did not fall within recommended range was adequate enough for microbial activity and thus efficient decomposition.

5.1.2 TOTAL SOLIDS

The total solids of compost give a measure of all the amount of solid materials contained in a compost. It is found to be the reverse of the moisture content of compost. Results obtained showed opposite trend of total solids and moisture content. Where mean percentage values of total solids decreased, mean percentage values of moisture content increased. Whilst mean percentage values of moisture content of almost all piles show decline with initial values not up to recommended range, mean percentage values of total solids consistently maintained relatively high values. From the results, for the first two weeks where moisture content had drastic decline in value, total solids also recorded highest values. Generally while moisture content had decreased mean percentage values for the finished compost, total solids had increased mean percentage values for finished compost for all piles. This is confirmed by Watson (2002), that total solids form the reverse of the moisture content of a compost.

The mean difference of the final compost was statistically significant ($P<0.0001$) signifying that regardless of the moisture content, all piles were efficiently transformed into stable compounds at the end of the composting period.

5.1.3 TEMPERATURE

Temperature is a key important parameter used in determining the success of a composting process. The source of heat in a compost is obtained from the micro-organisms and their microbial activities. As vigorous degradation takes place micro-organisms give off heat which stays in the pile as temperature. The composting process occurs basically in three phases which is conventionally defined in terms of the kinds of microorganism population that thrive in the different temperature ranges. These phases according to Hubbe *et al.* (2010), are the psychrophilic, mesophilic and thermophilic.

The result showed temperature variations of the composting piles as described in the different temperature phases (basically mesophilic-thermophilic-mesophilic). In Smith and Friend (2013), it was indicated that the drop in compost pile temperature is not a sign that composting is complete, but rather an indication that the compost pile is entering into another phase of the composting process, hence the changes in temperatures of the process was an indication of lag periods.

The initial temperatures between 25ºC to 27ºC depict the incubation stage of mesophilic bacteria populations in the compost. This is succeeded by a thermophilic phase with a general rise in temperature of between 34ºC to 46ºC, showing the dominance of heat-tolerant thermophilic bacteria to initiate rapid degradation of composting materials. The temperature remaining between 28ºC and 39ºC but with a fluctuating trend for days also indicated availability of decomposable composting materials and adequate oxygen for further microbial activities. This is intimated by Cooperband (2011), that mesophilic bacterial whose working temperature range is generally between 21ºC to 38ºC colonize the compose again and rapidly decompose organic matter, producing acids, carbon dioxide and heat. The gradual drop in temperature to 27ºC and below also indicated the process entering into a second mesophilic phase where temperature stabilized between 25ºC and 24ºC for some days until the end of the composting period. The general rise in temperature from day 6 and continued for six days (thermophilic phase) is an indicator of vigorous microbial activities since thermophilic bacteria use up too much of the degradable materials to sustain their population for any length of time during the process (Smith and Friend, 2013). The second mesophilic phase is intimated by Graves and Hattemer. (2000), that mesophilic bacteria consume remaining organic material with the help of other organisms to ensure further decomposition of the product of the thermophilic phase. The process entered into the curing phase when temperature dropped to the range of 25ºC and 24ºC and stabilized for some time until the end of the composting process.

5.1.4 COMPOST VOLUME

A general reduction in volume was observed for all compost piles. Generally volume reduction was considerably high with the nitrogen-rich materials. This may have been possible because of the ability of micro-organisms to effectively thrive in nitrogenous environment with high prolific growth. Decomposition rate is exponentially high because of vigorous microbial activities thereby resulting in a considerable reduction in volume of the compost. Carbon-rich compost piles were observed to have minimal reduction in volume throughout the composting period. This may have resulted due to the high sawdust proportion of the piles. Sawdust been a carbon-rich material with high lignin content reduced microbial growth and activities due to its complex structure. This is intimated by Richard (1996), that because lignin is the most difficult component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate for decomposition.

5.1.5 *E.COLI*, TOTAL COLIFORM AND FAECAL COLIFORM

E.coli, total coliform and faecal coliform are pathogens that can be found in a compost. Compost is characterized by numerous types of micro-organisms to degrade the organic substrate through their microbial activities. Pathogens found in compost usually are the ones that can be found in the raw materials used for the compost. The result showed a general decrease in the mean population counts of the *E.coli*, total coliform and faecal coliform at the end of the composting period.

The fall in population counts of the *E.coli*, total coliform and faecal coliform at the end of the composting period can be attributed to the presences of higher temperature in the compost during the thermophilic phase which reduced the pathogen population. This is corroborated by Hoffmeister *et al*. (2005), who though did not obtain decreased count for pathogen in their work but agreed with other authors who obtained decreased population count for pathogen and attributed it, to high temperatures in the compost during the thermophilic phase.

5.2.1 CHEMICAL CHANGES

5.2.2 CARBON, NITROGEN AND CARBON/NITROGEN RATIO

C/N ratio is one of the most important parameters that determine the extent of composting and degree of compost maturity (Shyamala and Belagali, 2012). Micro-organisms require carbon, nitrogen, phosphorus and potassium as primary nutrients for optimal microbial activities (Hubbe *et al.*, 2010). However, of particular importance is the C/N ratio of the composting materials because, composting micro-organisms sustain themselves with food from organic matter in the form of carbon and nitrogen. Hence a good proportion of carbon and nitrogen in a composting material provide a well-balanced diet for micro-organisms as well as energy and protein for optimal growth and reproduction.

Carbon and nitrogen levels may vary with each organic material (Smith and Friend, 2013). Solid waste and sawdust piles started the composting process with relatively high C/N ratio due to the sawdust proportion (carbon) while the solid waste and moringa piles and the solid waste and grass clippings piles also started composting with relatively low C/N ratio due to the moringa and grass clipping proportion (nitrogen).

Decomposition of highly rich carbon materials tends to be slow due to the high lignin content of the material. It was observed that decomposition of SWSD 1:1, SWSD 1:2, SWSD 2:1 samples was generally very slow resulting in low volume reduction at the end of the composting process compared to the other piles. Decomposition of carbon-rich materials is more slowly because they contain cellulose, hemicelluloses, and lignin. Lignin forms one of the main constituents of plant cell walls, and its complex chemical structure makes it highly resistant to microbial degradation (Chen *et al*., 2011). And this is because lignin is the most difficult component of the plant cell wall, hence the higher the lignin proportion the lower the bioavailability of the substrate to degradation (Richard, 1996). This may cause piles with high carbon content to sit for a year or even more without much apparent decay (Smith and Friend, 2013).

The C/N ratio of a compost is expected to fall during composting, and its final value can be used as one criterion to determine relative maturity of the compost (Hubbe *et al.*, 2010). The C/N ratio of the study generally showed a significant fall in values throughout the composting period. According to Chen *et al*. (2011), this decline occurs because each time organic compounds are consumed by micro-organisms, two-thirds of the carbon is given off as CO_2. The remaining third is incorporated along with nitrogen into microbial cells and then later released for further use once those cells die. However depending on the bioavailability of carbon and nitrogen, the C/N ratio in a compost may vary (Richard and Trautmann, 1996).

When decomposing organisms do not have the proper diet of carbon, the organisms may lose nitrogen to the atmosphere as ammonia (McLaurin and Wade, 2012). Nitrogen content however showed steady increasing trend all through the composting process. This implies that carbon and nitrogen proportions in the compost heaps were standard resulting in not much nitrogen loss to the atmosphere. Hence green and moist composting materials were observed to have relatively high nitrogen content while carbon-rich materials had relatively low nitrogen content.

Significant decrease in volume of SWM 1:1, SWM 1:2, SWM 2:1, SWGC 1:1, SWGC 1:2 and SWGC 2:1 was observed at the end of the composting process. This may have resulted from increased microbial activity during the composting process. A balanced proportion of nitrogen in a compost enhance protein production and protein being the building blocks of life increased growth and reproduction of micro-organisms, hence increased microbial activity resulting in faster degradation rate of the piles.

Increasing trend of nitrogen content also shows that not much nitrogen was lost to the atmosphere during the process. Although total nitrogen content values in the finished compost was not as high as estimated by Bueno *et al.* (2008), who defined acceptable total nitrogen content in finished compost at least 3.2%, Bueno *et al.*, (2008), and Hubbe *et al.*, (2010), in their study indicate that extending composting time (long time) is necessary to produce compost with high nitrogen content. Therefore considering the increasing trend of the nitrogen content depicts that, an extension of the composting period may have resulted in the estimated nitrogen content in the finished compost.

The mean difference of nitrogen content in the final compost was however statistically significant ($P<0.0001$).

5.2.2 pH

A pH of 7.0 is neutral in reaction; pH less than 7.0 designates an acidic condition, while a greater value than 7.0 is an alkaline condition. A recommended initial pH values of a compost range between 7.0 and 7.5. Compost piles recorded relatively high initial pH values indicating high initial pH levels for the composting process. Variation in pH levels of piles may have been due to variations in pH levels of the different raw material used for mixing the compost piles. This was indicated by Graves and Hattemer. (2000), that there is variation in pH levels of raw materials used for a compost mix. However these variations do not impact significantly on the composting process because different micro-organisms thrive at different pH levels of the compost.

High pH levels with variation in values observed on the first fortnight, sixth and tenth weeks throughout the composting period gave an indication of changes in both physical and chemical composition of the piles. Too much nitrogen content can cause rise in pH levels (Smith and Friend, 2013). High pH levels may have occurred due to the high nitrogen content of moringa especially with SWM1:2 since it recorded both the highest nitrogen content and pH level.

Although most pH values obtained were above the ideal pH range, normal composting process was observed and this was supported by Ahmed *et al.* (2007), who stated that there is no specific pH required for composting, as different organic materials suitable for composting have a range of pH from 5.0 to 12.0. Graves and Hattemer. (2000), also indicated that composting is possible at the extremes of 5.0 and 9.0 pH but at a slower pace.

5.2.3 ORGANIC MATTER

Organic matter of a compost simply provide a measure of the carbon- based materials in the compost (Darlington, 2001). Knowledge in changes of organic matter content in a compost informs the decomposition rate of the process. The general organic matter concentration reduction observed at the end of the composting period is an indicator of degradation of organic materials during the composting process. This is because during vigorous microbial activity, organic matter is converted into volatile carbon dioxide and water resulting in reduction in organic matter content. Therefore reduction in organic matter gives an indication of increased rate of microbial activity, this is supported by Troy *et al.* (2012) who indicated that the total loss of organic matter in a compost can be used as an indicator of compost degradation.

Highest mean percentage values organic matter content recorded for both initial and finished compost of SWSD 1:1, SWSD 1:2 and SWSD 2:1 was due to the sawdust proportion. This is because the high lignin concentration in sawdust which also have high resistive effect to microbial degradation due to its complex chemical structure, resulted in reduced microbial activities and decomposition; slowing down the decomposition process for the piles. Low carbon content in SWM 1:1, SWM 1:2 and SWM 2:1 resulted in low organic matter values because of high microbial activities and degradation.

5.2.4 ASH CONTENT

The ash content of a compost forms the inorganic fraction of the compost. Hence during organic matter (organic fraction) degradation where carbon is converted to volatile carbon dioxide and water, leading to reduction in organic fraction, there is a simultaneous occurrence of corresponding increase in ash content (inorganic fraction). This can be attributed to the reason why decrease of organic matter content caused increase of ash content of the compost. This trend was observed in both the initial and final mean percentage values of ash content.

5.2.5 POTASSIUM

Potassium in finished compost is much more available for plant uptake than nitrogen and phosphorus since potassium is not incorporated into organic matter (Mangan *et al.,* 2013). But because of its water solubility much of potassium can easily be leached out from a compost. However there was a general increasing trend of potassium with all composting piles throughout the process. This is because the insoluble potassium salts can be solubilized by the decomposition of the wastes. General increase in potassium was as a result of effective use of some fibrous materials like leaves or sawdust which could absorb relatively large quantities of water and still maintain structural integrity and porosity, thereby preventing loss of potassium from the compost formed (Shyamala and Belagali, 2012).

5.2.6 PHOSPHORUS

Phosphorus is always an important nutrient for plant growth (Shyamala and Belagali, 2012). Unlike potassium but similar to nitrogen, much of the phosphorus in finished compost is not readily available for plant uptake since it is incorporated in organic matter (Mangan *et al.,* 2013). The total phosphorus content was found to be higher in all compost piles. Gradual general increase in phosphorus content during composting process occurred due to decreased phosphorus water solubility with humification, so that, phosphorus solubility during the decomposition was subjected to further immobilization factor (Shyamala and Belagali, 2012).

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Composting process was successful through monitoring and analysis of selected Physico-chemical and biochemical parameters.

Three most important macro-nutrients recommended for soil amendment and plant growth; nitrogen, phosphorus and potassium (NPK) recorded appreciable increase at the end of the composting period. SWM 1:2 recorded highest NPK.

General pathogenic population count fall revealed generation of high heat in the compost to destroy pathogens.

At the end of the study solid waste mixed with Moringa *Oliefera* leaves had high NPK content making it the compost mixture with the best compost quality.

6.2 RECOMMENDATION

From the study it is recommended that

- SWM 1:2 should be used as soil amendment for planting to study the compost quality.
- Composting period should be extended to observe the increasing nitrogen trend of the compost pile, since nitrogen value did not reach recommended nitrogen value of 3.0 for a finished compost.

- High pH levels in compost especially piles of the different mixing ratios of solid waste/ moringa leaves should be studied.

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APPENDICES

APPENDIX A:

Percentage mean organic matter values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	16.09	23.37	21.52	11.01	15.09	11.53	9.28
SWM 1:1 Rep B	16.06	23.13	21.15	9.57	14.49	10.51	8.53
Mean	16.08	23.25	21.34	10.29	14.79	11.02	8.91
SWM 1:2 Rep A	15.29	23.07	24.75	14.03	15.12	12.59	11.29
SWM 1:2 Rep B	15.03	22.81	24.45	13.02	15.03	12.35	10.15
Mean	15.16	22.94	24.60	13.53	15.08	12.47	10.72
SWM 2:1 Rep A	17.20	24.01	24.08	11.18	12.96	11.33	8.88
SWM 2:1 Rep B	17.04	23.19	24.16	10.20	12.84	11.01	8.92
Mean	17.12	23.60	24.12	10.69	12.90	11.17	8.90
SWSD 1:1 Rep A	19.14	8.94	13.83	16.23	16.19	16.47	15.39
SWSD 1:1 Rep B	19.39	8.56	13.41	16.71	16.17	16.45	15.33
Mean	19.27	8.75	13.62	16.47	16.18	16.46	15.36
SWSD 1:2 Rep A	17.43	8.65	13.94	18.15	16.81	15.47	15.87
SWSD 1:2 Rep B	17.49	8.69	14.13	18.17	16.75	15.48	15.91
Mean	17.46	8.67	14.04	18.16	16.78	15.48	15.89
SWSD 2:1Rep A	25.21	8.59	24.03	13.12	14.03	9.96	13.11
SWSD 2:1 Rep B	25.19	8.63	24.00	13.15	14.03	10.08	13.17
Mean	25.20	8.61	24.01	13.14	14.03	10.02	13.14
SWGC 1:1 Rep A	24.93	10.12	22.79	13.36	11.61	9.54	11.73
SWGC 1:1 Rep B	25.30	10.48	23.01	13.44	11.52	9.98	11.79
Mean	25.11	10.30	22.90	13.40	11.61	9.76	11.76
SWGC 1:2 Rep A	24.75	8.11	16.38	8.98	10.17	10.53	10.70
SWGC 1:2 Rep B	24.91	8.09	16.74	9.56	10.09	10.49	10.69
Mean	24.83	8.10	16.56	9.27	10.13	10.51	10.69
SWGC 2:1 Rep A	18.04	12.42	8.11	12.09	11.88	12.31	12.43
SWGC 2:1 Rep B	18.10	12.58	8.25	12.11	12.08	12.35	12.49
Mean	18.07	12.50	8.18	12.10	11.98	12.33	12.46
SW	17.34	21.03	20.04	17.69	15.32	15.24	14.94
SD	14.99	10.36	10.24	10.09	10.08	9.83	9.54
M	15.01	14.92	14.35	13.94	13.12	13.07	12.08
GC	18.29	16.24	16.07	14.08	11.94	10.94	12.10

APPENDIX B:

Percentage mean moisture content values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	37.16	11.26	41.87	36.31	34.40	33.82	21.45
SWM 1:1 Rep B	37.16	11.24	41.95	36.39	34.42	33.90	21.35
Mean	37.16	11.25	41.91	36.35	34.41	33.86	21.40
SWM 1:2 Rep A	47.12	12.96	22.73	51.00	38.18	36.62	17.79
SWM 1:2 Rep B	47.16	13.02	22.79	51.00	38.24	36.68	17.72
Mean	47.14	12.99	22.78	51.00	38.21	36.65	17.76
SWM 2:1 Rep A	35.11	12.57	24.61	25.30	25.99	19.05	14.19
SWM 2:1 Rep B	35.15	12.69	24.55	25.32	25.95	19.09	14.15
Mean	35.13	12.65	24.58	25.31	25.97	19.07	14.17
SWSD 1:1 Rep A	35.16	27.97	35.31	32.32	36.95	39.69	21.26
SWSD 1:1 Rep B	35.23	27.19	35.39	32.40	36.83	39.61	21.22
Mean	35.21	27.58	35.35	32.36	36.89	39.65	21.24
SWSD 1:2 Rep A	31.83	19.10	34.73	34.89	35.64	36.99	18.28
SWSD 1:2 Rep B	31.79	19.02	34.77	34.85	35.70	36.93	18.32
Mean	31.81	19.06	34.75	34.87	35.67	36.96	18.30
SWSD 2:1 Rep A	31.36	38.58	29.68	37.27	37.99	38.92	19.20
SWSD 2:1 Rep B	31.34	38.64	29.60	37.19	37.97	38.94	19.20
Mean	31.35	38.60	29.64	37.24	37.98	38.93	19.20
SWGC 1:1 Rep A	40.03	32.37	25.11	27.24	26.79	23.79	16.79
SWGC 1:1 Rep B	39.99	32.23	25.03	27.32	26.75	23.85	16.91
Mean	40.01	32.30	25.07	27.28	26.77	23.82	16.85
SWGC 1:2 Rep A	59.23	25.29	21.23	21.69	21.45	12.69	15.78
SWGC 1:2 Rep B	59.29	25.25	21.27	21.71	21.41	12.71	15.84
Mean	59.26	25.28	21.24	21.70	21.43	14.70	15.81
SWGC 2:1 Rep A	38.08	22.25	27.77	25.81	25.37	22.38	16.58
SWGC 2:1Rep B	38.02	22.19	27.69	25.83	25.29	22.32	16.62
Mean	38.05	22.22	27.71	25.82	25.33	22.35	16.60
SW	56.91	54.99	49.10	43.97	37.89	36.78	34.26
SD	23.68	23.68	23.36	23.02	22.13	22.07	21.52
M	80.08	78.97	79.22	76.85	76.00	67.01	64.96
GC	82.01	81.70	81.61	80.35	80.01	79.99	79.49

APPENDIX C:

Percentage mean nitrogen values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	1.80	2.17	2.28	2.32	2.34	2.36	2.41
SWM 1:1 Rep B	1.98	2.23	2.32	2.34	2.36	2.40	2.41
Mean	1.89	2.20	2.31	2.33	2.35	2.38	2.41
SWM 1:2 Rep A	1.70	2.05	2.39	2.39	2.41	2.41	2.76
SWM 1:2 Rep B	1.52	2.11	2.37	2.39	2.39	2.41	2.84
Means	1.61	2.08	2.38	2.39	2.40	2.41	2.80
SWM 2:1 Rep A	1.11	1.96	2.27	2.28	2.29	2.30	2.32
SWM 2:1 Rep B	1.13	1.80	2.21	2.23	2.24	2.29	2.30
Mean	1.12	1.88	2.24	2.26	2.26	2.28	2.31
SWSD 1:1 Rep A	0.70	0.78	0.96	1.07	1.85	2.07	2.05
SWSD 1:1 Rep B	0.70	0.92	1.00	1.13	1.79	1.99	2.01
Mean	0.70	0.85	0.98	1.10	1.82	2.03	2.03
SWSD 1:2 Rep A	0.56	0.78	0.97	1.00	1.59	1.79	1.81
SWSD 1:2Rep B	0.56	0.81	0.99	1.08	1.63	1.81	1.83
Mean	0.56	0.79	0.98	1.04	1.61	1.80	1.82
SWSD 2:1 Rep A	0.69	1.05	1.36	1.46	1.77	2.11	2.07
SWSD 2:1 Rep B	0.57	0.93	1.30	1.43	1.80	2.03	2.13
Mean	0.63	0.99	1.33	1.45	1.78	2.07	2.10
SWGC 1:1 Rep A	1.06	1.91	2.00	2.05	2.04	2.05	2.07
SWGC 1:1 Rep B	1.16	1.45	2.00	2.01	2.02	2.03	2.07
Mean	1.12	1.68	2.00	2.03	2.03	2.04	2.07
SWGC 1:2 Rep A	1.15	1.65	1.93	1.97	1.99	2.05	2.08
SWGC 1:2 Rep B	1.23	1.53	1.99	1.99	2.09	2.15	2.16
Mean	1.19	1.59	1.96	1.98	2.04	2.10	2.12
SWGC 2:1 Rep A	1.50	1.96	2.26	2.38	2.39	2.42	2.43
SWGC 2:1 Rep B	1.30	1.90	2.50	2.42	2.43	2.46	2.47
Mean	1.40	1.93	2.38	2.40	2.41	2.44	2.45
SW	0.54	0.60	0.72	1.02	1.70	1.83	1.83
SD	0.52	0.58	0.65	0.92	1.45	1.68	1.70
M	3.43	3.45	3.48	3.23	3.08	2.98	2.42
GC	1.42	1.50	1.45	1.43	1.43	1.33	1.25

APPENDIX D:

Percentage mean carbon-nitrogen ratio values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	5.17	6.22	5.41	2.54	3.68	2.64	2.21
SWM 1:1 Rep B	4.72	6.03	5.35	2.55	2.55	2.72	2.07
Mean	4.94	6.13	5.38	2.55	3.12	2.68	2.14
SWM 1:2 Rep A	5.18	6.50	5.97	3.26	3.63	3.00	2.26
SWM 1:2 Rep B	5.75	6.29	6.01	3.30	3.62	2.97	2.18
Mean	5.46	6.40	5.99	3.28	3.63	2.99	2.22
SWM 2:1 Rep A	9.37	6.97	6.15	2.72	3.27	2.82	2.23
SWM 2:1 Rep B	9.17	7.61	6.33	2.77	3.32	2.82	2.24
Mean	9.27	7.29	6.24	2.75	3.29	2.82	2.24
SWSD 1:1 Rep A	15.94	6.53	8.23	8.95	5.03	4.58	4.34
SWSD 1:1 Rep B	16.02	5.50	7.89	8.42	5.23	4.81	4.44
Mean	15.98	6.01	8.06	8.68	5.13	4.70	4.39
SWSD 1:2 Rep A	18.12	6.48	8.42	10.47	6.14	5.02	5.11
SWSD 1:2 Rep B	18.05	6.17	8.19	9.80	5.94	4.95	5.01
Mean	18.08	6.33	8.31	10.14	6.04	4.99	5.06
SWSD 2:1 Rep A	21.23	4.76	10.24	5.19	4.59	2.74	3.68
SWSD 2:1 Rep B	25.59	5.37	10.70	5.34	4.52	2.86	3.57
Mean	23.41	5.05	10.47	5.27	4.56	2.80	3.63
SWGC 1:1 Rep A	13.75	3.11	6.65	3.78	3.30	2.18	3.30
SWGC 1:1 Rep B	12.53	4.13	6.63	3.88	3.32	2.22	3.28
Mean	13.14	3.62	6.64	3.83	3.31	2.21	3.29
SWGC 1:2 Rep A	12.53	2.86	4.94	2.71	2.95	2.38	2.20
SWGC 1:2 Rep B	11.69	3.05	4.85	2.70	2.80	2.31	2.05
Mean	12.11	2.95	4.89	2.71	2.88	2.34	2.13
SWGC 2:1 Rep A	6.93	3.68	2.11	2.95	2.93	2.96	2.98
SWGC 2:1 Rep B	8.07	3.84	1.88	2.88	2.87	2.89	2.91
Mean	7.50	3.76	1.99	2.92	2.90	2.93	2.95
SW	18.62	20.33	16.14	10.06	5.22	4.83	4.74
SD	16.71	10.36	9.14	6.36	4.02	3.39	3.25
M	2.54	2.51	2.39	2.50	2.47	2.54	2.90
GC	7.47	6.28	6.43	5.71	4.85	4.77	5.62

APPENDIX E:

Percentage mean potassium content values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	0.99	1.07	1.09	1.15	1.18	1.30	1.81
SWM 1:1 Rep B	0.97	1.01	1.08	1.09	1.28	1.36	1.85
Mean	0.98	1.04	1.09	1.12	1.23	1.33	1.82
SWM 1:2 Rep A	1.00	1.58	2.27	2.26	2.28	2.28	3.01
SWM 1:2 Rep B	1.00	1.68	2.25	2.26	2.28	2.28	2.81
Mean	1.00	1.63	2.26	2.26	2.28	2.28	2.91
SWM 2:1 Rep A	0.96	1.44	1.85	1.89	1.90	1.91	2.27
SWM 2:1 Rep B	1.00	1.38	1.77	1.79	1.82	1.87	2.23
Mean	0.98	1.41	1.81	1.84	1.86	1.89	2.25
SWSD 1:1 Rep A	1.14	1.16	1.16	1.16	1.19	1.19	1.21
SWSD 1:1 Rep B	1.10	1.14	1.16	1.16	1.17	1.19	1.25
Mean	1.12	1.15	1.16	1.16	1.18	1.19	1.23
SWSD 1:2 Rep A	0.69	0.79	0.88	0.91	0.93	0.93	0.97
SWSD 1:2 Rep B	0.75	0.81	0.86	0.87	0.89	0.91	0.93
Mean	0.72	0.80	0.87	0.89	0.91	0.93	0.95
SWSD 2:1 Rep A	0.63	1.08	1.34	1.41	1.48	1.53	1.59
SWSD 2:1 Rep B	0.55	1.02	1.48	1.49	1.52	1.61	1.65
Mean	0.59	1.05	1.41	1.45	1.50	1.57	1.62
SWGC 1:1	0.89	1.37	1.87	1.89	1.93	1.97	2.51
SWGC 1:1	0.83	1.41	1.91	1.93	1.97	1.99	2.59
Mean	0.86	1.39	1.89	1.91	1.95	1.98	2.55
SWGC 1:2 Rep A	0.45	0.92	1.26	1.31	1.66	1.81	1.81
SWGC 1:2 Rep B	0.41	0.98	1.30	1.37	1.70	1.85	1.85
Mean	0.43	0.95	1.28	1.34	1.68	1.83	1.83
SWGC 2:1 Rep A	0.53	1.39	2.13	2.14	2.14	2.15	2.55
SWGC 2:1 Rep B	0.59	1.41	2.17	2.18	2.18	2.21	2.67
Mean	0.56	1.40	2.15	2.16	2.16	2.18	2.61
SW	0.38	0.69	0.76	0.79	0.79	0.88	0.84
SD	0.45	0.79	0.84	0.86	0.95	0.94	0.89
M	1.34	1.36	1.24	1.24	1.19	1.15	1.15
GC	1.05	1.10	1.10	1.13	1.08	1.02	1.02

APPENDIX F:

Percentage mean pH values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	8.70	9.71	9.53	10.11	9. 71	10.16	9.02
SWM 1:1 Rep B	8.66	9.67	9.55	10.05	9. 63	10.12	8.91
Mean	8.68	9.60	9.53	10.08	9.67	10.14	8.95
SWM 1:2	9.36	9.75	9.90	9.23	9.81	10.29	10.01
SWM 1:2	9.28	9.81	9.92	9.13	9.83	10.23	9.99
Mean	9.32	9.78	9.91	9.18	9.82	10.26	10.00
SWM 2:1	9.26	9.58	8.31	10.00	9.96	10.12	9.87
SWM 2:1	9.30	9.62	8.25	10.04	10.00	10.18	9.91
Mean	9.28	9.60	8.28	10.02	9.98	10.15	9.89
SWSD 1:1 Rep A	7.23	8.82	9.50	8.64	8.58	8.74	8.40
SWSD 1:1 Rep B	7.27	8.74	9.34	8.70	8.50	8.68	8.41
Mean	7.25	8.70	9.46	8.67	8.54	8.71	8.40
SWSD 1:2 Rep A	7.27	8.70	8.39	8.13	8.71	8.00	9.10
SWSD 1:2 Rep A	7.35	8.74	8.41	8.17	8.75	8.00	9.04
Mean	7.32	8.72	8.40	8.15	8.73	8.00	9.07
SWSD 2:1 Rep A	7.50	8.31	9.46	9.09	9.80	9.17	9.24
SWSD 2:1 Rep B	7.46	8.33	9.60	9.02	9.84	9.11	9.16
Mean	7.48	8.32	9.53	9.06	9.81	9.15	9.20
SWGC 1:1 Rep A	7.77	9.68	9.34	10.00	9.89	10.24	9.90
SWGC 1:1 Rep B	7.89	9.60	9.26	10.02	9.83	10. 16	9.84
Mean	7.84	9.64	9.30	10.05	9.86	10.20	9.87
SWGC 1:2	7.25	9.80	9.40	9.50	9.53	9.62	9.07
SWGC 1:2	7.17	9.78	9.46	9.45	9.55	9.66	9.09
Mean	7.21	9.79	9.43	9.48	9.54	9.64	9.08
SWGC 2:1 Rep A	8.13	9.55	9.71	9.61	9.68	10.26	9.72
SWGC 2:1 Rep B	8.19	9.51	9.67	9.65	9.62	10.20	9.68
Mean	8.16	9.53	9.69	9.63	9.65	10.23	9.70
SW	7.20	7.81	8.06	8.11	9.14	9.14	9.09
SD	7.21	8.08	8.18	8.21	8.21	8.34	8.37
M	5.93	5.98	6.68	6.81	6.81	6.84	6.56
GC	7.16	7.10	7.88	8.00	7.98	8.30	8.33

APPENDIX G:

Percentage mean phosphorus values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	0.03	0.12	0.25	0.35	0.49	0.48	0.57
SWM 1:1 Rep B	0.11	0.18	0.19	0.37	0.47	0.51	0.53
Mean	0.07	0.15	0.22	0.36	0.48	0.49	0.54
SWM 1:2 Rep A	0.13	0.19	0.22	0.32	0.47	0.48	0.61
SWM 1:2 Rep B	0.09	0.15	0.20	0.36	0.41	0.42	0.59
Mean	0.11	0.17	0.21	0.34	0.44	0.45	0.60
SWM 2:1 Rep A	0.01	0.14	0.26	0.31	0.39	0.44	0.47
SWM 2:1 Rep B	0.07	0.16	0.22	0.33	0.45	0.48	0.49
Mean	0.04	0.15	0.24	0.32	0.42	0.46	0.48
SWSD 1:1 Rep A	0.02	0.05	0.04	0.09	0.14	0.17	0.16
SWSD 1:1 Rep B	0.08	0.09	0.10	0.13	0.16	0.21	0.24
Mean	0.05	0.07	0.07	0.11	0.15	0.19	0.20
SWSD 1:2 Rep A	0.07	0.08	0.08	0.10	0.11	0.12	0.13
SWSD 1:2 Rep B	0.03	0.04	0.06	0.10	0.15	0.16	0.15
Mean	0.05	0.06	0.07	0.10	0.13	0.14	0.14
SWSD 2:1 Rep A	0.02	0.03	0.06	0.09	0.13	0.26	0.27
SWSD 2:1 Rep B	0.05	0.07	0.08	0.13	0.17	0.32	0.33
Mean	0.03	0.05	0.06	0.11	0.15	0.29	0.30
SWGC 1:1 Rep A	0.05	0.16	0.18	0.25	0.34	0.36	0.36
SWGC 1:1 Rep B	0.07	0.14	0.20	0.29	0.32	0.40	0.40
Mean	0.06	0.15	0.19	0.27	0.33	0.38	0.38
SWGC 1:2 Rep A	0.06	0.19	0.27	0.26	0.28	0.28	0.30
SWGC 1:2 Rep B	0.10	0.15	0.19	0.20	0.26	0.30	0.34
Mean	0.08	0.17	0.23	0.23	0.27	0.29	0.32
SWGC 2:1 Rep A	0.03	0.12	0.18	0.20	0.30	0.34	0.38
SWGC 2:1 Rep B	0.07	0.16	0.24	0.24	0.28	0.36	0.36
Mean	0.05	0.14	0.21	0.22	0.29	0.35	0.37
SW	0.02	0.03	0.05	0.08	0.10	0.11	0.09
SD	0.03	0.03	0.05	0.10	0.13	0.13	0.11
M	0.49	0.48	0.36	0.36	0.34	0.37	0.34
GC	0.12	0.11	0.12	0.10	0.10	0.09	0.11

APPENDIX H:

Percentage mean organic carbon values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	9.31	13.51	12.34	5.91	8.62	6.37	5.13
SWM 1:1 Rep B	9.35	13.45	12.42	5.97	8.52	6.41	5.22
Mean	9.33	13.48	12.38	5.94	8.57	6.39	5.17
SWM 1:2 Rep A	8.81	13.33	14.29	7.81	8.75	7.23	6.24
SWM 1:2 Rep B	8.75	13.29	14.25	7.89	8.67	7.17	6.20
Mean	8.78	13.31	14.27	7.85	8.71	7.20	6.22
SWM 2:1 Rep A	10.41	13.68	13.97	6.22	7.51	6.50	5.13
SWM 2:1 Rep B	10.37	13.70	14.01	6.18	7.45	6.46	5.19
Mean	10.39	13.69	13.99	6.20	7.48	6.48	5.16
SWSD 1:1 Rep A	11.16	5.10	7.91	9.58	9.31	9.50	8.90
SWSD 1:1Rep B	11.22	5.06	7.89	9.52	9.37	9.58	8.93
Mean	11.18	5.08	7.90	9.55	9.34	9.55	8.91
SWSD 1:2 Rep A	10.15	5.06	8.17	10.47	9.77	9.00	9.25
SWSD 1:2 Rep B	10.11	5.00	8.11	10.59	9.69	8.96	9.17
Mean	10.13	5.03	8.14	10.53	9.73	8.98	9.21
SWSD 2:1 Rep A	14.65	5.00	13.93	7.59	8.13	5.79	7.63
SWSD 2:1 Rep B	14.59	5.00	13.91	7.65	8.15	5.81	7.61
Mean	14.62	5.00	13.92	7.62	8.14	5.80	7.62
SWGC 1:1 Rep A	14.58	5.95	13.30	7.76	6.75	4.48	6.84
SWGC 1:1 Rep B	14.54	5.99	13.26	7.80	6.71	4.52	6.80
Mean	14.56	5.97	13.28	7.78	6.73	4.50	6.82
SWGC 1:2 Rep A	14.42	4.72	9.54	5.35	5.89	4.89	4.59
SWGC 1:2 Rep B	14.39	4.68	9.66	5.39	5.87	4.97	4.43
Mean	14.40	4.70	9.60	5.37	5.88	4.93	4.46
SWGC 2:1 Rep A	10.46	7.22	4.77	7.03	7.01	7.17	7.25
SWGC 2:1 Rep B	10.50	7.30	4.71	6.99	6.99	7.13	7.21
Mean	10.48	7.26	4.74	7.01	7.00	7.15	7.23
SW	10.06	12.20	11.62	10.26	8.88	8.84	8.67
SD	8.69	6.01	5.94	5.85	5.83	5.70	5.53
M	8.71	8.65	8.32	8.09	7.60	7.58	7.01
GC	10.61	9.42	9.32	8.17	6.93	6.35	7.02

APPENDIX I:

Percentage mean ash content values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1 Rep A	21.81	19.72	31.35	43.02	39.60	38.92	52.94
SWM 1:1 Rep B	21.79	19.88	31.85	42.98	39.40	38.68	53.05
Mean	21.80	19.80	31.60	43.00	39.50	38.80	53.00
SWM 1:2 Rep A	17.11	18.78	27.05	31.03	31.74	32.23	45.41
SWM 1:2 Rep B	16.99	18.22	26.55	30.97	31.88	32.57	45.59
Mean	17.05	18.50	26.80	31.00	31.80	32.40	45.50
SWM 2:1 Rep A	16.20	19.11	28.78	39.17	36.32	37.06	50.63
SWM 2:1Rep B	16.32	18.98	28.82	39.23	36.08	37.34	50.17
Mean	16.26	19.00	28.80	39.20	36.20	37.20	50.40
SWSD 1:1 Rep A	13.66	11.27	13.00	20.84	22.69	24.39	28.26
SWSD 1:1 Rep B	13.74	11.33	13.00	20.36	22.91	24.41	28.14
Mean	13.70	11.30	13.00	20.60	22.80	24.40	28.20
SWSD 1:2 Rep A	12.63	11.79	12.21	18.63	21.54	25.15	28.00
SWSD 1:2 Rep B	12.57	11.81	12.19	18.57	21.86	25.25	28.00
Mean	12.60	11.80	12.20	18.60	21.70	25.20	28.00
SWSD 2:1 Rep A	11.87	11.96	16.42	26.61	25.07	28.84	29.42
SWSD 2:1 Rep B	11.93	12.04	16.38	26.59	25.11	28.96	29.38
Mean	11.90	12.00	16.40	26.60	25.09	28.90	29.40
SWGC 1:1 Rep A	20.83	24.14	29.00	36.41	37.12	39.04	38.58
SWGC 1:1 Rep B	20.37	24.26	27.40	35.99	36.90	38.96	38.62
Mean	20.60	24.20	28.20	36.20	37.01	39.00	38.60
SWGC 1:2 Rep A	21.32	43.00	38.66	43.06	31.65	20.57	42.22
SWGC 1:2 Rep B	21.18	43.01	38.54	42.94	31.83	20.39	42.21
Mean	21.20	43.00	38.60	43.00	31.74	20.48	42.20
SWGC 2:1 Rep A	13.35	15.16	31.01	33.03	33.00	33.79	38.62
SWGC 2:1 Rep B	13.45	15.04	30.59	32.57	33.00	33.81	38.58
Mean	13.40	15.10	30.80	32.80	33.00	33.80	38.60
SW	11.16	11.18	12.00	18.04	20.8	20.13	26.60
SD	11.03	11.30	12.03	18.29	21.00	24.12	27.67
M	6.52	10.89	11.77	17.69	21.40	24.40	24.96
GC	10.01	11.03	11.96	18.10	20.93	23.95	27.82

APPENDIX J:

Percentage mean total solids values for the duplicates of the ratios in weeks

COMPOST HEAP	0	2	4	6	8	10	12
SWM 1:1Rep A	62.82	88.86	51.07	63.62	65.61	63.12	78.64
SWM 1:1 Rep B	62.86	88.64	51.11	63.68	65.54	63.16	78.58
Mean	62.84	88.75	51.09	63.65	65.58	63.14	78.60
SWM 1:2 Rep A	52.88	84.34	77.26	49.00	61.77	63.39	82.21
SWM 1:2 Rep B	52.84	84.40	77.18	49.00	61.81	63.31	82.27
Mean	52.86	84.37	77.22	49.00	61.79	63.35	82.24
SWM 2:1 Rep A	64.90	87.36	75.43	74.83	74.08	80.96	85.79
SWM2:1Rep B	64.84	87.34	75.41	74.55	73.98	80.90	85.87
Mean	64.87	87.35	75.42	74.69	74.03	80.93	85.83
SWSD 1:1 Rep A	64.72	72.23	64.61	67 .73	63.24	60.38	78.80
SWSD 1:1Rep B	64.86	72.61	64.69	67.55	62.98	60.32	78.72
Mean	64.79	72.42	64.65	67.64	63.11	60.35	78.76
SWSD 1:2 Rep A	68.21	80.97	65.37	65.09	64.32	63.03	83.17
SWSD 1:2 Rep B	68.17	80.91	65.23	65.17	64.35	63.05	83.13
Mean	68.19	80.94	65.25	65.13	64.33	63.04	83.15
SWSD 2:1 Rep A	68.69	61.41	70.30	62.71	62.01	61.04	80.80
SWSD 2:1 Rep B	68.61	61.39	70.42	62.81	62.03	61.10	80.80
Mean	68.65	61.40	70.36	62.76	62.02	61.07	80.80
SWGC 1:1 Rep A	60.06	67.72	74.90	72.39	73.04	76.28	83.18
SWGC 1:1 Rep B	59.92	67.68	74.96	73.05	73.42	76.08	83.12
Mean	59.99	67.70	74.93	72.72	73.23	76.18	83.15
SWGC 1:2 Rep A	40.39	74.56	78.69	77.89	85.37	86.16	84.10
SWGC 1:2 Rep B	41.09	74.88	78.83	78.71	85.23	86.44	84.28
Mean	40.74	74.72	78.76	78.30	85.30	86.30	84.19
SWGC 2:1 Rep A	62.01	77.82	72.35	74.19	74.74	77.81	83.39
SWGC 2:1 Rep B	61.89	77.74	72.23	74.19	74.60	77.49	83.41
Mean	61.95	77.78	72.29	74.18	74.67	77.65	83.40
SW	43.09	45.01	50.90	56.03	62.11	63.22	65.74
SD	76.32	76.32	76.64	76.98	77.87	77.93	78.48
M	19.92	21.03	20.78	23.15	24.00	28.99	35.04
GC	17.99	18.30	18.39	19.65	19.91	20.00	20.51

APPENDIX K:

Initial *Ecoli*, Total Coliform and Feacal Coliform Values

Compost Heap	Total Coliforms/100ml cfu. 35/37ºc	Feacal Coliform/100ml cfu. 44ºc	E. Coli/100 ml cfu 44º
SWM 1:1 Rep 1	4.3×10^{11}	2.4×10^{9}	9.3×10^{7}
SWM 1:1 Rep 2	4.0×10^{11}	2.3×10^{9}	9.0×10^{7}
Mean	4.15×10^{11}	2.35×10^{9}	9.15×10^{7}
SWM 1:2 Rep 1	9.3×10^{10}	4.3×10^{8}	2.4×10^{6}
SWM 1:2 Rep 2	9.0×10^{10}	4.0×10^{8}	2.3×10^{6}
Mean	9.15×10^{10}	4.15×10^{8}	2.35×10^{6}
SWM 2:1 Rep 1	9.3×10^{10}	4.3×10^{8}	9.3×10^{6}
SWM 2:1 Rep 2	9.0×10^{10}	4.0×10^{8}	9.0×10^{6}
Mean	9.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:1 Rep 1	4.3×10^{10}	4.3×10^{8}	9.3×10^{6}
SWSD 1:1 Rep2	4.0×10^{10}	4.0×10^{8}	9.0×10^{6}
Mean	4.15×10^{10}	4.15×10^{8}	9.15×10^{6}
SWSD 1:2 Rep 1	2.4×10^{11}	9.3×10^{8}	2.4×10^{7}
SWSD 1:2 Rep2	2.3×10^{11}	9.0×10^{8}	2.0×10^{7}
Mean	2.35×10^{11}	9.15×10^{8}	2.2×10^{7}
SWSD 2:1 Rep 1	2.4×10^{10}	9.3×10^{8}	4.3×10^{7}
SWSD 2:1 Rep2	2.3×10^{10}	9.0×10^{8}	4.0×10^{7}
Mean	2.35×10^{10}	9.15×10^{8}	4.15×10^{7}
SWGC 1:1 Rep 1	9.3×10^{11}	4.3×10^{9}	9.3×10^{7}
SWGC 1:1 Rep 2	9.0×10^{11}	4.0×10^{9}	9.0×10^{7}
Mean	9.15×10^{11}	4.15×10^{9}	9.15×10^{7}
SWGC 1:2 Rep 1	4.3×10^{10}	9.3×10^{8}	9.3×10^{6}
SWGC 1:2 Rep 2	4.0×10^{10}	9.0×10^{8}	9.0×10^{6}
Mean	4.15×10^{10}	9.15×10^{8}	9.15×10^{6}
SWGC 2:1 Rep 1	2.4×10^{11}	4.3×10^{8}	4.3×10^{6}
SWGC 2:1 Rep 2	2.3×10^{11}	4.0×10^{8}	4.0×10^{6}
Mean	2.35×10^{11}	4.15×10^{8}	4.15×10^{6}
SW	9.3×10^{8}	9.15×10^{8}	2.3×10^{5}
SD	4.15×10^{6}	2.10×10^{6}	4.0×10^{4}
M	2.3×10^{5}	Nil	Nil
GC	2.35×10^{6}	4.0×10^{-4}	Nil

APPENDIX L:

Final *Ecoli*, Total Coliform and Faecal Coliform Values

Compost Heap	Total Coliforms/ 100ml cfu. 35/37ºc	Faecal Coliform / 100ml cfu. 44ºc	*Ecoli* / 100 ml cfu 44º
SWM 1:1 Rep 1	2.10×10^{10}	2.40×10^{7}	2.3×10^{5}
SWM 1:1 Rep 2	2.10×10^{10}	2.30×10^{7}	2.3×10^{5}
Mean	2.10×10^{10}	2.35×10^{7}	2.3×10^{5}
SWM 1:2 Rep 1	4.30×10^{10}	1.50×10^{6}	4.00×10^{5}
SWM 1:2 Rep 2	4.00×10^{10}	1.50×10^{6}	4.00×10^{5}
Mean	4.15×10^{10}	1.50×10^{6}	4.00×10^{5}
SWM 2:1 Rep 1	2.40×10^{10}	9.30×10^{7}	3.00×10^{5}
SWM 2:1 Rep 2	2.30×10^{10}	9.00×10^{7}	3.00×10^{5}
Mean	2.35×10^{10}	9.15×10^{7}	3.00×10^{5}
SWSD 1:1 Rep 1	9.30×10^{9}	2.10×10^{7}	9.00×10^{5}
SWSD 1:1 Rep2	9.00×10^{9}	2.10×10^{7}	9.00×10^{5}
Mean	9.15×10^{9}	2.10×10^{7}	9.00×10^{5}
SWSD 1:2 Rep 1	9.30×10^{10}	4.30×10^{7}	2.30×10^{6}
SWSD 1:2 Rep2	9.00×10^{10}	4.00×10^{7}	2.30×10^{6}
Mean	9.15×10^{10}	4.15×10^{7}	2.30×10^{6}
SWSD 2:1 Rep 1	2.10×10^{9}	2.40×10^{7}	4.00×10^{5}
SWSD 2:1 Rep2	2.10×10^{9}	2.30×10^{7}	4.00×10^{5}
Mean	2.10×10^{9}	2.35×10^{7}	4.00×10^{5}
SWGC 1:1 Rep 1	1.50×10^{10}	2.10×10^{7}	2.30×10^{6}
SWGC 1:1 Rep 2	1.50×10^{10}	2.10×10^{7}	2.30×10^{6}
Mean	1.50×10^{10}	2.10×10^{7}	2.30×10^{6}
SWGC 1:2 Rep 1	9.30×10^{9}	4.30×10^{7}	9.00×10^{5}
SWGC 1:2 Rep 2	9.00×10^{9}	4.00×10^{7}	9.00×10^{5}
Mean	9.15×10^{9}	4.15×10^{7}	9.00×10^{5}
SWGC 2:1 Rep 1	1.20×10^{10}	4.30×10^{7}	2.30×10^{5}
SWGC 2:1 Rep 2	1.10×10^{10}	4.00×10^{7}	2.30×10^{5}
Mean	1.15×10^{10}	4.15×10^{7}	2.30×10^{5}
SW	9.1×10^{8}	1.9×10^{6}	2.8×10^{4}
SD	3.2×10^{6}	8.9×10^{4}	3.8×10^{3}
M	9.9×10^{4}	Nil	Nil
GC	2.1×10^{6}	4.15×10^{-5}	Nil

APPENDIX M:

Mean weekly volume of compost heap and controls

Compost Heaps	Weeks												
	0	1	2	3	4	5	6	7	8	9	10	11	12
SWM 1:1	0.88	0.09	0.000745	0.000727	0.000546	0.000467	0.000427	0.000396	0.000275	0.000269	0.000278	0.000261	0.000253
SWM 1:2	0.23	0.1	0.00087	0.000962	0.000883	0.000752	0.000584	0.00054	0.000482	0.000486	0.000428	0.000477	0.000401
SWM 2:1	0.35	0.17	0.00148	0.00149	0.001	0.000511	0.000105	0.000447	0.000697	0.000692	0.000619	0.000752	0.000536
SWSD 1:1	0.26	0.17	0.00146	0.00159	0.00143	0.00117	0.00116	0.00111	0.0012	0.00108	0.0011	0.000985	0.000843
SWSD 1:2	0.38	0.29	0.00278	0.0026	0.00262	0.00231	0.00214	0.00196	0.00222	0.00218	0.00202	0.00191	0.00191
SWSD 2:1	0.4	0.2	0.00199	0.00214	0.00185	0.00166	0.00163	0.00153	0.00152	0.00141	0.00139	0.00126	0.00121
SWGC 1:1	0.19	0.11	0.00102	0.000994	0.000734	0.000551	0.000584	0.000488	0.000483	0.000417	0.000412	0.000394	0.000344
SWGC 1:2	0.28	0.11	0.0011	0.00077	0.000639	0.000689	0.00069	0.000645	0.000529	0.000487	0.000477	0.000457	0.000445
SWGC 2:1	0.34	0.19	0.00167	0.00136	0.00114	0.00116	0.000885	0.000929	0.000719	0.000793	0.000733	0.000719	0.000654
SW	0.000537	0.000503	0.00029	0.000275	0.000196	0.000187	0.000168	0.000162	0.000101	0.0000986	0.0000916	0.0000886	0.0000878
SD	0.000896	0.00071	0.000846	0.000837	0.000821	0.000831	0.000812	0.00074	0.000788	0.000711	0.000736	0.000779	0.000107
M	0.0215	0.0000561	0.0000308	0.0000339	0.000041	0.0000413	0.0000328	0.0000327	0.0000316	0.0000299	0.0000287	0.0000266	0.0000245
GC	0.000502	0.000376	0.000383	0.000429	0.000287	0.00026	0.000312	0.000274	0.000217	0.000203	0.000225	0.000178	0.000176

APPENDIX N:

Analysis of Variance of bi-weekly organic matter content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	255.1	12	21.25	1.050	0.4134	0.1391
Residual (within columns)	1579	78	20.24			
Total	1834	90				

Significance at <0.05

APPENDIX O:

Analysis of Variance of bi-weekly moisture content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	30130	12	2511	32.69	0.0001	0.8342
Residual (within columns)	5991	78	76.80			
Total	36120	90				

Significance at <0.05

APPENDIX P:

Analysis of Variance of bi-weekly nitrogen content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	29.58	12	2.465	13.21	0.0001	0.6702
Residual (within columns)	14.56	78	0.1866			
Total	44.14	90				

Significance at <0.05

APPENDIX Q:

Analysis of Variance of bi-weekly C/N ratio of both compost heaps and controls

Source of Variation	SS	df	MS	F	P value	R squared
Treatments (between columns)	519.4	12	43.29	2.733	0.0039	0.2960
Residual (within columns)	1235	78	15.84			
Total	1755	90				

Significance at <0.05

APPENDIX R:

Analysis of Variance of bi-weekly Potassium content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	15.37	12	1.281	9.053	0.0001	0.5821
Residual (within columns)	11.04	78	0.1415			
Total	26.41	90				

Significance at <0.05

APPENDIX S:

Analysis of Variance of bi-weekly pH of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	72.74	12	6.062	14.98	0.0001	0.6974
Residual (within columns)	31.56	78	0.4046			
Total	104.3	90				

Significance at <0.05

APPENDIX T:

Analysis of Variance of bi-weekly Phosphorus content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	1.013	12	0.08444	7.156	0.0001	0.5240
Residual (within columns)	0.9204	78	0.01180			
Total	1.934	90				

Significance at <0.05

APPENDIX U:

Analysis of Variance of bi-weekly organic carbon of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	92.52	12	7.710	1.091	0.3798	0.1437
Residual (within columns)	551.4	78	7.069			
Total	643.9	90				

Significance at <0.05

APPENDIX V:

Analysis of Variance of bi-weekly Ash content of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	4502	12	375.2	5.099	0.0001	0.4396
Residual (within columns)	5740	78	73.58			
Total	10240	90				

Significance at <0.05

APPENDIX W:

Analysis of Variance of bi-weekly total solids of both compost heaps and controls

Source of Variation	SS	df	MS	F	P-value	R squared
Treatments (between columns)	30510	12	2543	31.92	0.0001	0.8308
Residual (within columns)	6214	78	79.67			
Total	36730	90				

Significance at <0.05