KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

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DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

ASSESSMENT OF COMPOST QUALITY FROM CO-COMPOSTING KITCHEN WASTE WITH GRASS CLIPPINGS

BY

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DECLARATION

I do hereby declare that the work herein presented is the result of my own research under the supervision of Dr. Bernard Fei-Baffoe of the Department Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology. Other inclusions from various authors have been duly acknowledged and cited.

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DEDICATION

I dedicate this research work to my parents Major (Rtd) and Mrs. Acheampong, my siblings, also to Mr. and Mrs. Botwe not forgetting Colonel Yaw Asamoah and my dear husband Nana Yaw Minta Botwe.

God bless you all for your unflinching love and support.

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ABSTRACT

To prevent the interruption of the carbon cycle by the disposal of waste to landfills, organic kitchen waste requires proper treatment such as composting to reduce its uncontrolled degradation on disposal sites and subsequent greenhouse gases, odour emissions and nutrient losses. The aim of this study was to investigate the quality of compost generated from co-composting kitchen waste with grass clippings and the influence of different ratios and turning regimes on the quality of the compost produced. Wastes were mixed in ratios of 1:1, 1:2, and 2:1 (v/v) ratio for food waste / grass clippings which were denoted by R1, R2 and R3. Turning of compost heaps was done manually in three different regimes; once weekly, every three days and everyday (T1, T3 and T7). Composting was conducted over a 60 days period where the temperature profiles were recorded twice a day and the carbon-to-nitrogen ratios were measured as an indication of compost maturity as well as other indicators of compost maturity such as pH, potassium, phosphorus, organic matter, carbon, nitrogen, moisture content, volume, faecal and total coliform. Again, turning was observed to influence the extent of decomposition much more than the quality of the compost. From the results, it can be concluded that, co-composting of kitchen waste with grass clippings produces acceptable quality compost, which can be used as fertilizer or soil amendment.

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R1	Food Waste / Grass clipping ratio (1:1)
R2	Food Waste / Grass clipping ratio (1:2)
R3	Food Waste / Grass clipping ratio (2:1)
R4	Control (only food waste)
T1	Turning regime of once weekly
T3	Turning regime of every three days
T7	Turning regime of everyday
MPN	Most Probable Number
ANOVA	Analysis of Variance
pH	Hydrogen ion concentration
N	Nitrogen
C	Carbon
P	Phosphorus
OM	Organic matter
K	Potassium
MC	Moisture content
TS	Total solids
TC	Total coliform
FC	Faecal coliform

CHAPTER ONE

1.0 INTRODUCTION

Problems of waste management have existed ever since humans made a transition from hunting and gathering societies to settled communities. Waste is more easily recognized than defined. Something can become waste when it is no longer useful to the owner or it is used and fails to fulfill its purpose (Gourlay, 1992). It could as well be any substance or object which the holder discards or intends or is required to discard (EC, EU Waste Framework Directive, 2008/98/).

Waste can be categorized into organic and inorganic waste, there are also, many alternatives when it comes to sublevels (United Nations Environment Program, 2005), the distinct difference between the composition of waste in developing and developed countries is the degree of organic content. In general, developing countries have a larger extent of organic waste, a difference which can be up to three times the degree of organic content in waste from a developed country (Medina, 2010).

According to Razvi *et al*. (1989), approximately 70 % (by weight) of waste generated is biodegradable. Proper management of solid waste has become a major concern overwhelming practically all communities of the world today. In developing countries most especially, the problem stems from increase in population and issues of waste management such as, constraints related to economics, technology, and qualified personnel to narrow the choice of acceptable solid waste management, treatment, and disposal options (OECD, 2004).

On an average daily waste generation per capita of 0.45 kg, Ghana generates annually about 3 million tons of solid waste based on an estimated population of about 18 million in which Accra and Kumasi alone produces about 3,000 tons of solid waste daily (Mensah and Larbi, 2005), and in all about 44 % of waste produced in Kumasi are biodegradable organics (Mensah and Larbi, 2005). Nevertheless only 10 % of this waste generated is properly disposed off as estimated by Mensah and Larbi (2005).

Landfilling and incineration are the most widely used means of solid waste disposal throughout the world. In Ghana for instance landfills used for waste management are primarily open dumps that have no leachate or gas recovery systems. Further to this, land filling of biodegradable waste is proven to contribute to environmental degradation mainly through the production of highly polluting leachate and methane gas which constitute about 30 % of the global anthropogenic emissions of methane to the atmosphere (COM, 1996).

However, as landfills reach their capacity with its associated increased nuisance factor of organic wastes putrefaction, composting tends to be an increasingly viable means of organic waste management. The use of composting to stabilize putrescible wastes and to transform them into a valuable resource is presently experiencing an expanding trend of application in many countries as well as Ghana, as landfill sites become scarce and expensive and as people are more aware of the impacts that land disposal or mass burning of unsorted wastes have on the environment and on their health.

Composting of organic waste is an environmentally sound means of recycling raw organic material into valuable soil amendments with many uses.

Composting is the biological decomposition of wastes consisting of organic substances of plant or animal origin under controlled conditions to a state sufficiently stable for nuisance-free storage and utilization (Diaz *et al.,* 1993).

Bulking agents also known as bulking particles are very important to control composting parameters including the air supply and moisture (Adhikari *et al.*, 2008).

Bulking agents are supplemented in the composting process serving different purposes like energy source for microbes, appropriate air movement through the pile by increasing porosity, good absorption and to enhance the degradation of composting materials.

Recognised bulking agents used for composting include sawdust rice hulls and chips of tree cuttings, horticultural waste compost and mulch hay and wood shavings, they also include grass hay, wheat straw, corn stalks, grass clippings, rabbit manure, fruit and vegetable waste, garden trimmings, horse manure deciduous leaves and cow dung (Cekmecelioglu *et al.*, 2005; Chikae *et al.,* 2006; Gea *et al*., 2007; Kalamdhad *et al.*,2008; Stabnikova *et al*.,2005; Sundberg and Jönsson, 2005) Food waste, saw dust, yard trimmings and paper materials were traditionally been landfilled as components of municipal solid waste (U.S. Congress Office of Technology Assessment, 1989) and can henceforth be used as bulking agents in composting. This study seeks to assess the quality of compost from co-composting kitchen waste with grass clippings as bulking agent.

1.1 PROBLEM STATEMENT AND JUSTIFICATION

Disposal of kitchen waste, which contains about 80 % of moisture to the landfills,

causes various problems like easy putrefaction, offensive odour and pollution of ground and surface water by leachate (Rogoshewski *et al.*, 1983; Wang *et al.*, 2001). Due to interruption of the carbon cycle by disposal of waste to landfills, organic kitchen waste requires proper composting system to reduce its uncontrolled degradation on disposal sites and subsequent greenhouse gases, odour and nutrient emissions (Luostarinen and Rintala*,* 2007). In addition, the nutritive matter in kitchen waste which could be tapped for composting may be lost if it is just dumped into landfills as it will break up naturally and never be used directly again.

While people give attention to recycling inorganic wastes such as plastics, glass and metals, kitchen waste which is rich in organic material and possesses more than 90% of biodegradability can also be easily recycled into compost (Veeken and Hamelers, 1999).Composting of kitchen waste can be an effective method to reduce waste in landfills while helping conserve the environment. Kitchen waste is produced everyday and everywhere from processed and unprocessed food for human consumption, and its composition is quite variable which serves as good criteria for quality compost feedstock. An optimised kitchen waste formulation and composition involving the use of bulking materials and presence of microbes are important in ensuring the commencement of an effective composting process (Cayuela *et al.*, 2006;Cekmecelioglu *et al.*, 2005; Chang and Chen, 2008; Fang *et al.*, 2001; Ishii and Takii, 2003; Stabnikova *et al.*, 2005).

1.2 MAIN OBJECTIVE

The main objective of this study was to assess the compost quality produced from co-composting food waste generated on KNUST campus with grass clippings.

1.3 SPECIFIC OBJECTIVES

- To evaluate the effect of different turning regimes on the compost quality
- To assess the influence of varying ratios on the physico-chemical and biological parameters of compost quality
- To determine the compost quality at the end of the process

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 HISTORY OF COMPOSTING

Reference and mentions to compost occur in the 10th and 12th century Arab writing in medieval church text and in Renaissance literature. Composting is not a recent practice. Composting is an ancient technology, practiced today at every scale from the backyard compost pile to large commercial operations (Smith *et al.*, 2007).

Composting can be traced at least as far back as Marcus Cato, a farmer and statesman from Rome, Italy, who lived over 2,200 years ago. He reported the virtues of compost for enhancing agricultural productivity, stating that all food and animal wastes should be composted and returned to the soil (http://web.extension.illinois.edu/homecompost/ history.cfm).

There are Roman and biblical references to composting as well, however, one of the first records of the application of this technique in agriculture dates back to the Empire of Akkad in Mesopotamia, about 4500 years ago. Since then several civilizations, including Chinese, Egyptians, Greeks and Romans, piled in stacks of vegetable matter, manure, food scraps and other organic waste, and left them to decompose and stabilize until they are ready to be returned to the soil (Rodale *et al.*, 1960).

The first president of the United States, George Washington, was also the nation's first recognized avid composter. Washington recognized the degradative effects of farming on soil and he built a "dung repository" to make compost from the animal manures so hecould replenish the soil's organic matter. Further to this, he designed a building specifically for that purpose on his farm in Mount Vernon, Virginia (Higgins, 2001; Pogue and Arner, 1997)

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

By the 19th century, composting was commonly practiced to restore organic matter to soils. Today organic methods of farming and gardening are more popular than ever as farmers are moving away from harmful fertilizers and pesticides. With this growing movement and trend, there comes ironically, a return to past methods involving the use of natural compost or manure to re-nourish soils (US Composting Council, 2008).

2.2 DEFINITION OF COMPOSTING

UNEP (2009) defines composting as a biological decomposition of biodegradable solid waste under controlled predominantly aerobic conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture. Again, Diaz et al. (1993) defined composting as the biological decomposition of wastes consisting of organic substances of plant or animal origin under controlled conditions to a state sufficiently stable for nuisance-free storage and utilization. In other definitions composting is a biological process which reduces the volume and mass of solid organic wastes, while producing a safe, stabilized and nutrient enriched soil amendment (Pace et al., 1995; Mato et al., 1994).

It can also be defined as the controlled, heat dependent, microbiological process of decomposing organic materials into a biologically stable, humus-rich material (Alexander, 1996). It is “the disinfected and stabilized product of the decomposition process that is used or sold for use as a soil amendment, artificial topsoil, growing medium amendment or other similar uses" (Storey et al, 1995).

Composting process uses microorganisms to degrade the organic content of the waste. Aerobic composting proceeds at a higher rate and converts the heterogeneous organic waste materials into homogeneous and stable humus (Centre for Environment and Development, 2003).

According to the UNEP (2009), composting is the option that, with few exceptions, best fits within the limited resources available in developing countries. A characteristic that renders composting especially suitable is its adaptability to a broad range of situations. According to Zerbock (2003), a low-technology approach to waste reduction is composting. He further says that in developing countries, the average city's municipal waste stream is over 50 % organic material.

2.3 PRINCIPLES OF COMPOSTING

During composting, microbial decomposition aerobically transforms organic substrates into a stable, humus-like material (Brown and Subler, 2007). Therefore compost is produced through the activity of aerobic microorganisms that require oxygen, moisture, and food in order to multiply. These microorganisms in turn generate heat, water vapor, and carbon dioxide as they transform raw material into a stable soil conditioner (Alexander, 1996). Effective composting begins with a basic knowledge of the material or feedstock properties, the general principles of decomposition, and a method for controlling the process. Several feedstock characteristics are critical in the composting process. These include carbon to nitrogen (C/N) ratio, moisture content, and the size and distribution of the feedstock particles (Rynk *et al*, 1992).

2.3.1 COMPOSTING PROCESS

The processes of composting are undertaken by groups of microorganisms which are naturally found in soils. Bacteria, fungi, actinomycetes and protozoa colonize organic material and break them down to fuel their own growth and reproduction. Initial temperatures of between 10 and 45 ˚C support a host of mesophilic microorganisms, but as microbial biomass (and metabolic activity) increases, temperatures quickly move into the 55 – 70 ˚C range, which is inhospitable to the mesophiles and instead supports thermophilic microorganisms which are responsible for the active phase of composting. It is during this phase that temperatures are sufficient to kill weed seeds and pathogens. Following the high-temperature active phase, mesophiles re-colonize the compost to continue decomposition during the curing phase, which can last for a period of weeks to months, depending upon substrate chemistry, water and oxygen contents (Cooperband, 2002).

The whole process is one of natural biological breakdown of organic materials, with successions of different microbes responsible for the degradation of different chemical components of those materials. Microorganisms function most efficiently when certain environmental parameters are within a relatively narrow range, and it is important that these are provided if the whole composting process is to be as rapid and thorough as possible. There are two fundamental types of composting aerobic and anaerobic:

AEROBIC

Aerobic composting is the decomposition of organic wastes in the presence of oxygen (air); products from this process include carbon dioxide (CO_2), ammonia (NH_3), water and heat. This can be used to treat any type of organic waste but, effective composting requires the right blend of ingredients and conditions. These include moisture contents of around 60 -70 % and carbon to nitrogen ratios (C/N) of 30/1. Any significant variation inhibits the degradation process. Generally wood and paper provide a significant source of carbon while sewage sludge and food waste provide nitrogen. To ensure an adequate supply of oxygen throughout, ventilation of the waste, either forced or passive is essential (Yvette *et al.,* 2000).

ANAEROBIC

Anaerobic composting is the decomposition of organic wastes in the absence of oxygen, the products being methane (CH_4), carbon dioxide (CO_2), ammonia (NH_3) and trace amounts of other gases and organic acids. Anaerobic composting was traditionally used to compost animal manure and human sewage sludge, but recently is has become more common for some municipal solid waste (MSW) and green waste to be treated in this way (Yvette *et al*., 2000).

2.4 COMPOSTING TECHNOLOGIES

Four methods are commonly used by the composting industry to turn feedstock into finished compost (Rynk *et al*., 1992; Haug, 1993). These methods include passive composting, aerated static piles, windrows, and in-vessel composting.

2.4.1 PASSIVE COMPOSTING

Passive composting is probably the most common method used today because it involves simply stacking feedstock and leaving them to decompose over a long period oftime. Very little, if any, management is performed once the pile has been constructed. Initial composting parameters, such as moisture, are controlled, but control over these parameters is not usually maintained. Passive composting is relatively easy, but can have problems such as odor generation from anaerobic conditions and leachate from too much moisture. The process also requires an extended period of time for complete composting (Rynk *et al.*, 1992).

2.4.2 AERATED STATIC PILE

Aerated static pile modifies the passive composting technique by using blowers or vacuums to supply air to the composting feedstock. This process does not involve turning or agitation of the piles after the initial mixing of feedstock. Bulking agents are often used to help maintain the porosity of the compost piles, which aids in aeration. In this type of composting, the capacity of the blowers and the characteristics of the feedstock dictate the size of the piles. Electronic feedback controls are often used to monitor the pile temperature and control the operation of blowers or vacuums (Rynk *et al.*, 1992).

2.4.3 WINDROW COMPOSTING

Windrow composting is another common method used by which materials are placed in long rows and turned or aerated by mechanical equipment to maintain optimum conditions. Dimensions of the windrow normally range from 3 to 12 feet high and from 8 to 20 feet wide. The size and shape of the windrows is based on the characteristics of feedstocks and the type of equipment used for turning. Windrow aeration is accomplished through the natural chimney ventilation effect of warm air rising through the pile and by mechanical turning. Mechanical turning is usually done with a front-end loader or a machine specifically designed for turning windrows. The flow rate of air into the pile is determined by the porosity of the feedstocks. Frequent turning helps maintain a porous media and allows for the replenishment of oxygen used by the microorganisms. The area where the composting takes place is commonly referred to as a compost pad. The size of the pad depends on the volume of material handled, the windrow shape and length, and the type of equipment used for turning. Advantages of this composting system are the possibility to manage large volumes of wastes, a good stabilization of the end product, and relatively low-capital investments (Rynk *et al.*, 1992).

2.4.4 IN-VESSEL COMPOSTING

In-vessel composting refers to any type of composting that takes place inside a structure, container, or vessel. Each type of system relies upon mechanical aeration and turning to enhance and decrease the duration of the composting process. The goal of in-vessel composting systems is to combine various composting techniques into one controlled environment, which utilizes the strengths and minimizes the weaknesses inherent to other forms of composting. These systems control the moisture and temperature of the feedstock during composting, and require frequent turning to maintain a good feedstock mixture. High capital and operational costs are normal characteristics of in-vessel systems, which are often highly automated. In-vessel systems are often used where available land is a limiting factor (Rynk *et al.*, 1992).

2.5 FACTORS AFFECTING COMPOSTING

2.5.1 C/N RATIO

The supply of carbon (C) relative to nitrogen (N) is an important quality of compost feedstock. It is designated as the C/N ratio. The ratio of C/N is the parameter most often considered in studies dealing with the composition of compost mixtures (Dickson *et al.*, 1991). Of many elements required for microbial growth, carbon and nitrogen contents of a matrix are the most influential affecting substrate decomposition throughout composting. Nevertheless, these two elements have to be not only simply available, but necessarily in a balanced ratio. As noted by Beck (1997), if the C/N ratio is too high temperature in the compost pile may fail to rise, whereas if the C/N ratio is too low the mixture may emit unpleasant odours since nitrogen will be supplied in excess and will be lost as ammonia. It has been recommended that compost mixtures should be prepared so that the initial C/N ratios are between 25:1 to 30:1 or even 40:1 which is considered ideal for faster compost stabilization (Dickson *et al.*, 1991).

Table 1: shows the carbon to nitrogen ratios of selected composting materials.

Table 1: Carbon: nitrogen ratios of selected composting materials

MATERIAL	C:N RATIO
CORN STALKS	50-100:1
FRUIT WASTE	35:1
GRASS CLIPPINGS	12-25:1
HAY, GREEN	25:1
LEAVES, ASH, BLACK ELDER AND ELM	21:-28:1
LEAVES, PINE	60-100:1
LEAVES, OTHER	30-80:1
MANURE, HORSE, COW	20-25:1
PAPER	170-200:1
SAWDUST	200-500:1
SEAWEED	19:1
STRAW	40-100:2
VEGETABLE WASTE	12-25:1
WEEDS	25:1
WOOD CHIPS	500-700:1

Source: (http://web.extension.illinois.edu/homecompost/science.html).

If the carbon of a specific compostable material (e.g., lignin rich residues) is scarcely assimilable (i.e., resistant to biological degradation), a higher C/N ratio in the initial substrate biomass can still be acceptable. However, matrices with C/N ratios higher than 40:1 decompose at relatively slow rates, so longer composting times are needed.

2.5.2 MOISTURE

Moisture is of crucial importance for two basic reasons

i. It facilitates substrate decomposition through mobilizing microorganisms activities
ii. It provides better condition for nitrogen fixation in compost

A low moisture condition can restrict the mobility of organisms. Under drier conditions the ammonium and ammonia present generate a higher vapour pressure; thus creating conditions for nitrogen loss. Ammonia is highly soluble in water; thus higher moisture content inhibits ammonia escape from compost and promotes nitrogen fixation. Addition of water is sometimes recommended for preventing premature drying (Atkinson et al.,1996). The ammonia that is preserved in a moist environment can subsequently become immobilized in the biomass of new generation of microorganisms (Liang et al., 2000). The moisture level in a compost mixture should be optimized in order to achieve the best result (Beck, 1997, Bueno et al., 2008).

Dickson et al. (1991) and Dougherty (1998), recommended a moisture content in the range of 40 to 60 % whereas Tchobanoglous et al. (1993) recommended 50 to 60 % moisture, Petric et al. (2009), on the other hand recommended an initial 69% moisture for composting poultry manure and wheat straw. Bueno et al. (2008) found most favorable results at the intermediate moisture level in their experimental design which was 40 %. Hwang et al. (2002) recommended a moisture content of 46 % for composting kitchen waste. It has further been recommended to maintain 60 % moisture in the outer layer of compost (Recycled Organics Unit, 2007).

The lower temperature in the outer layer of a compost pile can be favorable for conversion of ammonia to more stable forms, i.e., nitrogen fixation (Rynk et al., 1992). However excessively wet compost fills the smaller pores, limiting the oxygen transport and causing emission of odours that are associated with anaerobic conditions.

Accordingly, Zhang et al. (2009) recommended that the moisture conditions be kept below 65 %.

2.5.3 pH

The acidity or alkalinity of the organic materials, measured by the pH value, affects the growth of microorganisms. The initial pH values in the range 4.2 to 7.2 or 7.0 to 7.5 have been recommended (Tchobanoglous *et al.*, 1993; Dickson *et al.*, 1991). It has been reported that the production of lactic and acetic acid during initial degradation of biomass often leads to an acidic pH in the ranges of 4.2 to 5.5 (Hultman, 2009). In cases where the materials to be composted are very acidic it is sometimes recommended to add a small amount of lime or fly-ash (Dickson *et al.,* 1991; Beck, 1997). Later in the thermophilic stage of composting the pH can rise to 9 resulting in the release of ammonia, and therefore the pH usually returns to near neutral conditions as the compost becomes mature (Hultman, 2009). With an increase pH to about 6 the organic acids are decomposed by microorganisms and the associated rise in pH is sometimes taken as evidence of successful composting. Optimum pH for bacterial and fungal activities has been reported in the ranges of 6 to 7.5 and 5.5 to 8.9 respectively (Golueke, 1972).

2.5.4 TEMPERATURE

Temperature is probably the most important factor affecting microbial metabolism during composting. It is either a consequence or a determinant of the microbial activity. In general, composting is characterized by a first step of temperature rising, possibly to the thermophilic range (T > 50 ^{o}C). Composting of putrescible organic wastes is typically a thermophilic process in which the most favourable range of temperatures for microbial decomposition should be maintained between 55 and 60 ^{o}C and preferably should not exceed 65 ^{o}C. Temperatures in excess of 55 ^{o}C for several days (at least three) are usually instrumental in inactivation of pathogenic organisms, especially when septic materials such as sewage sludge are processed. Above 60 ^{o}C the metabolic activity of microorganisms begins to decline. To maintain temperature within the optimal range during the thermophilic phase, substrate biomass aeration should be provided. Moving air through the matrix has the potential to dissipate heat excess. Heat removal occurs primarily via sensible heating of aeration air, while evaporation can also remove heat because of the high heat required for water vaporization (Tchobanoglous *et al.*, 1993).

2.5.5 AERATION AND OXYGEN SUPPLY

Aeration and oxygen supply allows oxidative reactions to predominate in composting matrices; it also provides the necessary oxygen to decomposers, removes water vapour and other gaseous product and can be used to adjust temperatures to a desired level. Though the contact of oxygen-rich air with biomass is essential for composting to occur the challenge lies in accomplishing such contact within a relatively compact mass of material such that temperatures are able to rise, further stimulating the metabolic processes. However inadequate oxygen levels lead to the establishment of an anaerobic microflora, which can produce odorous compounds and phytotoxic metabolites.

Aeration undoubtedly also occurs due to wind and due to diffusion of air. However mostreferences recommend further measures to promote air contact during composting, by either tuning of the compost pile or use of forced aeration. Tchobanoglous *et al.* (1993) stated that aerobic composting requires the oxygen within the pile to be kept at a concentration at least half that of the ambient air. Wang *et al.* (2007) made detailed measurement of turned and aerated piles and found oxygen concentration below 1.5 % in the air within non-aerated compost piles. The oxygen level was always above 4 % in the aerated piles. By suppressing the amount of air i.e. microaerobic conditions, the thermophilic phase could be extended from 15 to 23 days. Zhang *et al*. (2009) found that there was an optimum level of aeration that would minimize emission of odour, however the main adverse consequence of having insufficient air was an observed low rate of biodegradation. Maeda and Matsuda (1997) and Tamura *et al.* (1999) reported that a higher aeration rate reduced methane and nitrous oxide emissions but increased ammonia volatilization. Beck-Friis *et al*. (2003) compared compost aeration at different oxygen concentrations (1 %, 2.5 % and 16 %). They observed prolongation of the mesophilic phases and reduction of microbial activities at lower oxygen concentration (1 % and 2.5 %). The ammonia condition was also delayed and nitrous oxide was notobserved in the thermophilic stage. Brouillette *et al*. (1996) reported an increased degree of composting along with increased nitrogen fixation and aeration.

2.5.6 PARTICLE SIZE

By reducing the sizes of the feedstock components in the compost one can increase the area that is readily accessible to enzymatic action (Nazhad *et al.*, 1995). Thus particle size reduction in general as a means of accelerating the process (Bueno *et al.*, 2008).

Tchobanoglous *et al*. (1993) recommended particles between about 2.5 cm and 7.2 cm in size. Bueno *et al.* (2008) obtained best results when cellulosic materials were chopped to about 1 cm. Fujino *et al*. (2008) found that they could further reduce resistance to biodegradation if they ground the material with a mortar and pestle. Lhadi *et al*. (2006) observed when the particle size is small enough then it can be easier to discern effects on biodegradability attributable to chemical differences. Dickson *et al*. (1991) recommended varying the size of particles in a compost mixture in order to achieve a good air-permeability of the mixture. Bending and Turner (1999) also observed that particle size may influence nitrogen mineralization or protection of aging microbial tissues from attack by microorganisms. Sharma *et al*. (1998), reported higher intentional biogas emission over (70 %) by an anaerobic digester using smaller size particles.

2.5.7 VOLUME

Volume is a factor in retaining compost pile heat. The optimum volume size depends on whether the pile is aerated, whether it is turned and whether extremities are partly contained in insulating materials. In case of static piles, Dickson *et al*. (1991) recommend a minimum volume of approximately one cubic meter to ensure sufficient self-insulation so that the material will heat up.

2.5.8 TURNING

Turning was already advocated by Howard (1935) as part of the indore composting process, and the practice is recommended in popular books on composting (Ball, 1997). Tchobanoglous *et al*. (1993) stated that turning can be used as needed to overcome the following problems; charring, drying, caking and air channeling.

Alburquerque *et al*. (2009) found that turning improved results even in the case of aerated compost piles. The frequency of turning can be an issue, since every turning results in at least a temporary reduction in temperature of the contents. A turning frequency of once or twice a week is recommended by Tchobanoglous *et al.*, (1993). Dickson *et al*. (1991) and Beck (1997) recommend turning piles once a week and suggest that more frequent turning may not be a good investment of time and energy. Tiquia *et al*. (1997) found that turning a mixture of swine manure and sawdust every two or four days yielded faster composting, compared to weekly turning. Ball (1997) recommends turning the pile again as soon as the core temperature drops to about 55 ^{o}C. Brito *et al*. (2008) observed that turning increased the rate, but did no greatly change the end results of composting of cattle slurry as long as one is willing to wait long enough for unturned piles to reach completion. Golouеke (1972) concluded on the basis of the small size and temporary nature of temperature drops due to turning that the biological processes of composting are highly active and somewhat self-regulating. His book recommends turning schedules that depend on moisture content. Piles containing 60 to 70 % moisture should be turned at a two day interval, whereas piles with 40 to 60 % moisture should be turned each third day. However, a more soggy pile might be in greater need of turning as a means of ensuring adequate aeration.

2.5.9 ODOUR

Good aeration promotes active aerobic decomposition. When piles are too wet, too large, not porous enough, or are degrading too quickly, aerobic bacteria cannot get enough oxygen and anaerobic bacteria take over. Sulfur compounds and other by-products of anaerobic respiration form and odours build. Odours can originate from specific incoming or stockpiled feedstocks (such as sewage sludge, liquid manure or fish by-products) or poorly aerated compost piles. Anaerobic respiration, and resulting odours, can also occur in standing pools of water around compost windrows and in water retention ponds. You can minimize odours by proper pile management. Once aerobic conditions are reestablished, the bacteria will "eat" the odourous compounds (Tiquia *et al.,* 1996).

2.6 COMPOST QUALITY

Compost Quality reflects the chemical makeup of a given compost. A compost can be mature (i.e., fully composted) but can be of poor quality due to low nutrient levels. Not all composts are created equal, what goes in as feedstocks partly determines what comes out. Compost quality depends on the composting process used, the state of biological activity, and, most importantly, the intended use of the compost.

There are some specific chemical, physical and biological parameters that can be used to evaluate compost quality such as moisture content, heavy metal, stability, and nutrient content, particle size distribution, pathogen levels, product consistency over time.

However for on-farm use of compost as a soil amendment, moisture content, organic matter content, C/N ratio and pH should be determined before its application (James, *et al*., 2008).

Table 2 below shows the composition of mineral elements in finished compost.

Table 2: Composition of mineral elements in finished compost

SUBSTANCE	PERCENTAGE BY WEIGHT
Organic matter	25-50
Carbon	8-50
Phosphorus (P_2O_5)	0.3-3.5
Potassium (K_2O)	0.5-1.8
Calcium (Ca_2O)	1.5-7
Nitrogen (as N)	0.4-3.5
Ash	20-65

Source: Gotass, 1956

2.7 CONTRIBUTION OF BULKING AGENT TO COMPOST QUALITY

For maintaining the moisture and carbon-to nitrogen ratio, the bulking agents play a very important role in the composting. The bulking agents, also called the bulking particles are very effective to control the air supply, moisture and other important composting parameters (Adhikari *et al.*, 2008). There are different types of bulking agents used in the composting such as wood chips, saw dust, grass hay, wheat straw, corn stalks, grass clippings, rabbit manure, fruit and vegetable waste, garden trimmings, horse manure, deciduous leaves, cow dung, etc. (Gea *et al.*, 2007). The use of bulking agent in composting process is very useful and efficient for producing good quality, time efficient and cost effective compost. There are several examples of effectiveness of bulking agents in composting as increased nutritive value, fast degradation of materials which makes bulking agent a very useful composting material (Chang and Chen, 2010).

2.8 BENEFITS OF COMPOST

2.8.1 PHYSICAL BENEFITS

IMPROVED STRUCTURE

Compost greatly enhances the physical structure of soils. In fine-textured (clay, clay loam) soils, the addition of compost reduces bulk density, improve friability (workability) and porosity, and increase its water and gas permeability, thereby reducingerosion. It has both an immediate and long-term positive impact on soil structure when added to soils in sufficient quantities. It resists compaction in fine-textured soils and increases water holding capacity and improves soil aggregation in coarse-textured (sandy) soils. The soil-binding properties of compost are due to its humus content.

Humus is a stable residue resulting from a high degree of organic matter decomposition. The constituents of the humus act as a soil 'glue,' holding soil particles together, makingthem more resistant to erosion and improving the soil's ability to hold moisture (US Composting Council, 2008).

MOISTURE MANAGEMENT

The addition of compost may provide greater drought resistance and more efficient water utilization, in turn the frequency and intensity of irrigation may be reduced. Recent research also suggests that the addition of compost in sandy soils can facilitate moisture dispersion by allowing water to more readily move laterally from its point of application (US Composting Council, 2008).

2.8.2 BIOLOGICAL BENEFITS

PROVIDES SOIL BIOTA

The activity of soil organisms is essential in productive soils and for healthy plants. Their activity is largely based on the presence of organic matter. Soil microorganisms include bacteria, protozoa, actinomycetes, and fungi. They are not only found within compost, but proliferate within soil media. Microorganisms play an important role in organic matter decomposition which, in turn, leads to humus formation and nutrient availability. Microorganisms can also promote root activity as specific fungi work symbiotically with plant roots, assisting them in the extraction of nutrients from soils. Sufficient levels of organic matter also encourage the growth of earthworms, which through tunneling, increase water infiltration and aeration (US Composting Council, 2008).

SUPPRESSES PLANT DISEASES

Disease incidence on many plants may be influenced by the level and type of organic matter and microorganisms present in soils. Research has shown that increased population of certain microorganisms may suppress specific plant diseases such as pythium and fusarium as well as nematodes. Efforts are being made to optimize the composting process in order to increase the population of these beneficial microbes (US Composting Council, 2008).

2.8.3 CHEMICAL BENEFITS

MODIFIES AND STABILIZES pH

The addition of compost to soil may modify the pH of the final mix. Depending on the pH of the compost and of the native soil, compost addition may raise or lower the soil compost blend’s pH. Therefore, the addition of a neutral to slightly alkaline compost to an acidic soil will increase soil pH if added in appropriate quantities. In specific conditions, compost has been found to affect soil pH even when applied at quantities as low as 10-20 tons per acre. The incorporation of compost also has the ability to buffer or stabilize soil pH, whereby it will more effectively resist pH change (US Composting Council, 2008).

INCREASES CATION EXCHANGE CAPACITY

Compost will also improve the cation exchange capacity of soils, enabling them to retainnutrients longer. It will also allow crops to more effectively utilize nutrients, while reducing nutrient loss by leaching. For this reason, the fertility of soils is often tied to their organic matter content. Improving the cation exchange capacity of sandy soils by adding compost can greatly improve the retention of plant nutrients in the root zone (US Composting Council, 2008).

PROVIDES NUTRIENTS

Compost products contain a considerable variety of macro and micronutrients. Although often seen as a good source of nitrogen, phosphorous, and potassium, compost also contains micronutrients essential for plant growth. Since compost contains relatively stable sources of organic matter, these nutrients are supplied in a slow-release form. On a pound-by- pound basis, large quantities of nutrients are not typically found in compost in comparison to most commercial fertilizers. However, compost is usually applied at much greater rates, therefore, it can have a significant cumulative effect on nutrient availability. The addition of compost can affect both fertilizer and pH adjustment (lime/sulfur addition). Compost not only provides some nutrition, but often makes current fertilizer programs more effective (US Composting Council, 2008).

2.8.4 ADDITIONAL BENEFITS OF COMPOST

Some additional benefits of compost have been identified, and has led to new uses for it. These benefits and uses are described below.

BINDS CONTAMINANTS

Compost has the ability to bind heavy metals and other contaminants, reducing both their leach ability and absorption by plants. Therefore, sites contaminated with various pollutants may often be improved by amending the native soil with compost. The same binding effect allows compost to be used as a filter media for storm water treatment and has been shown to minimize leaching of pesticides in soil systems (US Composting Council, 2008).

DEGRADES COMPOUNDS

The microbes found in compost are also able to degrade some toxic organic compounds, including petroleum (hydrocarbons). This is one of the reasons why compost is being used in bioremediation of petroleum contaminated soils (US Composting Council, 2008)

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 (US Composting Council, 2008).

EROSION CONTROL

Coarser composts have been used with great success as a mulch for erosion control and have been successfully used on sites where conventional erosion control methods have not performed well. In Europe, fine compost has been mixed with water and sprayed onto slopes to control erosion (US Composting Council, 2008).

WEED CONTROL

Immature composts or ones which possess substances detrimental to plant growth (phytotoxins) are also being tested as an alternative to plastic mulches for vegetable and fruit production. While aiding in moisture conservation and moderating soil temperatures, immature composts also can act as mild herbicides (US Composting Council, 2008).

CHAPTER THREE

3. METHODOLOGY

3.1 STUDY AREA AND SAMPLING

The study area was eating joints behind and around Department of Theoretical and Applied Biology of Kwame Nkrumah University of Science and Technology located in Kumasi, Ghana. The main university campus which is about seven square miles in area, is located about eight miles (13 km) to the east of Kumasi, the Ashanti Regional capital with coordinates 06°41′5.67″N and 01°34′13.87″W.

3.1.2 SOURCE OF WASTE

Food waste was collected from various eating joints located on KNUST campus but most especially from eateries behind and around Department of Theoretical and Applied Biology. This was done personally with the aid of some of the food joint operators.

Food waste comprised mainly of solid organic waste materials such as ripe and unripe plantain peels, cassava peels, fruit waste, vegetable waste and food leftovers/scraps. Grass clippings were acquired from the Horticulture Department of the School of Agriculture. There was no need for sorting to remove any inorganic or unwanted materials as most of the waste was not contaminated.

3.1.3 EXPERIMENTAL DESIGN

The experimental set up was done under a constructed shed on a piece of plot located behind Department of Theoretical and Applied Biology on the campus of the Kwame Nkrumah University of Science and Technology. The essence of the shed was to provide shelter for the set up and protect the composting process from extreme environmental conditions such as rain and excessive sunlight. The pile was constructed in windrow form and the different turning regimes applied manually with a shovel to enhance aerobic decomposition. The compost piles were prepared by measuring in volumes different ratios of food waste to grass clippings using a 10 litre bucket. The ratios used were 1:1 food waste to grass clippings (R1), 1:2 food waste to grass clippings (R2), 2:1 food waste to grass clippings (R3) and 1:0 food waste only (R4). All the various ratios were replicated twice including the control, which consisted of only food waste, hence there were 21 piles in all. The different ratios of the food waste and grass clippings measured were then mixed thoroughly, using a shovel, until a uniform mixture was obtained. The same measurements and procedures were carried out for the replicates. They were then put in three groups where different turning regimes were applied to each group. The first group was turned everyday, the second group (thus the first replicate) was turned every three days and the last group/third group (thus the second replicate) was turned once a week for the entire composting period. Furthermore, preliminary test were conducted to adjust the moisture content to be in the range of 50 to 60 % for all the ratios to enable efficient composting. This was achieved by adding water in some cases. Plate 1: shows a picture of the composting process set up.

Plate 1: Setup for composting process

3.2 LABORATORY ANALYSIS OF COMPOST

3.2.1 MEASUREMENT OF TEMPERATURE

A mercury in glass thermometer with a temperature range of 0 ^oC to 100 ^oC was inserted into each pile at five different points; one at the peak of the pile and at the other four edges of the pile. The temperature readings were recorded from all the five different points. The average for all five points recorded was then calculated. Temperature measurements were taken twice per each day, thus morning and evening at 10 am and 4 pm respectively. Readings were taken each day for the entire period of the composting process.

3.2.2 pH DETERMINATION

Ten grammes (10 g) of compost sample was measured and placed into a 50 ml beaker, and 20 ml of distilled water was added. The sample was allowed to absorb the water without stirring, and then stirred thoroughly for 10 seconds using a glass rod for uniform mixture of sample and water. The suspension was stirred for 30 minutes after which the probe of the pH Tester 20 pH meter was inserted into the solution for the recordings to be taken

3.2.3 MEASUREMENT OF PILE VOLUME

The pile volume was measured every two weeks with the aid of a measuring tape and a metal rod. The measuring tape was used to measure the circumference whereas the rod was used to measure the height occupied by the pile. The total volume was then calculated using the area of a cone formula;

$$v = \frac{1}{3}\pi r^2 h$$

Where v = volume   r = radius

c = circumference   h = height

The measurement of the volume was taken every two weeks for the entire composting period.

3.2.4 CARBON CONTENT DETERMINATION

All the organic and inorganic carbon was burnt off after heating at a temperature of 400 °C. It is generally assumed that, on average, OM contains about 58 percent organic carbon. Hence percentage carbon was calculated using the formula: The % C is given by; % OM × 0.58.

3.2.5 TOTAL NITROGEN DETERMINATION

Nitrogen determination was carried out in three main steps namely digestion, distillation and titration. The digestion stage was carried out by weighing 10 g of oven dried sample into 500 ml long-necked Kjeldahl flask and 10 ml distilled water to moisten the sample. A spatula full of Kjeldahl catalyst (mixture of 1 part selenium + 10 parts $CUSO_4$ + 100 parts Na_2SO_4) was added, followed by 20 ml conc. H_2SO_4. The solution was digested until the solution was clear and colorless. The flask and its contents were allowed to cool, and the fluid decanted into a 100 ml volumetric flask and made up to the mark with distilled water.

Distillation was carried out by transferring an aliquot of 10 ml fluid from the digested sample by means of a pipette into Kjeldahl distillation flask. Ninety milliliters (90 ml) ofdistilled water was added to make it up to 100 ml in the distillation flask. Twenty milliliters (20 ml) of 40 % NaOH was dispensed into the contents of the distillation flask. The distillate was collected over 10ml of 4 % boric acid and 3 drops of mixed indicator added in a 200 ml conical flask. The presence of nitrogen was indicated by a blue color change. The last stage which is the titration stage was done by titrating the collected distillate (about 100 ml) with 0.1N HCl until the blue color changed to grey and then to pink. A blank was prepared and the run through the process. The percentage nitrogen was calculated using the formula given below:

$$\% \ N = \frac{14 \times (A-B) \times N \times 100}{(1000 \times 0.2)}$$

Where:

A = volume of standard HCl used in sample titration

B = volume of standard HCl used in blank titration

N = normality of standard HCl

3.2.6 C/N RATIO

Carbon and nitrogen levels vary with each organic material and thus their C/N ratios. This was calculated using the formula:

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

3.2.7 ORGANIC MATTER (LOSS ON IGNITION METHOD)

Ten grammes (10 g) of compost sample was weighed into an empty crucible, the crucible was placed with the compost sample in a drying oven for 4 hours at 105 ^{o}C. It was then removed from the drying oven and placed in a dry atmosphere to cool, it was then transferred into a muffle furnace with the temperature set to 400 ^{o}C for 4 hours. The crucible was removed from the muffle furnace and the final weight after ignition was taken.

The percentage of OM is given by:

Percent organic matter (OM) = $(W_1 - W_2)/W_1 \times 100$

Where:

W_1 is the weight of compost at 105 °C;

W_2 is the weight of compost at 400 ^{o}C

3.2.8 MOISTURE CONTENT DETERMINATION

Ten grammes (10 g) of the compost samples were weighed using an electronic precision balance. The samples were dried in an oven for 24 hours at a temperature of 105 ^{o}C and reweighed. The difference in weight expressed the amount of water in the sample taken.

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

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

Where:

W1 is the initial weight of sample before drying

W2 is the final weight of sample after drying.

3.2.8 TOTAL SOLIDS

This is the measure of the amount of material remaining after all the water has been evaporated. Total dry solids content was determined by weighting 10 g of each sample into a Petri dish and designated W_1, oven dried for 24 hours at 105^oC and then reweighed, W_2. The percentage of total dry solid is then calculated using the formulae;

$$\text{Total Solids} = \frac{W_2}{W_1} \times 100$$

Thus, % Total solids = (100 − % Moisture)

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

3.2.9 PHOSPHORUS AND POTASSIUM DETERMINATION

Two grammes (2g) of a ground plant sample was weighed and placed into 300 ml volumetric flask and 10 ml of di-acid mixture of HNO_3 and $HClO_4$ with ratio 9: 4 was added and the content well mixed by swirling thoroughly (Motsara and Roy, 2008; Okalebo and Gathua, 1993). The flask with content was then placed on a hotplate in the fume chamber and heated, starting at 85 ^oC and then temperature raised to 150 ^oC. Heating continued until the production of red NO_2 fumes ceased. The contents were further heated until the volume reduced to 3 – 4 ml and became colorless or yellowish, but not dried. This was done to reduce interference by organic matter and to convert metal associated particulate to a form (the free metal) that can be determined by the Atomic Absorption Spectrophotometer (AAS). The contents were cooled and the volume made up with distilled water and filtered through No 1 filter paper. The resulting solution was preserved at 4^0C, ready for spectrophotometric determination of phosphorus and the result digitally determined in milligram per litre (mg/l).

3.2.10 POTASSIUM DETERMINATION

Potassium determination was run through the same process ad that of phosphorus but potassium was determined in the resulting solution by the use of a flame photometer in milligram per litre (mg/l) after the photometer had been calibrated.

3.2.11 MICROBIAL ANALYSIS (TOTAL AND FAECAL COLIFORMS)

The Most Probable Number (MPN) method was used to determine total and faecal coliforms in the samples (Anon, 1994). Ten grammes (10 g) of each compost sample was introduced into 90 ml of distilled water. Serial dilutions of 10^{-1} to 10^{-5} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into a 5 ml MacConkey broth and incubated at 35 ^{o}C for total and 44 ^{o}C for faecal coliforms for 24 hours. Tubes showing colour change from purple to yellow after the 24 hour period were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from the Most Probable Number tables.

3.3 STATISTICAL ANALYSIS

The two factor (two way) ANOVA was used to evaluate the interrelation of anormality of the various parameters, they were shown to have a normal distribution prior to the analysis at a significance level of 95 %.

CHAPTER FOUR

4. RESULTS

Results obtained from assessing the parameters used to indicate the effect of turning andratios on the quality of the compost from co-composting grass clippings and kitchen waste are indicated. The parameters measured include; temperature, pH, volume, carbon, nitrogen, carbon to nitrogen, organic matter, moisture content, total solids, phosphorus, potassium, total and faecal coliform.

4.1 TEMPERATURE

Temperature variation during the composting period and the ambient temperature is also shown in figure 1 below. The figure shows the gradual rise of the pile temperatures from a near ambient temperature to a peak of 53 ^oC and then saw gradual reduction to the ambient temperature (28 to 30 ^oC). But getting to the end of the composting process period, the temperatures fell below the ambient temperature (30 ^oC) to as low as 27 ^oC.

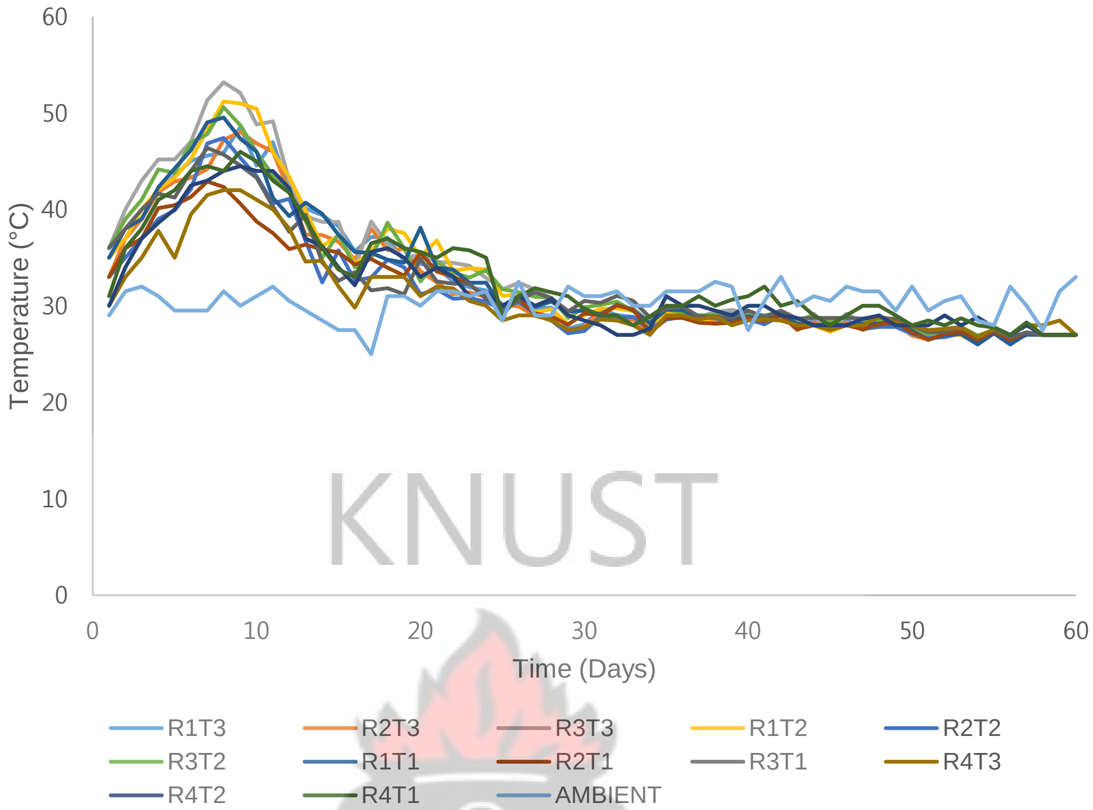

Fig.1: Mean daily temperature of both control and experimental treatments

4.2 pH

Table 3: Statistical summary of pH values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard value
6.47	0.05	5.78	7.18	6.5-7.2

The summary statistics of the pH observed over the period of the experimentation is shown in Table 3. The average pH is 6.47 with a maximum of 7.18 and a minimum of 5.78. The average pH was found to be not statistically significant for both the turning criteria (i.e. daily, every three days and weekly) and the independent ratios (i.e. 1:0, 1:1, 1:2 and 2:1). This implies that the pH of the samples was not affected by turning or the different ratios during the entire composting period. The range for the dataset shows that if falls in the acceptable range as postulated by Carr *et al*. (1998)

4.3 VOLUME

Table 4: Statistical summary of Volume values for the entire composting period

Mean	Standard error	Minimum	Maximum
0.06	0.00	0.03	0.11

Table 4 shows the summary statistics of the volume observed during the entire experimentation period. The average volume recorded was not statistically significant for both the independent ratios and the various turning criteria (Appendix 2) with p-values >0.05. The average volume was 0.06 with a maximum of 0.11 and a minimum of 0.03, meaning that the volume of the samples was not influenced by ratio or turning and/or the interaction between the two.

4.4 TOTAL ORGANIC CARBON

Table 5: Summary statistics of TOC values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard v alue
34.84	0.09	26.44	46.83	8-50

Table 5 above gives a statistical summary of observation of TOC and it indicates an average TOC of 34.84 with a maximum of 46.48 and a minimum of 26.44. The average TOC was not statistically significant in both the turning criteria and the independent ratios implying that the TOC of the samples were not affected by turning or ratio. The range for the dataset shows that it is within the accepted standard range as stipulated by Gotass (1956).

4.5 NITROGEN

Table 6: Summary statistic of N values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard values
2.44	0.05	1.71	3.22	0.4-3.5

The summary of statistical values observed for Nitrogen during the entire experimentation period is displayed in Table 6. The average N value is 2.44 with a maximum of 3.22 and a minimum of 1.71. The average N is not statistically significant for both the turning criteria and the independent ratios ($p > 0.05$) (Appendix 5). This implies that the N of the samples was not affected by the turning or the different ratios. The range for the dataset is within the acceptable range according to Gotass (1956) for the composition of mineral elements in finished compost.

4.6 C/N Ratio

Table 7: Statistical summary of C/N values for the entire composting period

Mean	Standard error	Minimum	Maximum
14.31	0.26	11.82	19.35

Table 7 above gives a statistical summary of observation of Carbon/Nitrogen values. The average C/N is 14.31 with a maximum of 19.35 and a minimum of 11.82. The average C/N was not statistically significant in the turning criteria ($p > 0.05$) but was significant in the independent ratios ($p < 0.05$) (Appendix 5) implying that the C/N of the samples were not affected by turning but was affected by ratio unlike the other parameters which showed no significance for all treatments.

4.7 ORGANIC MATTER

Table 8: Summary statistic of OM values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard value
59.94	1.57	45.59	80.74	30-70

The summary statistics of the OM observed during the entire experimentation period is summed up in Table 8. The average volume is statistically not significant for both the independent ratios and the various turning criteria. The average volume was 59.94 with a maximum of 80.74 and a minimum of 45.59, meaning that the OM of the samples were not influenced by neither ratio nor turning. The above dataset points to the fact that it is in the acceptable range according to USEPA (1994).

4.8 MOISTURE CONTENT

Table 9: Statistical summary of MC values for the entire composting period

Mean	Standard error	Minimum	Maximum
44.15	01.44	24.28	58.17

The statistical summary observed for MC during the period of the experimentation is summarized in table 9. The average MC value is 44.15 with a maximum of 58.17 and a minimum of 24.28. The average MC is not statistically significant for both the turning criteria and the independent ratios. This implies that the MC of the samples was not influenced by the different ratios and/or turning.

4.9 TOTAL SOLIDS

Table 10: statistical summary of TS values for the entire composting period

Mean	Standard error	Minimum	Maximum
55.69	1.42	41.84	75.72

Table 10 above gives a statistical summary of observation of TS during the entire experimentation period. The average TS was 55.69 with a maximum of 75.72 and a minimum of 41.84. The average TS was not statistically significant in both the turning criteria and the independent ratios implying that the TS of the samples was not affected by turning or ratio ($p > 0.05$).

4.10 PHOSPHORUS

Table 11: statistical summary of P values for the entire composting period

Mean	Standard error	Minimum	Maximum
0.40	0.02	0.19	0.63

The summary statistics of the P observed during the entire experimentation period is summed up in Table 11. The average P is statistically not significant for both the independent ratios and the various turning criteria. The average P was 0.40 with a maximum of 0.63 and a minimum of 0.19, meaning that the P content of the samples is not influenced by neither ratio nor turning (Appendix 9).

4.11 POTASSIUM

Table 12: Summary statistic of K values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard values
1.06	0.04	0.65	1.63	0.5-1.8

The statistical summary observed for K during the period of the experimentation is summarized in table 12. The average K value is 1.06 with a maximum of 1.63 and a minimum of 0.65. The average K is not statistically significant for both the turning criteria and the independent ratios. This implies that the K of the samples was not affected by turning or the different ratios. The dataset shows that it falls within the acceptable range as according Gotass (1956).

4.12 TOTAL AND FAECAL COLIFORM

Table 13: Summary statistic of Total coliform values for the entire composting period

Mean	Standard error	Minimum	Maximum	Standard values
3.18	10.12	2.19	4.96	3.0

Table 14: Summary statistic of Faecal coliform values for the entire composting period

Mean	Standard error	Minimum	Maximum	WHO
1.36	0.33	0	5.62	3.0

The summary statistics of total and faecal coliform observed during the entire experimentation period is summed up in Table 13 and 14. The average total and faecal coliform is statistically not significant for both the independent ratios and the various turning criteria. The average total and faecal coliform was 3.18 and 1.36 with a maximum of 4.96 and 5.62 and a minimum of 2.19 and 0 respectively. This then implies that total and faecal coliform of the samples is not influenced by neither ratio nor turning. The dataset is an indication that it falls within the acceptable range according to USEPA (1994).

CHAPTER FIVE

5.0 DISCUSSION

5.1 TEMPERATURE

Temperature is probably the most important factor as it affects microbial metabolism and is related to proper air and moisture levels during composting. It is either a consequence or a determinant of the microbial activity. In general, composting is characterized by a first step of temperature rising, possibly to the thermophilic range (T > 50 ^{o}C). This range is characterized by microorganisms that work to decompose the organic materials, giving off heat which in turn increases pile temperatures. The aerobic composting process can be grouped into three major stages, a mesophilic-heating phase, a thermophilic phase and a cooling phase (Leton and Stentiford, 1990).

The temperature within the piles was accompanied by fluctuations due to the effects of rainfall and sometimes turning, however the three major temperature phases of mesophilic, thermophilic, and a second mesophilic phase was experienced. Stentiford (1996) suggested that temperature ranges of 35 °C-40 ^{o}C was needed to maximize microbial diversity whilst ranges of 45-55 ^{o}C was needed to maximize the rate of biodegradation.

However, all compost piles underwent an initial rise in temperature from between 30 ^{o}C and 47 ^{o}C for the first six days (Mesophilic phase 10 to 50 ^{o}C). An overall temperature rise above 40 ^{o}C was measured in all the piles within 7 – 10 days between 41 and 50 ^{o}C (Thermophilic phase), this phase is marked by the active decomposition by heat-loving (thermophilic) bacteria that are vigorously degrading organic materials within the pile causing the piles to heat up to about 53 ^{o}C or even higher.

These temperatures corresponded to optimum biological activity (around 40 °C). Once the pile achieved the thermophile phase pathogens inside the residues were considered eliminated as discerned in the literature (Tognetti *et al.*, 2007; Weber *et al.*, 2007). The temperatures for the piles only stayed in the thermophilic phase for only about two more days after which it began to decline entering the second mesophilic phase. This decline, probably could be due to convective loss (Palmisano *et al.*, 1993) and a higher amount of readily degradable carbon, nonetheless, this tendency was found with composting fish offal in reactors (Laos *et al.*, 2002) and composting of green tea waste and rice bran (Khan *et al.*, 2009), which implied that the rapidly degradable organic matter had been reduced (Sundberg and Jönsson, 2005).

The second mesophilic phase which was marked by temperatures between 30 -39 °C also lasted for 14 days after which the temperature began to fall towards ambient temperatures to the end of the composting period. Rynk *et al*. (1992) indicated that when the compost pile temperature falls to that of the ambient air, the compost is ready for curing. Maturation (curing) was indicated by the temperature measurement for all compost windrows which fell to between 27 and 29 °C below the ambient temperature of averagely 30 °C. In all the composting started with mesophilic temperature, continued to thermophilic temperature and then dropped to ambient temperature.

5.2 pH

The pH is a measure of the acidic or alkaline nature of the compost as composting progresses. Composting process is relatively insensitive to pH because of the wide range of organisms involved (Epstein, 1997), hence, to attain the necessary conditions for optimum composting, it is necessary to ensure a neutral to slightly alkaline pH within the piles, the optimum pH range is therefore said to be between 6 to 8 (Carr *et al.*, 1998).

In recognition of this, the results obtained for the mean pH value was found to be in this range of 6.5 - 7.2 as postulated by Carr *et al.*(1998), (Table 3) which seem to be in contrast to the recommended standards of Bord na Mona (2003) of 6.9 to 8. This could have been because composting materials usually have a natural buffering capacity which allows a much wider range of initial pH values to be tolerated (Willson, 1993).

Also it could be attributed to the production of carbon dioxide from organic acids and loss of nitrogen (Lugtenberg and Kamilova, 2009). Furthermore, it has been reported that the production of lactic and acetic acid during initial degradation of biomass often leads to an acidic pH in the ranges of 4.2 to 5.5 (Hultman, 2009). In reference to Hultman's (2009) values of pH range, that was not the situation in this respect as the samples did not become too acidic This was therefore reinforced by the findings of Inckel *et al.* (1990), who indicated that a compost heap which is properly constructed will seldom decrease in acidity.

By the end of the composting process the pH value approached a near neutral value indicating maturity as the organic acids produced were converted to methane and carbon dioxide.

Final pH value was within the optimum range of 6.5 to 7.2 which is good to maintain a proper C/N ratio according to Carr *et al.* (1998).

5.3 VOLUME

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

Again results of the volume reduction was statistically not significant as the differences in the mean ratios of the volume of all the various piles did not vary much from each other during the entire composting period, these results were however, in agreement with that of Dao (1999) who reported of having registered over 50 % loss in volume when composting manure.

This reduction in volume could also be attributed to the conversion of bulky materials tofinely textured compost as well as the rapid breakdown of organic substances by enzymes and microorganisms in converting organic materials into humus and also the release of heat and moisture through evaporation as water vapor and thus causing the piles to reduce in volume.

5.4 CARBON, NITROGEN AND CARBON/ NITROGEN RATIO

Organic material provides food for organisms in the form of carbon and nitrogen. Carbon and nitrogen levels vary with each organic material, the carbon provides the primary energy source for microbial metabolism, and nitrogen is critical for microbial population growth (Stoffella and Khan 2001). The ratio of these two can be used to provide an indication of the rate of decomposition of the feedstock and to determine when ripeness has been reached (Anon, 1998), therefore making C/N ratio an accurate indication of compost maturity (Jimenez and Garcia, 1989).

In this study it was seen that the TOC content in the compost material reduced arbitrarily as compared to total nitrogen contents which increased resulting in a corresponding reduction of C/N ratio as composting proceeded, this fact was further confirmed by Inoko*, et al.* (1979) who recorded a decrease in total carbon including hemicelluloses, cellulose and increase in total nitrogen, crude ash and lignin during maturation of city refuse compost.

This reduction in TOC is mainly because of the intense mineralisation process that took place in the initial stages of composting (Grigatti *et al.*, 2004), a process where microbes employ organic matter and leave behind inorganic substances such as minerals, carbon dioxide and water.

The total organic carbon content was found to be reduced in all the degradation stages of compost samples thereby affecting the composting process.

It was found that, the percentage of organic carbon decreased, which shows the decomposition of waste by microbial population (Mondini *et al.,* 2003). Part of the carbon in the decomposing residues evolved as CO2 and a part was assimilated by the microbial biomass (Cabrera *et al.,* 2005). Fares *et al*. (2005) reported that carbon loss accounted for initial total carbon during the composting process, furthermore the final percentage range of TOC value was 26.44 corroborating the standard range of 8 to 50 % set by Gotass (1956).

Nitrogen content recorded a significant increase within the first 14 days. Increase in totalnitrogen concentration during this period could have been caused by the decrease of substrate carbon resulting from the loss of CO_2 (because of the decomposition of the organic matter, which is chemically bound to nitrogen).

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

Nonetheless, nitrogen content after 14 days decreased gradually till the end of the composting period, this loss however, could be accounted to the volatilization of gaseous ammonia and the conversion of the available nitrogen into bacterial proteins stored in the bodies of the microorganism during composting Wilson and Dalmat (1983), hence nitrogen content loss was not significant at the end of the period.

To report compost as having fertilizing capabilities and for it to be used in agriculture the content must be over 1 %, dry weight (Barker, 1997) in relation to this, the nitrogen content value at the end of the composting period was seen to be above 1 % (Table 6), hence can be said to have fertilizing capabilities.

Compost with nitrogen content over 3 % is usually found to be immature and ammoniacal (Barker, 1997), this statement slightly contradicts Gotass (1956) who set the standard at a range between 0.4 - 3.5 % necessary for a mature compost. However in either case, the final nitrogen content value was 1.71 which is within range as ascribed by both authors for matured compost.

C/N at the end of the composting period was significant for all the treatment ratios, however it was also reported that the C/N value can continually narrow down as nitrogen remains in the system, while some of the carbon is released as CO2 (Sadasivam and Manickam, 1993). Further nitrogen fixing microbes indirectly help in decreasing C/N ratio by making more nitrogen available from added Organic Matter (Shinde *et al.*, 1992). A ratio of > 25 likely indicated stable compost (Table7).

The Changes in the C/N ratio reflect organic matter decomposition and stabilization during composting process because microorganisms used carbon as source of energy and N for building cell structure.

5.5 ORGANIC MATTER (OM)

Organic matter is the quantity of carbon based materials in the compost. High quality compost will usually have a minimum of 50 % organic content based on dry weight.

However, there is no absolute value of organic matter, which is ideal for compost, as it may range from 30-70 % (US Composting Council, 2003).

Analysis of the results showed that, organic matter content as influenced by ratio and turning was statistically not significant during the entire composting period, again, a general decrease in OM content was observed during the experimentation. This decrease in OM content could be associated with high microbial activity in converting organic matter into volatile carbon dioxide and water.

Fang *et al*. (1999) in his study, reported a loss of 9 % in organic matter content when he composted sewage sludge and sawdust-fly ash, this seems to be contrary in this study as the percentage loss in OM was far greater than 9 %, this difference in percentage OM loss could be due to the difference in feedstock used in preparing the compost. Nonetheless, the general minimum average reduction was 45.59% (Table 8). According to Gotass (1956), the weight in percentage of OM content in finished compost must be between 25 and 50 %, however final OM value fell within this range (Table 8) hence is an indication of maturity.

5.6 MOISTURE CONTENT (MC) AND TOTAL SOLIDS (TS)

Moisture content is a measure of the amount of moisture present in a compost sample and is expressed as a percentage of fresh weight. Moisture content of the composting blend is an important environmental variable as it provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of micro-organisms (Elango *et al*., 2009). A low moisture condition can restrict the mobility of organisms. Whereas Dougherty (1998) recommended moisture content in the range of 40 to 60 % Tchobanoglous *et al*. (1993) recommended 50 to 60 % moisture.

The initial MC of all the various piles were within the recommended range of 50 to

60 % as can be seen in (Table 9) nonetheless, mean moisture content of the final compost was statistically not significant (Appendix 7)

Decline in the moisture content at the end of the experimentation period might have been due to evaporating as been recorded by Larney and Blackshow (2003).

Final MC value was below 45 % (Table 9) hence is an indication of compost stabilization or maturity (Steintiford, 1996).

During the entire composting period the MC of all the samples remained within the recommended range as any deviation from this such as a higher MC content would have resulted in loss of nutrients and pathogens to the leachate in addition to causing blockage of the air passageways in the pile (Polprasert, 1989).

TS increased as MC reduced this can be explained by the fact that percentage moisture and total solids have an inverse relationship, also TS just as MC was not statistically significant.

5.7 POTASSIUM AND PHOSPHORUS

Compost contains macro and micronutrients, which are required for plant growth (Zethner *et al.,* 2000). Phosphorous and potassium are nutrients which are utilized in greatest quantities by plants, these nutrients are usually low in composts as compared to synthetic fertilizer product hence, compost is usually applied in greater quantities and so that the nutrient contribution can be significant.

Potassium is a very abundant nutrient in plants. Potassium in its available form in compost exists as K_2O. The amount of potassium in compost depends on the feedstock but also on the composting process (Barker, 1997).

The mean values of both phosphorus and potassium with respect to the independent ratios and turning were not statistically significant, however phosphorus and potassium both decreased due to microbial activities, also in the case of phosphorus it might have been due to the mineralized phosphorus being bound to the grass clippings. It is also assumed that much of the phosphorus in finished compost is not readily available for plant uptake since it is incorporated in organic matter.

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

Potassium content also recorded decrease but the value was not as low as that of phosphorus. This decrease could have been due to its high water solubility as it can be easily leached from the feedstock during the composting process. This may occur especially in uncovered windrows (Fricke and Vogymann, 1994).

The final potassium content value was nevertheless adequate (Table 12), ranging within the standard of 0.5 % - 1.8 % set by Gotass (1956) and of Bord na Mona (2003) who also stated that the typical range of total potassium (TP) in biowaste and green waste compost is between 0.6-1.7 %, dry weight. This resulted in the availability of sufficient potassium in the compost mass to enable bacterial cells to absorb and regulate osmotic pressure (Amofa, 2010).

5.8 TOTAL AND FAECAL COLIFORMS

Total and faecal coliform measurements are used to determine the pathogenic load within finished compost and also to assess compost maturity. Pathogens are microorganisms that cause disease through infection. The presence of pathogens in composting materials is largely dependent upon the feedstock (Eunomia, 2001). They may come from faecal material, sanitary tissues or food and / or may also be introduced during the composting process (Eunomia, 2001).

However, during composting, microbial activities are diverse Finstein and Morris (1975). There was a decrease in both total coliform and faecal coliform population. The mean values of the total and faecal coliform was found to be statistically not significant ($P > 0.05$) (Appendix 13 and 14).

This notwithstanding, the values recorded at the end of the experimentation period even fell far below the required standard of less than 3.00 log10 MPN/g (< 1000 MPN/g) set by USEPA (1994) for faecal coliform as no value was recorded at the end of the composting period (thus faecal coliform was totally absent at the end of the composting period).

Decreased moisture content within the piles caused lack of availability of nutrients since the nutrients are easily assimilated by the microorganisms in thin films of water and also possibly, desiccation might have caused a reduction and further death in the microbial population. Also the possible presence of antagonistic and indigenous organisms as well as the rise in temperature during the thermophilic phase and time contributed in the destruction of pathogens from within the compost. This was emphasized by Himathongkham et al. (1999), who also reported a decrease in coliform during composting and attributed it to thermal kill, lack of nutrients and time.

CHAPTER SIX

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

From the study it could be concluded that all the various piles were of good quality compost as the indicator parameters were all within the recommended standards as stipulated by Gotass (1956) in the composition of mineral elements for finished compost

Furthermore, turning was observed to increase the extent of decomposition rather than the quality of the compost as the piles that were turned everyday were seen to decompose faster followed by those that were turned every three days and eventually once weekly. The grass clipping was seen to serve as a good bulking agent as it promoted aeration which enhanced aerobic degradation process and faster decomposition rate and yielded high quality compost when included in a compost recipe. Compost quality is there by usually attributed basically to the type of feedstock used.

6.2 RECOMMENDATION

From the analysis, it is recommended that;

- Further work should be carried out to co-compost food waste using only one ratio type for all the piles but different turning regimes to ascertain the effect of turning on the quality of compost
- Grass clipping is a good bulking agent which produces quality compost and as such could be co-composted with any form of waste to yield quality compost

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APPENDIX 1

LIST OF APPENDICES

APPENDIX 1: Analysis of variance of biweekly effect of ratio and turning on P^H

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.956[a]	11	.087	.648	.776
Intercept	2006.219	1	2006.219	14961.857	.000
Ratio	.178	3	.059	.443	.724
Turning	.085	2	.042	.317	.730
Ratio * Turning	.693	6	.115	.861	.532
Error	4.827	36	.134		
Total	2012.002	48			
Corrected Total	5.783	47			

Significance at 5%

APPENDIX 2: Analysis of variance of biweekly effect of ratio and turning on Volume

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.001[a]	11	5.379E-5	.056	1.000
Intercept	.161	1	.161	167.523	.000
Ratio	.000	3	9.722E-5	.101	.959
Turning	6.667E-5	2	3.333E-5	.035	.966
Ratio * Turning	.000	6	3.889E-5	.040	1.000
Error	.035	36	.001		
Total	.196	48			
Corrected Total	.035	47			

Significance at 5%

APPENDIX 3: Analysis of variance of biweekly effect of ratio and turning on TOC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	61.249[a]	11	5.568	.112	1.000
Intercept	58256.661	1	58256.661	1175.046	.000
Ratio	46.334	3	15.445	.312	.817
Turning	9.493	2	4.747	.096	.909
Ratio * Turning	5.422	6	.904	.018	1.000
Error	1784.814	36	49.578		
Total	60102.724	48			
Corrected Total	1846.063	47			

Significance at 5%

APPENDIX 4: Analysis of variance of biweekly effect of ratio and turning on N

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.834[a]	11	.076	.533	.868
Intercept	285.236	1	285.236	2005.734	.000
Ratio	.600	3	.200	1.405	.257
Turning	.196	2	.098	.690	.508
Ratio * Turning	.038	6	.006	.044	1.000
Error	5.120	36	.142		
Total	291.190	48			
Corrected Total	5.953	47			

Significance at 5%

APPENDIX 5: Analysis of variance of biweekly effect of ratio and turning on C/N

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	61.383[a]	11	5.580	2.231	.035
Intercept	9829.825	1	9829.825	3929.926	.000
Ratio	52.895	3	17.632	7.049	.001
Turning	4.141	2	2.071	.828	.445
Ratio * Turning	4.347	6	.725	.290	.938
Error	90.046	36	2.501		
Total	9981.254	48			
Corrected Total	151.429	47			

Significance at 5%

APPENDIX 6 : Analysis of variance of biweekly effect of ratio and turning on OM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	188.694[a]	11	17.154	.114	1.000
Intercept	172474.953	1	172474.953	1149.200	.000
Ratio	133.896	3	44.632	.297	.827
Turning	37.715	2	18.858	.126	.882
Ratio * Turning	17.082	6	2.847	.019	1.000
Error	5402.973	36	150.083		
Total	178066.620	48			
Corrected Total	5591.667	47			

Significance at 5%

APPENDIX 7 : Analysis of variance of biweekly effect of ratio and turning on MC

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	335.947[a]	11	30.541	.253	.991
Intercept	93545.904	1	93545.904	773.664	.000
Ratio	266.296	3	88.765	.734	.539
Turning	58.332	2	29.166	.241	.787
Ratio * Turning	11.319	6	1.886	.016	1.000
Error	4352.863	36	120.913		
Total	98234.714	48			
Corrected Total	4688.810	47			

Significance at 5%

APPENDIX 8 : Analysis of variance of biweekly effect of ratio and turning on TS

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	364.756[a]	11	33.160	.283	.985
Intercept	148856.029	1	148856.029	1271.554	.000
Ratio	288.940	3	96.313	.823	.490
Turning	73.935	2	36.967	.316	.731
Ratio * Turning	1.881	6	.313	.003	1.000
Error	4214.383	36	117.066		
Total	153435.167	48			
Corrected Total	4579.139	47			

Significance at 5%

APPENDIX 9 : Analysis of variance of biweekly effect of ratio and turning on P

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.101[a]	11	.009	.743	.691
Intercept	7.592	1	7.592	613.068	.000
Ratio	.098	3	.033	2.636	.064
Turning	.001	2	.001	.059	.943
Ratio * Turning	.002	6	.000	.025	1.000
Error	.446	36	.012		
Total	8.139	48			
Corrected Total	.547	47			

Significance at 5%

APPENDIX 10 Analysis of variance of biweekly effect of ratio and turning on K

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.082[a]	11	.007	.062	1.000
Intercept	53.552	1	53.552	447.358	.000
Ratio	.060	3	.020	.167	.918
Turning	.017	2	.009	.073	.930
Ratio * Turning	.005	6	.001	.007	1.000
Error	4.309	36	.120		
Total	57.944	48			
Corrected Total	4.392	47			

Significance at 5%

APPENDIX 12 Analysis of variance of biweekly effect of ratio and turning on Faecal coliform

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.492[a]	11	.136	.148	.999
Intercept	484.315	1	484.315	527.829	.000
Ratio	1.387	3	.462	.504	.682
Turning	.017	2	.008	.009	.991
Analysis of varia	.088	6	.015	.016	1.000
Ratio * Turning					
Error	33.032	36	.918		
Total	518.839	48			
Corrected Total	34.524	47			

Significance at 5%

APPENDIX 12: Analysis of variance of biweekly effect of ratio and turning on Faecal coliform

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	56.419[a]	11	5.129	.996	.469
Intercept	89.244	1	89.244	17.330	.000
Ratio	30.656	3	10.219	1.984	.134
Turning	5.514	2	2.757	.535	.590
Ratio * Turning	20.249	6	3.375	.655	.686
Error	185.386	36	5.150		
Total	331.048	48			
Corrected Total	241.804	47			

Significance at 5%

APPENDIX 13: Statistical summary of N, TOC and C/N values for the entire composting period

	Mean	Standard Error	Minimum	Maximum
N	2.44	0.05	1.71	3.22
TOC	34.84	0.90	26.44	46.83
C/N	14.31	0.26	11.82	19.35

APPENDIX 14: Statistical summary of P and K values for the entire composting period

	Mean	Standard Error	Minimum	Maximum
P	0.40	0.02	0.19	0.63
K	1.06	0.04	0.65	1.63

APPENDIX 15: Statistical summary of pH, Vol and OM values for the entire composting period

	Mean	Standard Error	Minimum	Maximum
pH	6.47	0.05	5.78	7.18
Vol	0.06	0.00	0.03	0.11
OM	59.94	1.57	45.59	80.74

APPENDIX 16: Statistical summary of MC, TS, Total and Faecal coliform values for the entire composting period

	Mean	Standard Error	Minimum	Maximum
MC	44.15	1.44	24.28	58.17
TS	55.69	1.42	41.84	75.72
Total coliform	3.18	0.12	2.19	4.96
Faecal coliform	1.36	0.33	0	5.62