KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI, GHANA

INTEGRATED WASTE MANAGEMENT-SOURCE SEPARATION AND COMPOSTING OF HOUSEHOLD WASTE IN THE AYUOM FARMING COMMUNITY IN THE BOSOMTWE DISTRICT OF THE ASHANTI REGION

BY

RACHEL ASANTEWAA OFORI , BSC. (HONS)

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CERTIFICATION

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

Rachel Asantewaa Ofori	____________________	______________
(PG 5833511)	Signature	Date

Certified by:

Dr. Moses Mensah	____________________	______________
(Supervisor)	Signature	Date

Prof. Samuel Kwoffie	____________________	______________
(Head of Department)	Signature	Date

ABSTRACT

Waste generation cannot cease due to the existence and activities of man. In most rural communities, organic waste represents the highest fraction of the waste generated. With the adverse effect of improper handling and disposal of waste, it has become important to produce compost out of the organic fraction to reduce the waste that would have otherwise be deposited in the landfill. The aim if this study was to produce compost from source separated waste in the Ayuom farming community in the Bosomtwe district. Forty household were identified and given two dust bins each, one for the collection of organics and the other for the collection of inorganic waste. Waste was collected weekly, weighed, further separated and then the organic fraction was formed into piles. During composting, the piles were monitored for temperature, C:N ratio, pH and moisture. Data collected for eight weeks were subjected to graphical interpretations, percentage, mean and t-test

The results showed that waste separation efficiency in the organic waste was 97% but that of the inorganic bin was 26.9%. The solid waste generated per capita per day was 0.22kg/day. The C:N ratio of the organic waste ranged between 14 - 16 but it was adjusted in some of the piles to determine the effect on the compost produced.

Compost produced had a mean NPK content of 0.06, 0.12 and 0.35 respectively. From the study, the mean heavy metal content recorded for Nickel: 13.1, Chromium: 14.5, Mercury; 0.2, Lead 12.4, Zinc: 42.2 and Cadmium recording less than 1 for all the piles and they all fell within range as described in literature.

Compost mixed with biochar and allowed to undergo incubation for 6weeks produced increase in nitrogen and phosphorus contents as well as potassium content but it was reduced with ratios of 50% compost 50% biochar and 25% compost 75% biochar

Waste sent to the landfill can be composted in order to complete the carbon cycle in the communities thus improving nutrient content by the application of compost. However it will be appropriate that during further studies the ratio is adjusted in order to create an optimal environment for the compost microorganisms which may affect the final qualities of the compost.

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1 CHAPTER ONE: INTRODUCTION

1.1 Background

All the activities of man generate waste which is mostly discarded because it is considered useless. Waste disposal became problematic with the emergence of towns and cities where large numbers of people started to congregate in relatively small areas in pursuit of livelihoods (Shafiul and Mansoor, 2003). Due to uncontrolled urbanization and increase in population large quantities of waste are generated daily and this has resulted in the unsanitary scenes of most cities.

The last three decades have witnessed development in urban areas through urbanisation. Growth through urbanisation is coupled with the growth of population of urban areas. The growth in population aside increasing the quantities of waste generated has also resulted in increase in the complexity of the generated wastes and in particular Municipal Solid Waste (MSW) due to changing life styles, culture, geographic location etc. (Khatib, 2011)

Municipal solid waste (MSW) includes all of the wastes generated in a community, with the exception of waste generated by municipal services, treatment plants, and industrial and agricultural processes. It includes waste from the residential, institutional, commercial and industrial (nonprocess) (Tchobanoglous et al, 2002).

Solid Waste Management (SWM) as defined by Tchobanoglous (2003) is that discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations and that is also responsive to public attitudes. All of these processes have to be carried out in an integrated manner within existing legal, social, and environmental guidelines that protect the public health and the environment and are aesthetically and economically acceptable.

Integrated solid waste management (ISWM) therefore has to do with the attitude and behaviour of citizens, waste management staff, private enterprises and waste pickers. It also includes managerial (in)capabilities, the institutional framework, the environment or the social or cultural context. It involves the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals (Tchobanoglous et al, 2002).

This implies that, solid waste management is an important environmental health service, and an integral part of basic urban services. This is because, the health implications of poor waste management can be very damaging to the people exposed to these unsanitary conditions. Unattended waste lying around attracts flies, rats and other creatures that in turn act as vectors that spread diseases (Danso-Manu, 2011). Diseases such as cholera, typhoid, dysentery and malaria are all related to the practice of poor waste management. The high incidence of diarrhoea in children under 6 is related in part to food contamination by flies (Boadu, 2005). According to a media report TV3 Ghana, September 18, 2008, diseases such as diarrhoea, cholera, malaria, typhoid fever and buruli ulcer among others make up 70 % of ailments or diseases in Ghana that are reported at the health facilities. Hygiene related diarrhoea alone is thought to cause loss of 20,300 human life needed in the development of the country per year (Danso-Manu, 2011).

Lucas and Gilles (2003) as cited by Abdulai (2011) share the notion that, different types of waste pose different problems but in general, failure to manage and dispose waste properly exposes people to increased risk of infectious diseases.

Considering the MSW generated in general, its main constituents are to some extent similar throughout the world, but the quantity generated, the density and the proportion of streams vary widely from country to country depending mainly on the level of income and lifestyle, culture and tradition, geographic location and dominant weather conditions (Khatib and Al-Khateeb, 2009).

Another element that characterizes differences between the generated MSW in low and high income communities (including urban and rural areas) is the percentage composition of MSW constituents. Solid waste characterization by Kotoka, (2001) in KMA recorded 44% organic waste. Asaase (2008) recorded 46%, 50% and 63% for 3rd, 2nd and 1st class residential areas respectively for Kumasi. Mensah (2010) recorded 45%, 69%, and 71% for low, middle and high income areas in Kumasi respectively. Rockson et al (2011) recorded an average of 40.32% of organic waste for Kumasi in a waste characterization excercise at the KMA final disposal site. Thus, the lifestyle of people decisively characterizes the percentage composition where organic waste stream form more than 40% of the total generated MSW.

Organic waste is a major source of contamination in urban water supply and environmental pollution when left unattended; since they decompose easily under hot temperatures and results in the production of leachates and bad odour (Everett, 1992). Under such circumstances, organic waste may also act as an important breeding site for disease causing vermin including flies, insects and rodents, which are vectors of diseases such as cholera, diarrhea, dysentery and typhoid fever (Fobil,*et al*., 2007.). Therefore, the management of organic waste in Ghana is a key strategy for urban environmental health promotion and disease control effort (NESSAP, 2010).

In urban areas of most developing and least developed countries, generated MSW is at best collected and dumped at arbitrary dump sites that mostly lack the appropriate norms. Such disposal entails collecting, transport and dumping into the nearest open space area. In other countries MSW is dumped into water bodies and wetland and part of the waste is burned to reduce its volume (UNESCO, 2006).

Reuse of organic waste material, which is often the highest composition of the total waste amount, is still fairly limited but often has great recovery potential. It reduces costs of the disposal facilities, prolongs the sites life span, and also reduces the environmental impact of disposal sites as the organics are largely to blame for the polluting leachate and methane problems.

These are the reasons why municipal authorities' as well as waste managers in many parts of the world are now exploring ways to reduce the flow of biodegradable materials to landfills. Improving the treatment and management of wastes on the whole will reduce carbon emissions arising from widespread indiscriminate dumping and burning of refuse which contributes to the phenomenon of climate change (global warming) with the attendant negative effects on health and livelihoods (NESSAP, 2010).

It is embodied in the strategic plan (NESSAP) of the Ministry of Local Government to have waste sorted at source in the municipal and district households for optimized recycling and composting. Preliminary studies' including a pilot is being undertaken in collaboration with KNUST. Zoomlion Ghana Ltd seeks to move a step further by carrying out source sorting of household wastes in selected areas and recycling of the components.

This is in line with the company's aims to become the leading fully integrated waste management company in West Africa sub region, were recycling will be employed to reduce the amount of waste that gets to the final disposal site, a key objective of the project.

Currently Waste collected in the municipalities is dumped together with the resultant effect of overstretched landfills. Particularly with the high proportion of organic wastes that can be composted. There are health hazards associated with the end of pipe sorting as well as contamination of the other recyclables, such as waste plastics. This renders the approach uneconomical. A more economical approach will be to source separate the waste, then a substantial reduction in final volumes of waste could be achieved and the recovered material and resources could be utilized to generate revenue to fund waste management.

Tremendous potential for waste sorting at source exist for the unemployed coupled with the benefits of recycling. Presently the level of recycling in Ghana is minimal. This has resulted in the rather huge volumes of refuse that gets to the final disposal sites. The whole of Accra is currently facing problems with over 2, 000 tons of refuse that is generated daily (AMA, 2011). It is envisaged that the final disposal site will be exhausted soon.

An Integrated Municipal Solid Waste Management requires the source-sorting of household waste ensuring the separation of those plastics wastes that can be recycled and organic wastes that can be composted. Developing and implementing ISWM requires comprehensive data on present and anticipated waste situations through waste characterization studies. The project will address this as well. Data obtained through the exercise will provide the basis for planning and decision making by the relevant authorities. It can also serve as input for policy documents. Hence the project will serve as reference project for replication in other districts and municipalities for which Zoomlion will provide the expertise and organizational framework.

1.2 Problem statement

The presence of man and the ever changing lifestyle of people, affects the generation and composition of waste generated hence the need to enhance its management. Due to the large volume of waste that goes to the landfill, it is reaching full capacity, and all components of our environment, air, water, as well as open spaces are increasingly threatened. Organic waste constitutes the highest composition of waste and the continual disposal at the landfill pose hazards such as leachate which affects ground water and emission of green house gases but it can as well serve as a resource for the production of compost.

Moreover, when different components of waste are mixed then sorting and separation for value addition become more difficult and resources are contaminated with other waste.

While inorganic fertilizer application can increase plant growth and are immediately available to plants, it comes with its share of detrimental environmental and health effects. Often crops are unable to absorb all the nutrients from fertilizer, thereby forcing excess into air and water. The presence of nitrogen fertilizers in water encourages algae blooms, both toxic and non-toxic, which depletes oxygen and reduces light penetration in water, resulting in the growth of weeds and stifling of aquatic life. Nitrogen in fertilizer leaches into ground water and ends up in drinking water. In the human body nitrogen becomes nitrate which inhibits the movement of oxygen through the body. Unabsorbed nitrogen from fertilizer can also leach into air contributing to greenhouse gas emissions and air pollution (Effects of inorganic fertilizers, http://www.ehow.com, accessed on 14/10/2012)

Furthermore, the importation of large quantities of inorganic fertilizer into the country at highly subsidized rates drains the economy and reduces resources available to other important economic sectors.

Therefore, this research work seeks to address the aforementioned problems by source separating the organic fractions of household for use in composting. This ensures reduced waste available for landfilling, avoids greenhouse gas emissions and leachate contamination of groundwater. The compost produced, with its nutrient composition known, is used to fertilize and condition the soil.

1.3 Aim

The aim of the project is to establish an Integrated Waste Management System on a pilot basis by producing compost from organic waste obtained from source separated household waste and to determine the characteristics of the compost mixed with biochar.

1.4 Objectives

- To create awareness on source separation of solid waste in the community and assess the effectiveess of source separation in households.
- To quantify and characterize the solid the solid waste generated from households at the Ayuom farming community.

- To assess the feasibility and quality of community based composting using the source-separated organic waste in the community.
- To assess the effectiveness of biochar in improving the quality of compost produced in the community.

1.5 Justification

Production of waste cannot be halted because of the presence of man and the utilization of resources hence the increase in the production of waste. There is therefore the need to find means of the proper management of the waste generated, since it has been identified that the current means of managing waste is not economically, socially and environmentally sustainable. ISWM considers the involvement of the different stakeholders in waste management in order to sustain the environment considering volumes and types of waste, generation and separation, collection and transfer, treatment and material recovery and final disposition as well as the local demographic, climatic and urban peculiarities.

Source separation of waste will improve the quality of materials for reuse and recycling (including organics) and so there is efficient treatment and reuse of organic waste. Therefore source separation reduces cost and simplifies the task of subsequent waste management and processing.

Composting organic waste significantly reduces the volume of waste dumped or landfilled, the quantity of landfill leachate, and greenhouse gas emissions. The compost produced can be used for soil amendment, horticultural purposes, erosion control, landscaping, and landfill cover where necessary. It would also help reduce the importation of inorganic fertilizers into the country which is a drain on government coffers. Furthermore the nutrient content of the soil will be enhanced with the introduction of compost mixed with biochar, resulting in high crop productivity and food production.

Growing concerns relating to land degradation, threat to eco-systems, atmospheric pollution, soil health, soil biodiversity and sanitation have rekindled the global interest in organic waste recycling practices like composting. Composting offers several benefits such as enhanced soil fertility and soil health, improved soil biodiversity, reduced ecological risks and a less-stressful environment.

2 CHAPTER TWO: LITERATURE REVIEW

2.1 Solid waste management in developing countries

The waste compositions in most developing countries keep increasing in quantity, variety and complexity due to the increase in population, urbanization and development in these countries. Changing lifestyles such as use of canned soft drinks, mobile phones, and disposable diapers (movement towards a "consumer society" in general), pose special waste management challenges, as waste management systems in developing countries are incapable of frequent adjustment to match these lifestyle changes (Khatib, 2011). Thus, the introduction of new technologies and approach to things brings about different compositions of waste whose handling may not be familiar to the waste management interventions.

In most developing countries, waste management is more of collection and disposal, but there is more to waste management. Solid waste management is defined by Tadesse (2004) as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid wastes in a manner that is in accordance with the best principles of public health, economics, engineering, conservations, and that is also responsive to public attitudes.

Improper solid waste management leads to substantial negative environmental impacts for example, pollution of air, soil and water, and generation of greenhouse gases from landfills, and health and safety problems such as diseases spread by insects and rodents attracted by garbage heaps, and diseases associated with different forms of pollution (Abdulai, 2011).

The waste situation in Ghana is in poor state and there is currently minimal recycling carried out. Generally, problems are encountered at all levels of waste management in Ghana; sorting, collection, transportation, disposal and evaluation of impact to environment and public health. Since waste management and disposal is a problem it can be a deterrent to economic development.

Kumasi has a population of over 2,035,064 (Statistical Service, 2010) and is currently producing 1,500 tonnes (KMA, 2012) of Municipal Solid Waste (MSW) daily, which is an increase of 40% from 1,200 tonnes in 2008. This is a rapid increase and if the amount of MSW produced continues to rise, which is highly possible due to increase in population and urbanization, this will be a serious burden on the environment and health of Kumasi's residents.

2.2 Integrated solid waste management

Integrated solid waste management (ISWM) refers to the strategic approach to sustainable management of solid wastes covering all sources and all aspects, covering generation, segregation, transfer, sorting, treatment, recovery and disposal, with an emphasis on maximizing resource use efficiency (Memon, no date). It involves the selection and application of suitable techniques, technologies, and management programs to achieve specific waste management objectives and goals (Tchobanoglous et al, 2002).

2.2.1 Hierarchy of Integrated Solid Waste Management

A hierarchy (arrangement in order of rank) in waste management can be used to rank actions to implement programs in the community. On the waste hierarchy pyramid (Figure 2.1), disposal is the least favoured option (Agunwamba et al., as cited by Otu, 2011). Currently approximately 90% of waste is being landfilled so there is a need to reduce this amount. Up from disposal on the pyramid is energy recovery, or waste to energy. It involves the combustion of waste material into heat, gas, steam and ash inside a specially engineered and purposed-built incinerator (Osei-Mensah, 2008). The next step on the pyramid is recycling and it involves the separation and collection of waste materials; the preparations of these materials for reuse, reprocessing and remanufacture (Tchobanoglous et al., 1993). That is what this report is concerned with, but with focus on composting the organic material. The most favored 3 steps on the pyramid focuses on reducing the amount of waste that is produced in the first place. The top 3 steps, reuse, minimization and prevention can only be encouraged by government and local policy, regulation, education and most importantly, public participation.

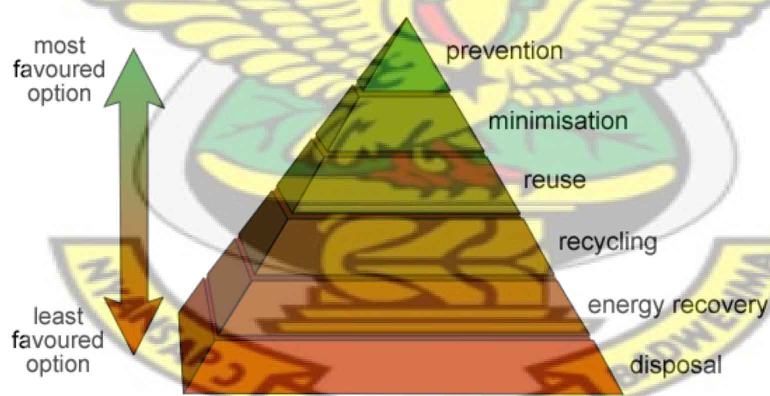

Figure 2.1: Waste Hierarchy Pyramid

Most of the municipal solid waste (MSW) in developing countries is dumped on land in a more or less uncontrolled manner. These dumps make very uneconomical use of the available space, allow free access to waste pickers, animals and flies and often produce unpleasant and hazardous smoke from slow-burning fires.

2.2.2 Dimensions of Integrated Solid Waste Management

ISWM has three major dimensions:

(1) The stakeholders involved in waste management, thus a person or an organisation that has an interest in waste management. However stakeholders in waste management differ in each city, so they need to be identified in the local context. Stakeholders have various interests and roles in their particular waste management, but they can cooperate for a common interest.

(2) The (practical and technical) elements of the waste system; All waste system elements should be looked upon as being stages in the movement, or flow of materials from the generation stage, via sorting, recycling and recovery stage towards final treatment and disposal. A waste management system is a combination of several stages in the management of the flow of materials within the city and the region. A waste management plan is part of an integrated materials management strategy in which the city makes deliberate and normative decisions about how materials should flow. The waste management then become specific tactics to deal with specific materials after they have been consumed.

(3) The aspects of the local context that should be taken into account when assessing and planning a waste management system; The ISWM concept distinguishes six aspects, or lenses, through which the existing waste system can be assessed and with which a new or expanded system can be planned. The ISWM aspects give a municipal manager a set of tools to perceive study and balance priorities and create measures to give the desired

results. The aspects are environmental, political/legal, institutional and organizational, social-cultural, financial and technical aspects.

2.3 Waste Composition

A waste composition survey was carried out by Zoomlion Ghana Limited in 2010, the results can be seen in Table 2.1. While this survey was carried out for MSW, the composition survey results combined with the total amount of solid waste produced in Kumasi give a good indication of how much of each type of waste material is being produced.

Table 2.1: Waste Composition Survey Kumasi 2010 (Source: Zoomlion)

Waste Type	**%**
Organic Material	40.2
Plastics	19.9
Glass/Bottles	1.2
Paper and Cardboard	7.0
Metals	2.2
Textiles	6.9
Inert Material (sand, ash, C&D)	20.8
Wood	1.7
Total	**100**

2.3.1 Organics

Organics make up the highest composition (40%) of MSW in Kumasi and are arguably the problem landfill operators' face. Composting organic waste will prolong the lifespan of the landfills, help reduce leachate that would have been produced from the landfills and go a long way in enhancing the nutrient content of our soils hence an increase in crop production (Mensah, 2010). It is important to note that, composting of organics has taken place in the past in Ghana but not successfully (Pace-Moody, 2003).

Unfortunately, because of a combination of poverty, demographic growth, economic fluctuations and fiscal austerity most compost facilities in West Africa could not be sustained.

The Teshie-Nungua Compost Plant was located east of the city of Accra and was established in 1980 by the Ministry of Local Government and the Accra Metropolitan Assembly (Pace-Moody, 2003). As at the year 2000, the facility composted more than 60 tonnes of domestic waste each day.

In 1998, there was also the establishment of the Ashiedu-Keteke Compost Pilot Project near the timber market in Accra by a community-based organisation (CBO). The main objective of this initiative was to collect source-sorted household and commercial wastes from local waste generators and to turn them, together with settled night soil, into compost for sale to vegetable growers and landscapers in Accra.

A pilot co-composting station at Buobai, Kumasi, initiated by the International Water Management Institute (IWMI) in collaborative efforts with the Department of Water and Sanitation in Developing Countries (SANDEC) of the Swiss Federal Institute of Environmental Science and Technology (EAWAG), the Kwame Nkrumah University of

Science and Technology and the Waste Management Department (WMD) of the Kumasi Metropolitan Assembly (KMA). The French Government provided the bulk of the sponsorship, whereas IWMI and SANDEC supplemented funding. The small-scale project at Buobai was designed to treat about 150m^3 of organic waste and 50m^3 of dewatered faecal sludge per annum.

Despite the great objectives, the composting projects failed due to the following:

- Unreliable supply of organic waste.
- Lack of Spare Parts, Water, Training and Public Education Programs, and reliable Energy.
- Poor funding of maintenance.
- No clearly defined marketing strategies.
- Persistent public complaints about location.
- No collaboration and networking amongst stake holders.

2.3.2 Plastics

Plastic has the greatest potential for a recycled material as there is a large demand for plastic. The amount of plastic waste is high. The results from a recent composition survey of MSW waste indicated it makes up nearly 20% of the waste generated in Kumasi.

Table 2.2Platic types and common uses

1	PET	**Polyethylene terephthalate** - Fizzy drink bottles, bottles for squash, mineral water and oven-ready meal trays.
2	HDPE	**High-density polyethylene** - Bottles for milk and washing-up liquids.

3	PVC	**Polyvinyl chloride** - Food trays, cling film and shampoo.
4	LDPE	**Low density polyethylene** – Water Sachets, carrier bags and bin liners.
5	PP	**Polypropylene** - Margarine tubs, yoghurt pots, microwaveable meal trays.
6	PS	**Polystyrene** - Foam meat or fish trays, hamburger boxes and egg cartons, vending cups, plastic cutlery, protective packaging for electronic goods and toys.
7	OTHER	**Any other plastics** that do not fall into any of the above categories. - An example is melamine, which is often used in plastic plates and cups.

Source: Tadesse, 2004

Not all plastics are recyclable. There are 4 types of plastic which are commonly recycled. Polyethylene (PE) - both high density and low-density polyethylene, polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC).

A common problem with recycling plastics is that plastics are often made up of more than one kind of polymer or there may be some sort of fibre added to the plastic (a composite) to give added strength. This can make recovery difficult.

2.3.3 Paper and Cardboard

7% of MSW was found to contain paper and cardboard. However cardboard is more likely to be sourced in high quantities in commercial waste.

2.4 Source separation of waste

Organized source separation of household waste has not been adopted yet in Ghana as a part of the solid waste management practice and limited information exists on the quantities of various waste materials available for recycling. Source separation of municipal solid waste as defined by Asase, 2008 is the practice of setting aside post-consumer materials, so that they do not enter mixed waste streams. There are different types of the waste separation scheme:

- Customary practices – This entails gift, barter and sale of post-consumer materials linked to charity, trading and recycling e.g. "selling post-consumer items to itinerant buyers.
- Collectively organized interventions –Thus obtaining materials for recycling and composting.

According to a research by Addo (2009), he recoreded 75.3% of households that would separate their waste only if they are given free bins, 72.3% were willing to separate their waste if the waste collection fee will be reduced and only 21.9% were willing to separate their waste with no incentive.

2.4.1 Hinderances to Source separation

Households are not willing to separate their waste due to : lack of time to separate, lack of space to accommodate extra bins, perceived health implications, difficulty of separating waste (not knowing the different compositions), perceived high cost with separating at source and untimely collection by the waste management company.

2.5 Problems with the management of MSW

It is clear that the main problems facing the proper management of MSW in many developing countries are the lack of adequate administrative and financial resources. There is no clear reliable framework by which the solid waste sector is administered from the collection, transformation to disposing or treatment phases. This situation is usually coupled with limited investment allocated for the MSW sector with complications of collecting or raising proper service fees (Khatib, 2011). The management activities of MSW are considered public services which are directly controlled by governmental institutions although, there are a few private companies springing up and partnering with government institutions to assist with regards to waste management.

Financing of safe disposal of solid waste poses a difficult problem as most people are willing to pay for the removal of the refuse from their immediate environment but then the idea of "Not In My Back Yard" are generally of great concern when we are to take into consideration the final disposal. The present disposal situation is expected to deteriorate even more as with rapid urbanization settlements and housing estates now increasingly encircle the existing dumps and the environmental degradation associated with these dumps directly affect the population.

Waste disposal sites are therefore also subject to growing opposition and it is becoming increasingly difficult to find new sites which find public approval and which are located at a reasonable distance from the collection area. Siting landfills at greater distances to the central collection areas implies higher transfer costs as well as additional investments in the infrastructure of roads hence intensifying the financial problems of the responsible authorities. In addition to all this, an increase in service coverage will even aggravate the disposal problem if the amount of waste cannot be reduced by waste recovery (Zubrigg, 2002).

Also inappropriate guidelines for siting, design and operation of new landfills as well as missing recommendations for possible upgrading options of existing open dumps are part of the waste disposal problems in a country as Ghana. Often the only guidelines for landfills available are those from high-income countries. These are based on technological standards and practices suited to the conditions and regulations of high-income countries and do not take into account for the different technical, economical, social and institutional aspects of developing countries.

The safe alternative, a sanitary landfill, is a site where solid wastes are disposed at a carefully selected location constructed and maintained by means of engineering techniques that minimize pollution of air, water and soil, and other risks to man and animals (Zubrigg, 2002). The lifespan of these landfills can as well be prolonged with the introduction of recycling of plastic waste and composting of organic waste.

Another related common problem is the absence of effective and comprehensive legislative frameworks governing the solid waste sector and the inadequate enforcement mechanisms, which are no less important than the legislations themselves. Such short-comings in the management of MSW create gaps and intensify the problems. Standards and norms are also critical for the implementation of the legislative frameworks especially that concern the setting, design, and operation of the landfills and the dealing with possible hazardous and healthcare wastes. In many developing countries where financial resources exist, shortcomings are found in both the human and organizational capacities.

Furthermore, the availability of the significant amount of accurate background data and information on the status of solid waste, including MSW, such as rate of generation of different solid waste constituencies, assessment of natural resources and land-use, collection and transportation needs, scenarios of treatment, growth scenarios of solid waste which is linked to several driving forces is also a significant problem with regards to management of MSW. Data and information are the crucial elements for developing MSW management system including the adequate monitoring of the sector (Khatib, 2011).

2.6 Composting and importance of composting

Composting is an alternative to landfilling organic waste and can be part of every community's waste management program. Composting is an aerobic (oxygen-dependent) degradation process by which plants (leaves, vegetable trimmings, lawn clippings, and similar garden debris) and other organic wastes (kitchen refuse, sludge) decompose under controlled conditions (Mid-scale Composting Manual, 1999). It is not a new process and has been an accepted agricultural practice for years. As a natural process, it can be carried out with little, or as much attention as desired.

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, due in part to the flexibility of its requirements. As a result, there is a composting system for nearly every situation; i.e., simple systems for early stages of industrial development to relatively complex, mechanised systems for advanced industrial development.

The basic parameters that influence the composting process are oxygen, temperature, moisture and the carbon-to-nitrogen ratio (C:N)(Environmental Fact Sheet, 2007).

The organic component of municipal solid waste represents the highest of the total waste stream that can be diverted to a managed composting process for the production of a beneficial soil amendment.

When placed in a landfill organic materials decompose under anaerobic conditions. One of the by-products of anaerobic decomposition is methane, an odorous gas that contributes to the greenhouse effect. Rain and groundwater percolation through the landfill combines with decaying organic matter to produce weak acids. As these acids are washed through the landfill the groundwater may become contaminated.

2.7 Systems of composting

Today a variety of composting processes exist that can be adapted for any scale of organic waste management. Systems range from simple to sophisticated technology, Passive windrows, Turned windrows, Aerated static pile and in-vessel composting systems are being used worldwide to treat different types of organic waste (Bass et al, 1992).

Table 2.3 Different systems and their periods for composting (Source: Composting fact sheet, 1996)

Composting System	**Passive Windrow**	**Turned Windrow**	**Aerated Static Pile**	**In-Vessel Channel**
General	Low technology Quality problems	Active systems most common on farms	Effective for farm and municipal use	Large-scale systems for commercial applications
Labour	Low labour required	Increases with aeration frequency and poor planning	System design and planning important. Monitoring needed	Requires consistent level of management/product flow to be cost efficient.
Land	Requires large land	Can require large area of land	Less land required given faster rates and	Very limited land, due to rapid rates and

	Areas		effective pile volumes	continuous operations
Bulking Agent	Less flexible, Must be porous	Flexible	Less flexible, Must be porous	Flexible
Active Period	Range: 6-24 Months	Range: 21-40 days	Range: 21-40 days	Range: 21-35 days
Curing	Not applicable	30+ days	30+ days	30+ days
Size: Height	1 - 4 metres	1 - 2.8 metres	3 - 4.5 metres	Dependent on bay design
Width	3 - 7 metres	3 - 6 metres	Variable	Variable
Length	Variable	Variable	Variable	Variable
Aeration System	Natural convection only	Mechanical turning and natural convection	Forced positive/negative air flow through pile	Extensive mechanical turning and aeration
Odour Factors	Odour from the windrow will occur. The larger the windrow the greater the odours.	From surface area of windrow. Turning can create odours during initial weeks.	Odour can occur, but controls can be used, such as pile insulation and filters on air system.	Odour can occur. Often due to equipment failure or system design limitations.

2.8 The composting process

Composting comprises various steps starting from waste sorting until the final bagging of the compost product.

The composting process has three main phases:

- Pre-processing - consists of sorting or removing contaminants, reducing the particle size of material if necessary and adding additives.
- Active composting - the period of vigorous microbial activity during which readily degradable material is decomposed as well as some of the more decay resistant material such as cellulose.
- Curing - follows active composting and is characterized by a lower level of microbial activity and the further decomposition of the products of the active composting stage (Mohee, 2007).

Waste from households arriving at the composting plant is sorted into several fractions. The organic fraction enters the composting process. It is mixed with additives if necessary and piled into the composting system. The composting process has to be monitored by different parameters (temperature, moisture). Finally, the mature compost is screened and prepared for selling. Residues from sorting and screening are recycled or disposed of.

2.8.1 Pre-processing

Pre-processing or preparation of feedstock usually is necessary to create suitable conditions for bacterial action. Compost quality is mainly determined by the quality of the input material. Hence, the sorting of the waste plays a vital role. Substances which are not biodegradable need to be separated from the biodegradable fraction. Sorting is especially crucial with regard to hazardous materials. They must be removed before the composting piles are formed. Otherwise they will contaminate the entire pile and severely compromise the final compost quality. If households are willing to segregate their waste at source it saves a tremendous amount of time and costs for the composting scheme. Moreover, it increases the quality of both biodegradable waste and recyclables. Hence, the long term goal should be the introduction of source segregation of waste in households (Ali, 2004).

The ratio of carbon (C) to nitrogen (N) - also called C/N ratio is very important for the biological degradation of organic waste. Both C and N are feedstock for micro-organisms responsible for the degradation of the organic matter. While carbon is important for the cell proliferation, nitrogen is the nutrient source. Generally one can classify "green" materials as being high in nitrogen and "brown" materials as high in carbon. The input material should have a carbon/ nitrogen ratio of 25:1 to 40:1 to allow most rapid and efficient degradation of the organic material. The wide range of the C/N ratio already indicates that a certain variation of waste components is possible (Cochran et al, 1996). Wood chips or sawdust (high C) or manure (high N) may be mixed with the organic waste to optimize the C/N ratio (Polprasert, n.d). Wood chips can also increase the pile porosity, thereby improving aeration. Organic screening residues from previous piles can be added to fresh piles as a carbon source. As the screening residues already contain micro-organisms, they also accelerate the start-up of the composting process (Rothenberger et al., 2006).

According to FAO (1987) as cited by Mohee (2007) if the particle size of the feedstock is too big, it affects the rate of decomposition therefore it is important to reduce the particle size. Smaller particles have more surface area per unit of weight and therefore facilitate microbial activity on their surfaces, leading to rapid decomposition. However, if all the particles are ground up, they pack closely together and allow few open surfaces for air to circulate. The optimum particle size has enough surface area for rapid microbial activity but also enough void spaces to allow air to circulate for microbial respiration. The appropriate range of particle size should be around 10-50mm.

2.8.2 Active composting

The sorted organic waste is loosely heaped into piles or filled in a box depending on the system. The composting piles have a width of 1.6 m and a maximum height of 1.6 m. The length depends on the space available and the amount of incoming waste, but 2 to 3 m is generally recommended (Rothenberger et al., 2006).

Active composting begins as soon as appropriate materials are piled together. Heat is given off, the temperature rises and other groups of micro-organisms develop. Some composting systems can more effectively deal with specific types of organic materials. For example, highly odorous material such as food organics are more easily processed in systems with forced aeration. The most common form of composting is the turned windrow system. This system is adequate for a large range of organics but requires more maintenance and a higher degree of process control (Mohee, 2007).

One of the important factors during the composting process is to ensure sufficient supply of air. Within a few days, aerobic micro-organisms exponentially proliferate, consuming an enormous amount of oxygen. A lack of oxygen likely favours the growth of anaerobic organisms which cause unpleasant odours. Furthermore, anaerobic environment slow down the degradation process resulting in a longer composting period. Thus, attention must be given to ensuring an adequate air supply (Landinos and Klundert, 1993).

For windrows and aerated piles, maintenance of the pile involves turning the pile and adding water to maintain conditions conducive to the composting process. After about a week, the windrow should be opened to the air and any compacted material loosened. Then the pile should be reconstructed; material previously on the top and sides of the pile should be moved to the centre. At each turning, the relatively un-decomposed outer layer can be scraped off and turned back to the centre of the pile. The centre material should be spread over the outer layer of the reconstructed pile. The turning frequency depends on the feedstock, temperature of the compost pile and aeration requirements (Mohee, 2007).

2.8.3 Process parameters and influencing conditions

The success of a composting process depends on a number of influencing factors, although the optimal conditions might differ. The main factors that contribute to an optimum environment for the microbial composting processes include temperature, odours, moisture, oxygen, and carbon dioxide (Paul and Geesing, 2007).

2.8.4 Temperature Control

Temperature is an indicator of microbial activity. Provided that the C:N ratio, the aeration and the moisture content are all within the optimal range, the microorganisms multiply exponentially. Thus, the temperature should begin to rise steadily as the microbial population begins to develop. This microbiological activity results in a temperature increase within some few days. The first three days of a compost pile, records temperatures between 10-40°C representing the psychrophilic phase (Cooperband, 2002).

After the psychrophilic phase, microbial activity increases and that results in increase in temperatures between 45-70 ^{o}C. This phase is the thermophilic phase. Temperatures above 70°C need to be avoided as they are too high for even thermophilic bacteria and so inhibit the microbiological activity. Temperatures above 80°C are lethal to most soil microorganisms and the process comes to a halt. Although composting will occur at temperatures below 65°C, a temperature of around 65°C favours rapid composting and ensures the destruction of weed seeds, insect larvae, and potential plant or human pathogens. Therefore, it is preferable for the temperature of the composting pile to stay at around 65°C for at least three days. From the thermophilic stage, the process moves into the mesophilic phase (45-50°C) and other microorganisms take over the transformation until the waste material is transformed into fresh compost (Rothenberger et al., 2006).

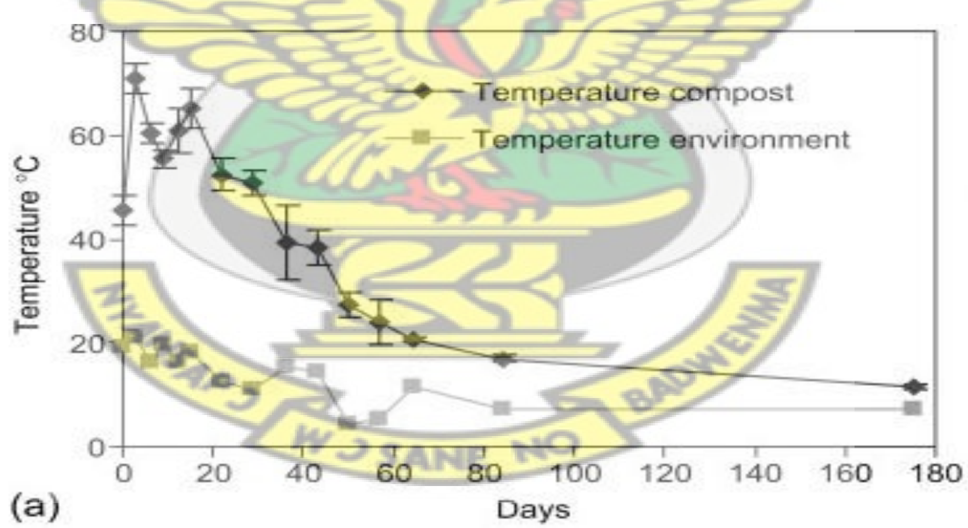

Figure 2.2: Temperature variations in a compost pile

A typical temperature profile for turned windrows is shown in Figure 2.2. A saw tooth is observed as the temperature at the core of the pile drops each time the pile is turned and picks up again due to microbial action. The fall in the temperature values toward the end gives indication of the stability and maturity of compost in the systems (Kutsanedzie et al, 2012). Lack of heating indicates that aerobic decomposition is not established. Failure for the pile to heat can be caused by factors such as lack of aeration and an inadequate nitrogen or carbon source. Also, the pile may fail to heat because of excessive heat losses. A compost pile begins to cool after achieving thermophilic temperatures and is near the end of the composting process. However, a lack of moisture or aeration can be the cause of the pile not heating. A loss of aeration can occur during composting as a result of a loss of structure and porosity as the material decomposes and the pile begins to collapse. Aerobic conditions can be re-established by turning or mixing the pile to rebuild porosity. A composting pile does not heat uniformly but has a temperature gradient from the inner core to the cooler outer surface. Temperatures on the outside of a windrow are much cooler than the centre of the pile (Stentiford and Mara, 1996). The initial compost temperature should be determined by measuring the temperature occurring at 240 to 360 mm inside the compost pile. Readings have to be taken deeper as composting progresses (Mohee, 2007).

2.8.5 Moisture Control

All living organisms including the microbes in compost pile need water to survive. Microbes take up nutrients as dissolved ions in a film of water (Beall, 1983 as cited by Kutsanedzie, 2009). Thus, the moisture content of the waste plays an important role. To ensure rapid decomposition, the moisture content in the compost piles must be maintained at a level of 40 to 60%. Ideally, water is added during turning. Moisture conditions vary constantly throughout the composting period mainly because of large amounts of evaporation and the addition of water through rain. Improper moisture can slow or stop the composting process, leading to anaerobic conditions that produce odours. A simple method for checking moisture content is called the squeeze test. If the compost is damp to touch but not so wet that water can be squeezed out of a handful of compost, it has sufficient moisture to sustain composting (Pace et al,1995).

Care must be taken to ensure that the compost does not dry out too quickly because decomposition will cease if the moisture content is low, resulting in partially finished compost. The simplest methods for correcting low moisture content are to spray water into the pile during turning or turning the pile after rainfall. To adjust high moisture content, dry bulky materials must be added and the pile turned (Mohee, 2007).

2.8.6 Odour management

Odour management is an effective indicator of whether the pile conditions are aerobic and whether nutrient losses are occurring through ammonia volatilization. The main compounds responsible for odour generation are nitrogen compounds and volatile fatty acids. Strong putrefied odours that smell of sulphur indicate anaerobic activity, particularly when low temperatures, high moistures and low porosity conditions accompany the odours. If excess moisture is not the cause, then the pile may be too large, leading to compaction and inadequate aeration. If the compost pile produces ammonia then add a carbon rich material to overcome the excessive nitrogen (Mohee, 2007).

2.8.7 Oxygen

The most important factor during the composting process is the availability of oxygen; without oxygen, composting is not possible. A constant level of oxygen should be maintained by aerating the composting material to ensure a stable end product. Aeration takes place naturally by air diffusion in the piles or windrows, but if the supply of oxygen is limited, it will slow down the process of biological degradation. To guarantee sufficient aeration, the compost pile or windrow is turned regularly, either manually or mechanically by wheel loaders. Another option is forced aeration by means of pipes laid under or through the windrows in such a way that air is constantly and uniformly circulated throughout the composting mass. Here, optimal conditions of oxygen supply, temperature and moisture can be maintained by mechanically blowing or drawing air through the windrow. Forced aeration is the best method of providing a controlled supply of oxygen to large compost piles.

The rate at which the material is aerated also affects the process of composting. If the aeration rate is too high; the excess flow of air will cause the compost mixture to cool down. If the aeration rate is too low, aerobic activity will decline and the process may become anaerobic (Lardinois et al., 1993)

2.8.8 pH level

In general, organic matter with a wide range of pH values (from 3 to 11) can be composted, although the optimum range is between 5.5 and 8. Whereas bacteria prefer a nearly neutral pH, fungi develop better in acidic environments. In practice, it is not easy to change the pH level in a pile. Generally, the pH begins to drop at the beginning of the composting process due to the activity of acid-producing bacteria that break down complex organic material to organic acid intermediates. In some cases, the pH may indicate that the process is malfunctioning. For example, if the condition within the composting mass begins to turn anaerobic, the pH may fall to about 4.5 due to the accumulation of organic acids. Conversely, as the process approaches stability, the pH shifts towards neutrality thus pH = 7 (ROU, 2007).

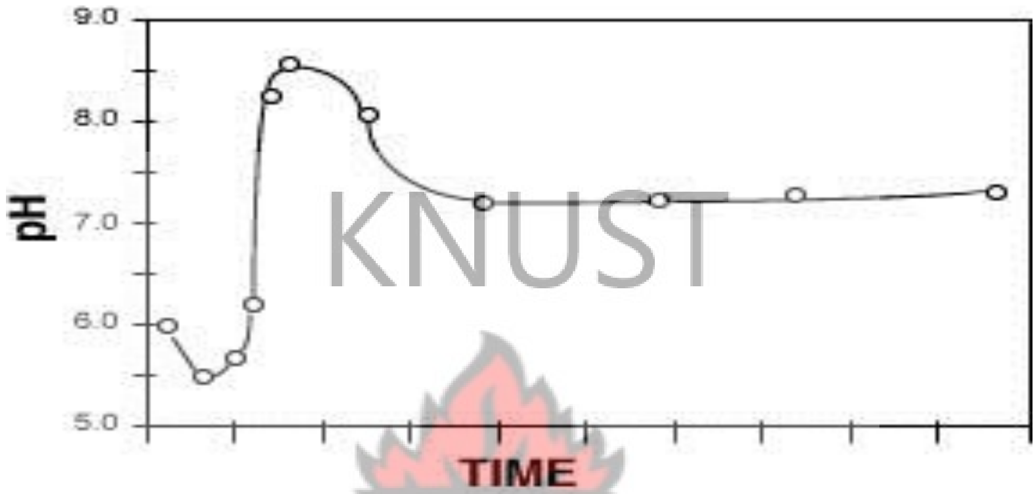

Figure 2.3: Typical changes in Ph during composting (Source: ROU, 2007)

2.9 Curing

By the end of the rapid phase of composting, a significant proportion of the easily degradable organic material has decomposed. The colour of the pile changes to a soil like colour and the pile temperature falls below 50^{o}C. Organic materials remaining after the active phase decompose slowly and microbial activity continues at a slower rate. This second phase, called curing, usually takes several weeks to months. During curing, after temperatures have gone down, fungi, actinomycetes, caterpillars, and bugs re-invade the compost and decompose the more resistant materials. During this phase, the compost needs less oxygen and less water. The temperature constantly goes down to the ambient temperature (Mohee, 2007).

The curing phase is important to reduce the presence of phytotoxic compounds normally present in immature compost, improve the pH, lower the C/N ratio, and remove any phytotoxic materials in low stability composts after thermal processing. Generally, curing uses passive aeration with occasional turning. As the pile cures, the micro-organisms generate less heat, the pile begins to cool and the compost becomes biologically stable (Shaffer, 2012).

2.10 Maturity/Stability

Compost stability, or the extent to which readily biodegradable organic matter has decomposed, constitutes an important aspect of compost quality, and probably the most controversial one in terms of evaluation; whereas maturity of compost is essential for its optimum use as a soil amendment and a source of plant nutrients. There is also more emphasis on compost maturity, quality and sustainability, which are key traits in the acceptance and use of the final product (Mohee, 2007). Maturity is associated with plant-growth potential or phytotoxicity (Iannotti et al., 1993), whereas stability is often related with the compost's microbial activity.

Immature and poorly stabilized composts may pose a number of problems during storage, marketing and use. During storage these materials may develop anaerobic pockets which can lead to odors, fire, and/or the development of toxic compounds. Continued active decomposition when these materials are added to soil or growth media may have negative impacts on plant growth due to reduced oxygen and/or available nitrogen or the presence of phytotoxic compounds (CCQC, 2001). Even compost made of high quality materials that are applied too soon to plants may burn leaves, stunt growth or even kill sensitive plant species. Immature compost continues to break down once it is incorporated into the soil. Mature compost is material whose biological activity has slowed (Mohee, 2007).

There are no universally accepted standards for the evaluation of compost stability. Several countries in Europe have produced and use their own set of standards and others are in the process of doing so (European Commission, 2001; Sánchez-Monedero et al., 2002). Physical characteristics such as colour, odour and temperature give a general idea of the decomposition stage reached, but give little information as regards the degree of maturation. For this, chemical methods are widely used, including measurement of the C/N ratio in the solid phase and in water extract, inorganic nitrogen, the cation exchange capacity, as well as the degree of organic matter humification (Bernal et al, 1997).

As composting is an aerobic microbial process methods based on microbial activity are considered by researchers and regulators to be the most logical to use for the assessment of compost stability. These are either directly related, such as the measurement of respiration using O_2 uptake or CO_2 production, or indirect reflections, such as self-heating and the evolution of other parameters such as volatile solids, C/N ratio, humification indices, nitrification, etc, (Iglesias-Jiménezand Pérez-García, 1992; Bernal et al, 1998 as cited by Sánchez-Monedero et al, 2002)

Finally, compost's maturity can be assessed by its microbial stability, which is determined by measuring the microbial biomass count, its metabolic activity and the concentration of easily biodegradable constituents (Bernal et al, 1997).

However, both stability and maturity usually go hand in hand, since phytotoxic compounds are produced by the microorganisms in unstable composts (Zucconi et al., 1985). A number of criteria and parameters have been proposed for testing compost maturity, although most of them refer to compost made from city refuse (Bernal et al,1997).

According to Canada Composting Council (2008), compost is deemed mature if it meets two of the following requirements:

1. C/N ratio is less than or equal to 25
2. Oxygen uptake rate is less than or equal to 150 mg O_2/kg volatile solids per hour; and
3. Germination of cress (Lepidium sativum) seeds and of radish (Raphanus sativus) seeds in compost must be greater than 90 percent of the germination rate of the control sample, and the growth rate of plants grown in a mixture of compost and soil must not differ more than 50 percent in comparison with the control sample.
4. Compost must be cured for at least 21 days
5. Compost will not reheat upon standing to greater than 20°C above ambient temperature.

2.11 Screening

The mature compost has a rather coarse texture. The particle size of the compost strongly depends on the size and the composition of the input material and the turning frequency. In many cases, finer compost is required and so the compost must be screened. The screening is done either by using a flat frame sieve or a rotating drum sieve. Each size and type of sieve with its particular mesh size is suited for a particular throughput and application. In any case, they need to be adjusted to the local conditions and compost structure. Organic screening residues from previous piles can be added to fresh piles as a carbon source. As the screening residues already contain micro-organisms, they also accelerate the start-up of the composting process. The use of the compost determines the appropriate particle size. But compost usually has a particle range of 1 – 10 mm (Rothenberger et al., 2006).

2.12 Storage and Bagging

Stable compost can be stored under cover for several months without the risk of spoilage. Stored compost should be kept dry to maintain product quality and minimize potential surface water contamination. This can be accomplished by covering the compost with tarpaulins or by storing it under a roof (Mohee, 2007).

Depending on customer needs compost may be stored in bulk (delivered loosely) or packed in bags of different volumes.

2.13 Importance of composting

The main reason for using chemical fertilizers is to enrich the soil with the elements nitrogen (N), phosphorus (P) and potassium (K), nutrients that are vital for crop growth. Compost also contains these elements, but in much smaller amounts. In contrast with chemical fertilizers, compost plays a complex role in maintaining the humus balance in the soil. Humus is the result of natural processes of breaking down and composting of leaves and roots in the ground by micro-organisms, which need air and water to survive. Humus improves the structure of the soil, ensuring the proper circulation of air and water, and is thus indispensable for the growth of healthy crops (Lardinois et al., 1993). Compost is easier to handle than manure and other raw organic materials, stores well and is odor-free (Cooperband, 2002).

Compost is an organic matter source with a unique ability to improve chemical, physical and biological characteristics of soils. It improves water retention in sandy soils and promotes soil structure in clayey soils by increasing the stability of soil aggregates.

Adding compost to soil increases soil fertility and cation exchange capacity and can reduce fertilizer requirements up to 50%. Soil becomes microbially active and more suppressive to soil borne and foliar patyhogens.

Enhanced microbial activities also accelerate the breakdown of pesticides and other synthetic organic compounds. Compost amendments reduce the bioavailability of heavy metals-an important quality in the remediation of contaminated soils (Cooperband, 2002). Composts are known to suppress plant diseases through a combination of physiochemical and biological characteristics. Physiochemical characteristics include any physical or chemical aspects of composts that reduce disease severity by directly or indirectly affecting the pathogen or host capacity for growth. Biological characteristics include compost- inhabiting microbial populations in competition for nutrients with pathogens, antibiotic production, lytic and other extra cellular enzyme production, parasitism and predation, induction of host-mediated resistance in plants, and other interactions that decrease disease development (Kuo et al., 2008).

2.14 The quality of compost

Compost quality is difficult to define and often-elusive term, meaning different things to different people according to their professional background and national legislations. Compost quality refers to the overall state of the compost in regard to physical, chemical and biological characteristics, which indicate the ultimate impact of the compost on the environment. The quality of compost is determined by the sum of its different features and properties; specifications are usually determined by minimum admissible levels of required substances or maximum tolerable limits for unwanted ones (de Bertoldi, 1993; Hogg et al., 2002).

A number of characteristics are said to determine compost quality, such as particle size distribution, moisture, organic matter and carbon content, concentration and composition of humus-like substances. Nitrogen content and forms of N, phosphorus and potassium, heavy metals, salinity and the nature of ions responsible for it, cation exchange capacity, water holding capacity, porosity and bulk density, inert contaminants, pathogens, and state of maturity or stability also describes the quality of compost (Lasaridi, 1998).

One of the earliest serious investigations of compost quality is the anonymous report from the German Waste Association (RAL) which set forth "Quality Criteria and Application Recommendations for Municipal Waste and MSW-Sludge Composts" (LAGA-10, 1984, in German). This study unleashed controversy by questioning the qualities and properties of composts made from "uncontrolled" mixed wastes, in particular shredded MSW and mixtures containing sludge. In this same period, between 1982 to 1990, scientific surveys of heavy metals in household wastes galvanized this direction (Bidlingmeier, 1982, 1987). A decade later, the issue of contaminants in hazardous waste derived fertilizers and metals in fertilizers broke over America (EWG, 1997). These studies and reports reinforced environmental concerns about the dangers of indiscriminate recycling and poorly defined composting of “decomposable” trash. In this same time period, the concept of source-separated "bio-composting" was established in the Hessen region of Germany by Fricke and co-workers, beginning with the first "bio-bin" separation project around 1982 (Fricke, 1988; Vogtman et al., 1989). Brinton, (2000) with focus on home separation for successful regional composting, published a series of reports and studies detailing the positive effects of source separation and examined partitioning of contamination in bio-composts and variations of them. These studies provided evidence that poor separation and handling standards would most likely result in large and unacceptable increases in concentration of undesirable and hazardous ingredients, and obviously heavy metals as well as glass, plastic and other physical inerts in matured compost.

The main requirement for compost is that it should be suitable for use as an organic soil conditioner. Physical, chemical and biological stability, non-toxicity and a balanced mineral element content are therefore the essential elements for compost to be useful. The amount of organic material or, more specifically, the quantity of humus, can be used as indicators to determine the quality of the compost. The quality of the compost obtained from aerobic and anaerobic degradation is more or less the same, and both depend on the quality of the original organic waste material. The best quality compost will be produced from stable organic material with low levels of visible contamination, micro contaminations and heavy metals (Lardinois et al., 1993).

2.14.1 Stability

Application of immature compost to the soil has negative effects on crops; robbing them of oxygen and nutrients that are immobilised by other microorganisms The need to monitor compost maturity becomes important to compost makers, plant operators and end users to avoid the negative consequences that emanate from application of immature compost to crops.

Unstable compost applied in the field maintains a higher microbial activity, leading to increased oxygen consumption. This decreases the supply of oxygen available to plant roots.

In addition, immature compost can contain higher levels of soluble organic matter (i.e., organic acids), which can lead to toxicity problems for certain horticultural applications, such as seed germination (Compost Microbiology and the Soil Food Web, 2008). Zucconi *et al*., (1981) also reported that when unstable or immature compost is used as a soil amendment or plant growth medium, it may reduce oxygen concentration in the soil and immobilize nitrogen, thereby causing serious N-deficiencies in crops (Kutsendzie, 2009).

2.14.2 Nutrients

An adequate supply of nitrogen (N), phosphorus (P), potassium (K), and other essential nutrients in soils is essential to sustain crop productivity. Without the availability of manufactured chemical fertilizers that typically contain high analysis of N, P and K several decades ago, composting was a technique utilized by some farmers to add stabilized organic matter to soil and to convert part of organic N in animal wastes and crop residues into a more readily available form for improving soil fertility and crop productivity. (Kuo et al., 2008). Pure compost contains a balanced mixture of Nitrogen, Phosphorous, Potassium, Calcium and other essential micronutrients. It cannot compete with artificial fertilisers in terms of nutrient content but is especially beneficial due to the high content of organic matter and the presence of useful micronutrients (Rothenbeger et al., 2006).

Table 2.4: Nutrient content of different finished compost

	Rothenbeger et al (2006)	**Whatcom Country Extension(2007)**	**Otu, 2011**
Carbon(%)	2 – 3	8 – 50	4.0
Nitrogen(%)	1 – 2	0.4 – 3.5	0.36
Phosphorus(%)	0.4 – 4.0	0.3 – 3.5	0.04
Potasium(%)	0.5 – 2.6	0.5 – 1.8	0.09

2.14.3 Heavy metals

Small amounts of metals such as zinc and manganese are necessary elements for the growth of living organisms. However, when inhaled or when present in excessive amounts, they may cause acute and sometimes chronic effects. Other metals, like mercury and cadmium, are non-essential and toxic elements. The presence of these heavy metals may affect the quality and suitability of the end products of organic waste recovery processes such as compost and meat from animals fed on contaminated material. They present a high pollution risk for the environment. When present at or above specific concentrations, heavy metals interfere with processes in the soil and in plants, and if they enter the food chain, they may form a health hazard for human beings and animals. The health effects of the various metals differ, and depend upon the concentration. Many countries have established legal maximum levels for individual metals; as an example, Table 2.4 gives the accepted levels of metals in compost in counties. Because the criteria used to determine safe levels have been tightened, a number of grades of compost are distinguished, i.e. 'compost', 'clean compost' and 'very clean compost'. To achieve these stricter criteria, the Dutch government actively promoted the separation of all waste at source. By 1994, in principle all Dutch households were separating the organic from other waste fractions.

The amounts of heavy metals that remain in end products depend on the origin of the raw material. Organic waste material may contain high concentrations of heavy metals due to contact with, for example, batteries or newspaper ink, during storage and transportation. (Lardinois et al, 1993)

Table 2.5: Maximum acceptable levels of heavy metals in finished compost.

Heavy metal	ASCP Guidelines, 2001 (g/tonne)	CCME, 2005 (mg/kg)	Woods End Research Laboratory,2005 (mg/kg)
Cadmium	1	3	2
Nickel	30	62	50
Chromium	100	210	100
Copper	100	-	100
Mercury	1	0.8	0.5

Lead	120	150	120
Zinc	400	700	400

2.14.4 Physical Composition of Composts

The acceptable quantity of foreign matter in compost has been a subject of some debate, but generally, there is greater agreement on these standards. Normally, stones are distinguished from non-decomposable "foreign matter" which includes glass, plastic and metal. The limits pertain to a percentage at a specific screen size. The following table summarizes physical standards of countries that regulate compost (Brinton, 2000).

Table 2.6: Physical standards of foreign matter acceptable in finished compost (Source: Brinton, 2000)

Country with Standard	Stones % of dry weight	Man-Made Foreign Matter glass, plastic, metal, as% of dry weight
Australia	must be < 5% of >5mm size	< 0.5% for >2mm fraction

Austria	must be < 3% of> 11 mm size	< 2% of> 2mm fraction
Belgium	< 2%	no visible contaminant, max 0.5% > 2mm
France	-	Max. Contamination 20%; <6% of > 5mm fraction
Germany	must be < 5% of > 5mm size	< 0.5% for >2mmfraction
Italy	-	< 3% total
Netherlands	must be < 3% of < 5mm size	< 0.5% for >2mmfraction
Spain	—	“free of contamination”
Switzerland	must be < 5% of > 5mm size	< 0.5% for >2mm fraction; max 0.1% plastic

United Kingdom	< 5% > 2mm	< 1% > 2mm < 0.5% if plastic

2.15 Biochar

Biochar is a fine-grained, porous charcoal substance formed via controlled, thermal conversion of biomass in the partial or complete absence of oxygen. Biochar may be added to soils to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to produce greenhouse gases (Reed, 2012).

2.15.1 Significance of Biochar

Biochar is an extremely stable way of sequestering carbon and a powerful soil ameliorant, so it could be a very effective way of sequestering carbon in farmland while improving soil fertility (Lehmann et al., 2006; Schouten, 2010). Pyrolysis is an exothermic reaction, so it emits energy. It could thus potentially represent the first carbon negative form of electricity generation, as the amount of carbon that is sequestered in biochar is higher than the amount of carbon dioxide emitted during pyrolysis (Woolf 2008 as cited by Galgani, 2012).

Biochar can be an important tool to increase food security and cropland diversity in areas with severely depleted soils, scarce organic resources, and inadequate water and chemical fertilizer supplies. It also improves water quality and quantity by increasing soil retention of nutrients and agrochemicals for plant and crop utilization. More nutrients stay in the soil instead of leaching into groundwater and causing pollution. In addition to creating a soil enhancer, sustainable biochar practices can produce oil and gas by products that can be used as fuel, providing clean, renewable energy (Reed, 2012).

2.15.2 Significance of adding biochar to compost

One efficient way to increase soil organic matter (SOM) level is compost application, however, up to now reported carbon sequestration potential due to compost management is limited in terms of carbon use efficiency and long-term carbon preservation. Therefore, new concepts for carbon sequestration combating against further raise of atmospheric CO_2 emissions are urgently needed. One promising option is combining biochar and composting technologies. This concept could enhance quality and material properties of compost products leading to a higher added value and to a much better carbon sequestration potential due to the long-term stability of biochar (Fisher et al., 2012).

Biochar with its high nutrient content when added to compost will improve the nutrient content in compost. With the biochar characteristic of retaining nutrient content in the soil, will retain the nutrients in compost preventing it from seeping into ground water.

3 CHAPTER THREE: MATERIALS AND METHODS

3.1 The study Area

3.1.1 The Location and Size

Ayuom, the community for the study is found in the Bosomtwe district and it lies within latitudes latitudes 6º 63’ 83’’ North and longitudes -1º 53’ 72’’ West.

Bosomtwe District is located at the central portion of the Ashanti Region. It spreads over a land area of 718sqkm. The District is bounded on the North by Atwima Nwabiagya and Kumasi Metropolis and on the East by Ejisu-Juaben Municipal. The southern section is bounded by Amansie West and East Districts. Kuntenase is the District Capital.

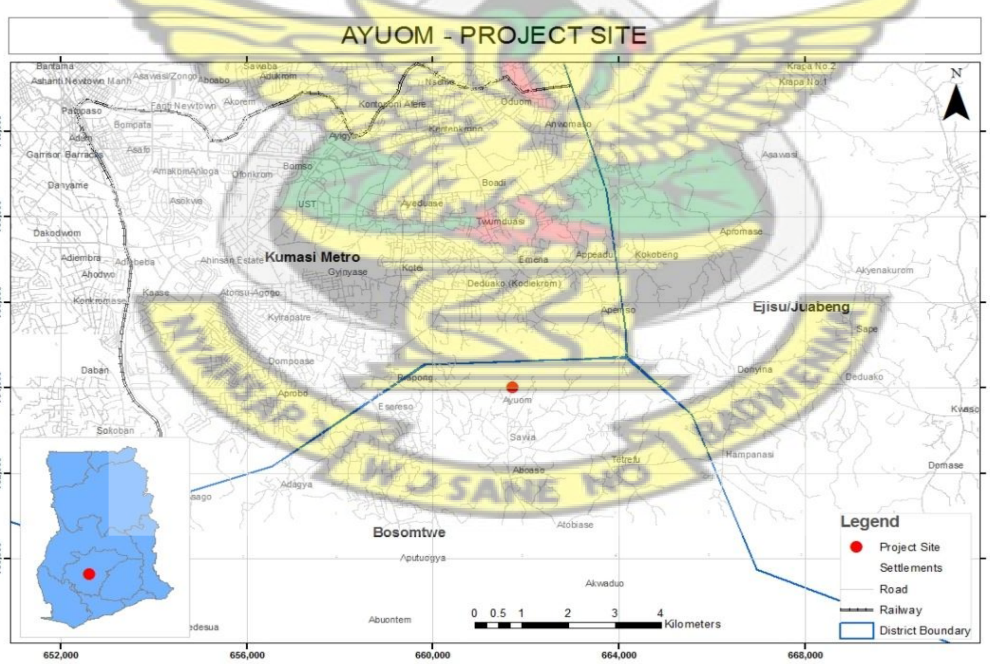

Figure 3.1: Map of Bosomtwe District showing Ayuom the project site

3.1.2 Climate

The district falls within the equatorial zone with a rainfall regime typical of the moist semi-deciduous forest zone of the country. There are two well- defined rainfall seasons. The main season occurs from March to July with a peak in June. The minor season starts from September to November with a peak in October. August is cool and dry. The main dry season occurs in December to March during which the desiccating harmattan winds blow over the area.

The natural vegetation of the area falls within the semi- deciduous forest zone of Ghana, which is characterized by plant species of the Celtis-Triplochetol Association. However, due to extensive and repeated farming activities in the past, the original vegetation has been degraded to mosaic of secondary forest, thicket and forb regrowth and various abandoned farms with relics of food crops and vegetables.

3.1.3 Population

According to the population census 2012, Ayuom has a population of four hundred and seventy four (474), with females constituting 51.69%. About 44.5% are children between the ages of 0-19years. Most of the inhabitants are farmers. All the inhabitants have had a form of formal education, however only 61.76% can speak the English language.

3.1.4 Housing

Ayuom has different categories of houses, which include separate house, semi detached houses, compound houses, flats and apartments, huts and containers. The table below describes the different housing systems at Ayuom.

Table 3.1: Different types of households in Ayuom

DWELLINGS	Counts	%	Cumul %
Separate House	44	49.44%	49.44%
Semi_detachedHs	3	3.37%	52.81%
Flat/Apartment	6	6.74%	59.55%
Rooms (Compound)	30	33.71%	93.26%
Several Huts/Bui	2	2.25%	95.51%
Hotel/Hostel	1	1.12%	96.63%
Kiosk/Container	1	1.12%	97.75%
Other	2	2.25%	100.00%
Total	89	100.00%	100.00%

Source: Ghana Statistical service, Ashanti Region(2012)

3.2 Community meeting and Sensitization

Meetings were held in the community on two occasions to inform the inhabitants of the project and also to explain to them using posters and the bins to explain which composition of waste to put in which colour of bin. Both meetings were very successful and that made the project very successful.

Plate 3.1: Community sensitization in Ayuom

3.3 Distribution of Logistics

After the community sensitization, two or four labeled bins depending on the size of a household were given to the households to do the separation of their waste. Brown dustbin with the poster of organic waste and ash dustbin with the poster of other waste were given to the forty households that took part in the exercise.

Plate 3.2: Lined dustbins in a house

3.4 Waste Collection and Transfer

Each bin was lined with a labeled plastic bag. With the help of five workers, the source-separated waste was collected weekly from the households and new plastic bags were replaced in the bins for the next week collection. Two tricycles were used to convey the waste from the households to the compost facility.

Plate 3.3: Waste collection and transportation process in Ayuom

3.5 Sorting and weighing of waste

Hand gloves, nose mask (to ensure safety), and a weighing scale were used to carry out the exercise. With the assistance of five workers, the sorting and weighing were done by the researcher. The activities took place at the compost plant on the CSIR Agric research farm at Ayuom, after every week of waste collection. Waste collected from all the forty households were weighed every week. The weight of waste; both organics and inorganics from each household was recorded and then sorted on a sorting table to remove any foreign material and also to assemble materials such as metals, rags, electronic waste and different kinds of plastics. The weight of the polythene bags used was subtracted from the weights to obtain a net weight of waste from each household. The quantity of solid waste generated in a week was determined by adding the total weight of all the waste components from all households.

Plate 3.4: Sorting and weighing of waste

3.6 Data Collected

For each waste collected, the type of waste material, source, quantity and date delivered were recorded. For each batch of waste being processed for compost, the following information were recorded

- Activities carried out when forming it. Records on weights and moisture content of input material and other amendments like water addition, C/N ratio adjustment with carbonaceous material like saw dust or nitrogenous material like garden waste.
- Information on start and finish dates
- Composting batch codes assigned (date and batch number e.g. 1st September 2011 batch 01: **0109201101**

3.7 Composting of organic waste

The feedstock or organic wastes from households in the Ayuom community were composted in trapezoidal cross section windrows over a 17-week period. The windrows were turned using a loading shovel once a week for the first 10 weeks and then, the material was allowed to mature for a period of 7 weeks with no turning when the temperature began to stabilize. Daily temperature measurement was monitored using thermocouples placed near the centre of the pile at six different points along its length. A representative sample was taken once a week after turning. The sample was a composite made up from 10 grab subsamples taken along the length on the windrow.

There was also periodic measuring of moisture content to monitor the compost pile using the simple hand squeezing test. This was measured by squeezing firmly a sample in the palm. If a lot of water came out then the pile was too moist, if there was no drop and the sample is unable to hold together then it was too dry. If it is able to hold together and there are a few drops of water, then the moisture content of the pile is ideal (Harwood et al., 2009).

The composting process was followed by post processing activities i.e. screening and packaging. The samples were screened through a 10 mm sieve and kept with ice blocks for physico-chemical analysis (Sánchez-Monedero et al, 2002)

Plate 3.5: Piling of waste and turning during composting process

3.8 Monitoring of the composting process

During the composting process, the parameters monitored were pH, temperature and moisture content. The carbon :Nitrogen ratio was also analysed.

3.8.1 Carbon: Nitrogen ratio

Laboratory analysis was done to determine the nitrogen and carbon content of the organic material used. The dry ashing method was used for the carbon whiles the Kjeldahl method was used to determine the nitrogen content (Mensah, 2010).

3.8.2 pH Determination

The representative samples from each pile were dried and ground. Three sub samples of 10g were taken from the representative sample of each pile and poured into labelled beakers for the pH determination. The triplicated sub samples were suspended in distilled water in the ratio (1:10) and shaken on a rotary shaker for Dimensions in meters 30mins.

The supernatant was then poured into a beaker and pH determined using a pH meter (Scientific Instruments Co. (Italy) model 9000/3).The pH of the triplicated samples for each system were averaged to represent pH of compost mass in each pile.

3.8.3 Moisture Determination

10g each of the representative samples from the different systems were weighed and triplicated for moisture content determination using the oven method. Samples were kept in the oven at 105ºC for 24hrs and the change in weight of samples were averaged and used as the measure of moisture content of compost mass in each system (Mensah,2010) Wet- weight Moisture content was expressed as follows

$$M = \frac{w - d}{w} \times 100$$

Where: M= wet- weight moisture content, %

w= initial mass of sample as delivered, kg

d= mass of sample after drying, kg

3.8.4 Temperature Determination

Temperature readings from three different locations: the top, middle and bottom of compost mass from the different systems under study were taken daily using the long stem thermometer (SalmoiraghiCo.thermometer model 17506) at the site. The daily ambient temperatures were also determined.

Plate 3.6: Thermometer reading temperature in compost pile

3.9 Stability and maturity methods

The self-heating test was performed according to the method described in FCQAO (1994). A screened sample with its moisture content adjusted to around 55 % was placed in insulated Dewar vessels and a thermocouple was placed into the centre of the material at the two-thirds point from the top. At the end of the test, the maximum temperature reached (Tmax) was used to determine the rotting degree which ranges from I (Tmax between 60 and 70°C) for active materials to V (Tmax between 20 to 30°C) for mature compost (Sánchez-Monedero et al, 2002).

3.10 Sampling of Compost Mass for Physico-chemical Analysis in the laboratory

Compost masses were sampled using the stratified sampling method, thus taking samples at the top, middle and bottom locations in the different piles mounted for laboratory study on moisture, carbon nitrogen ratio, pH, nutrient and heavy metal content. This type of sampling is commonly employed in heterogeneous compost. More precise sampling can be achieved if subpopulations are formed so that a heterogeneous population is divided into parts, called strata, each of which is fairly homogeneous (MOROCOMP, 2008). The samples taken were bulked to obtain a representative sample, packed with ice cubes in an ice chest and transported to the laboratory.

3.11 Laboratory analysis of compost

This consists of physical and chemical analysis of the compost produced. Parameters that were analysed include moisture content, colour, smell, pH, N.P.K values, and heavy metal concentration. The heavy metal content of Cadmium, Nickel, Chromium, Lead, Zinc, Copper and Mercury were determined. This enabled us access the quality of the compost produced.

The carbon, potassium, phosphorus and nitrogen content of the compost prepared were determined. The potassium, phosphorus and carbon content were determined by using the dry ashing method. However, the proportion of nitrogen was determined by using the Kjeldhal procedure, and it is in three steps; digestion, distillation and titration.

Ten grams of milled organic was weighed into a 500ml Kjeldahl flask moistened with distilled water. Kjeldahl tablet made up of Selenium and copper sulphate was added as a catalyst and 30ml of concentrated sulphuric acid was also added and then digested for

2hours using the Bunsen burner flame. The solution was then cooled and decanted into a 100ml volumetric flask and made up to the mark.

An aliquot of 10ml of the digested sample was taken into a distillation unit and 20ml of 40% NaOH and 10ml of 4% boric acid were added to it resulting in a pink colour, the distillate was then collected over NaOH solution and boric acid for about 5minutes.The presence of nitrogen gave a blue colour. The solution was then titrated with 0.1MHCL until the blue colour changed to pink signifying the end point.

Using the recorded titre value and the relation below the % of nitrogen was then calculated.

$$\% \text{ Total Nitrogen} = \frac{14x(A-B)\times N\times 100}{1000\times 1}$$

Where;

A is the volume of standard HCL used in the sample titration.

B is the volume of the standard solution used in the blank titration.

N is the normality of standard HCL.

3.11.1 Moisture and Organic Matter

Moisture and organic matter (OM) content were determined through the weight loss at 105 and 550 ^{o}C, respectively according to FCQAO (1994).

3.12 Mixing of Compost and Biochar

For an increase in NPK content in compost, different treatments of biochar was done to determine the best treatment for mixing compost and biochar. Biochar was ground to pass through a 2mm sieve, and mixed with ready compost and allowed to undergo an incubation experiment for 6 weeks at room temperature**.** The biochar used in this study was produced from corn husk from farms at Ayuom. The biochar and compost were mixed in the ratios (volume %) stated below.

Table 3.2 Biochar and compost mixing ratios

Sample No.	Biochar (vol. %)	Compost (vol. %)
1	100	0
2	75	25
3	50	50

The incubations was conducted in an open-top, 10-cm-diameter, 18-cm tall, PVC containers with the bottom perforated (McElligott, 2011). The biochar was incorporated and mixed thoroughly with the compost. Compost with no biochar additions were treated as the controls. Water was added to the mixture and control samples to maintain the field capacity. The mixture and control samples were replicated 3times to obtain 12 samples. During the incubation study soil-water content was maintained at the field capacity by adjustment based on weight. Analyses was conducted on the samples at the start of the experiment and six weeks after the samples were mixed to determine the nitrogen (N), phosphorus (P) and potassium (K) content. They were determined by the same methods used for the compost as described above.

4 CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents the results and discussion on waste composition, waste generation per capita, waste separation efficiency, physicochemical parameters of organic waste, process parameters monitored and physicochemical parameters of the compost produced in the Ayuom farming community.

4.1 Composition of waste in Ayuom

Table 4.1: Composition of waste sorted in Ayuom

	Mean	Std. Dev.
Organic Material	471.21	90.16
Plastics	0.02	0.09
i. PET Bottles	1.61	1.92
ii. Plastic chairs, buckets etc.	1.92	3.08
iii. Film rubbers	19.84	6.83
Glass / bottles	2.22	1.44
Paper and Cardboard	4.28	2.71
Metals	0.55	0.85
i. Other Metals (scrap)	0.09	0.26
ii. Cans, crowns etc.	4.66	2.23
iii. E-Waste (electronic gadgets)	0.12	0.17
Textiles	9.81	5.61
Inert (Sand, ash, fine organics etc.) Material	2.02	2.05
Miscellaneous or other waste	1.61	1.88

Ayuom recorded about 91% of organic waste in the total waste composition (Fig 4.1). Which does not conform to the study by Mensah, 2006 where the organic waste composition in a rural area was 54.8%. A few plastics, papers and metals were recorded in the composition of waste in Ayuom could be attributed to the minimal use of these items for the packaging of food in the community. Fig 4.1 and Fig 4.2 give a description of the waste composition in the community. Wood waste wasn't recorded since wood is used as a source of fire in a farming community as Ayuom.

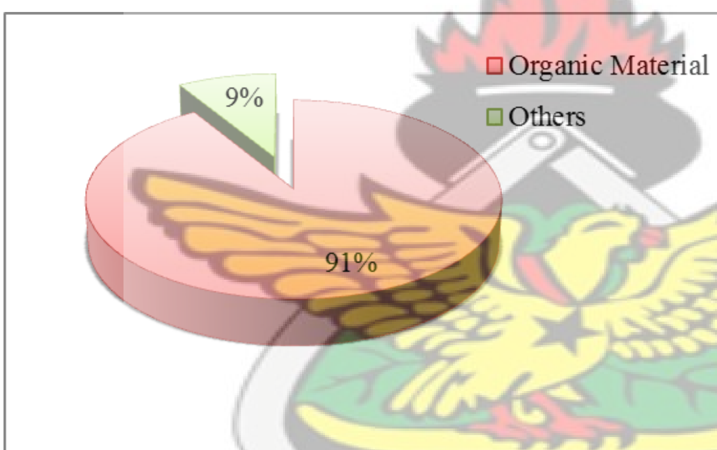

Figure 4.1: Organic and Inorganic waste Fraction in Ayuom

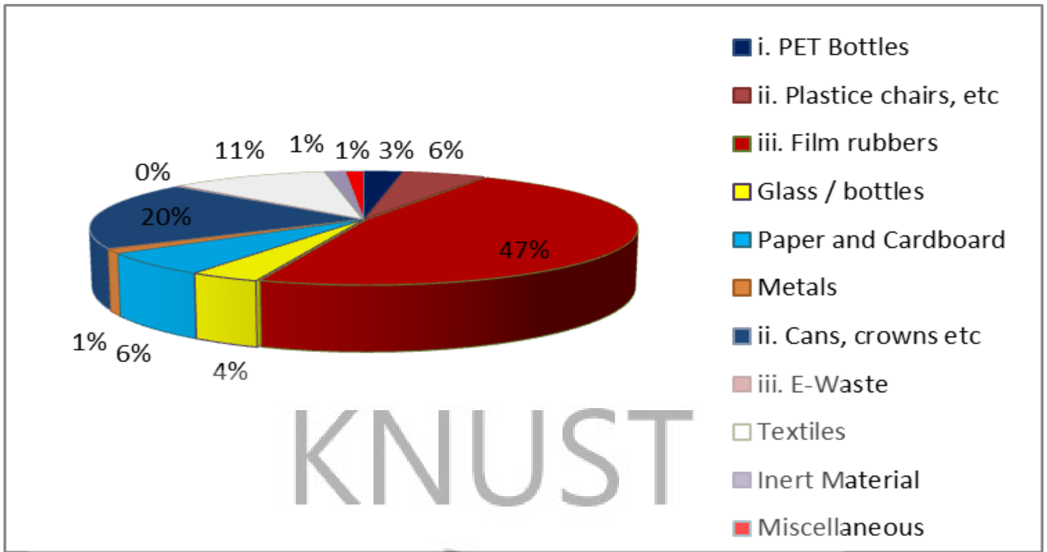

Figure 4.2: Different inorganic waste types in Ayuom

4.2 Waste separation Effectiveness

It was observed that a farming community such as Ayuom recorded 97% and 26.9% respectively for the organic and inorganic bins in the effectiveness of the source separation of waste. This can be attributed to the fact that, the indigenes understood source separation during the community meeting and sensitization. But the low records in the effectiveness of the inorganics may be due to inhabitant leaving food waste (organic) in the bags they were packaged in, and also two households involved in the production of gari who disposed of their cassava peels in the inorganic bins when their organic waste bin got full. Source separation of waste should be encouraged to prevent/reduce contamination of the different composition of waste and then encourage recycling and composting of recovered materials from waste.

4.3 Waste generation per Capita

The average rate of waste generation from the forty households was 0.22kg/per/day. This is lower than 0.46kg/per/day and 0.56kg/per/day as recorded by Kotoka, (2001) and Acquah (2008) respectively for low-income communities and 0.47kg/per/day as observed by Mensah, (2008) for rural communities. Nevertheless, according to WHO expert committee report (1982), generation rate of 0.2-3kg/capita/day was established for developing countries. The results obtained fall within the WHO expert committee report (1982). This largely may be because residents spend much more time outside their homes; for example on the farms and in school and as a result consume less at home leaving very little waste to be collected.

4.4 Chemical analysis of organic waste and Compost

4.4.1 C:N Ratio

According to Adholelya and Parakash (2004), the nutritional requirements of micro organisms in a compost pile is that, the C:N ratio must be at a level for optimum decomposition and efficiency. Because the microorganisms responsible for the decompostion can only degrade the organic carbon present in the waste if they have enough nitrogen for growth. In view of that, McClintock, (2005) reported that in general, C:N ratio in a compost pile should be between 20-30.

In this work, the organic waste was made up of cassava peels, plantain peels, orange and orange peels, water melon peels, yam peels, banana peel, corn husk, corn cobs, garden eggs food leftover and on a few occasions garden eggs, onion peels, tomatoes and pear. The C:N ratio of the compost pile (C:N) was between 14-16. Therefore the organic waste obtained may be considered as kitchen waste as shown by Holmer 2002. With a C:N ratio of 14-16, it may not support compost production as mentioned by McClintock but some of the organic waste formed into piles were allowed to undergo the composting process to determine the physicochemical parameters after composting.

The C:N ratio of other piles with similar C:N ratio were optimised and allowed to go through the composting process as well. .Saw dust has high carbon content so it was added to the pile in boosting the C:N ratio. The piles had a boost in C:N ratio from 14-16 to 23-25.3(Table 4.2).

4.4.2 Moisture Content

At the start of the composting process, piles had moisture content ranging between 61 and 69% (Table 4.2) which was quite higher than as reported by Cooperband, 2005 as the optimum on a moisture content of 40-60 % for compost production. After the composting process, the moisture content dropped to a mean of 37% which was good for handling.

4.4.3 pH

The pH range of 5.1-6.1 as shown in Table 4.2 for the compost piles conforms to 5.5-8 as the standard limit proposed by the midscale composting manual, 2007. pH affects the composting process by affecting the microbial population and by controlling the availability of nutrient to microbes. The optimum pH for most bacteria to operate is between 6.0 - 7.5 and for fungi and actinomycetes activity is between 5.5-8.0. At the end of the composting process, pH range of 7.5-8.8 was obtained, showing a slight increase above 7-8 as given by Mohee, 2007.

It is worth noting that the availability of nutrients somehow depends on the pH. Nitrogen is readily available from pH 6 to 8, Phosphorus availability is reduced at a lower pH as it binds with Al and Fe and at high pH as it binds with Ca. The solubility of Potassium increases with decreasing pH. Ca, Mg, Cu, B– solubility increases with lower pH, but insoluble at higher pH.

Table 4.2: Physicochemical parameters before composting and for ready compost

	Factor	Mean	Std. Dev.	Range	P-value
Baseline	C:N	18.2	4.6	14.9 - 25.3	
	PH	5.8	0.4	5.1 - 6.1	
	Moisture	65.2	3.2	61.0 - 69.0	
Compost	C:N	6.0	2.4	3.3 - 8.2	0.0004
	PH	7.9	0.5	7.5 - 8.8	0.0000
	Moisture	37.1	10.5	21.3 - 49.9	0.0002

4.5 Compost Parameters

4.5.1 Temperature monitoring throughout the composting period

Temperature readings within the different compost piles were not significantly different. However, there were differences between the piles and the ambient temperature throughout the experimental period.

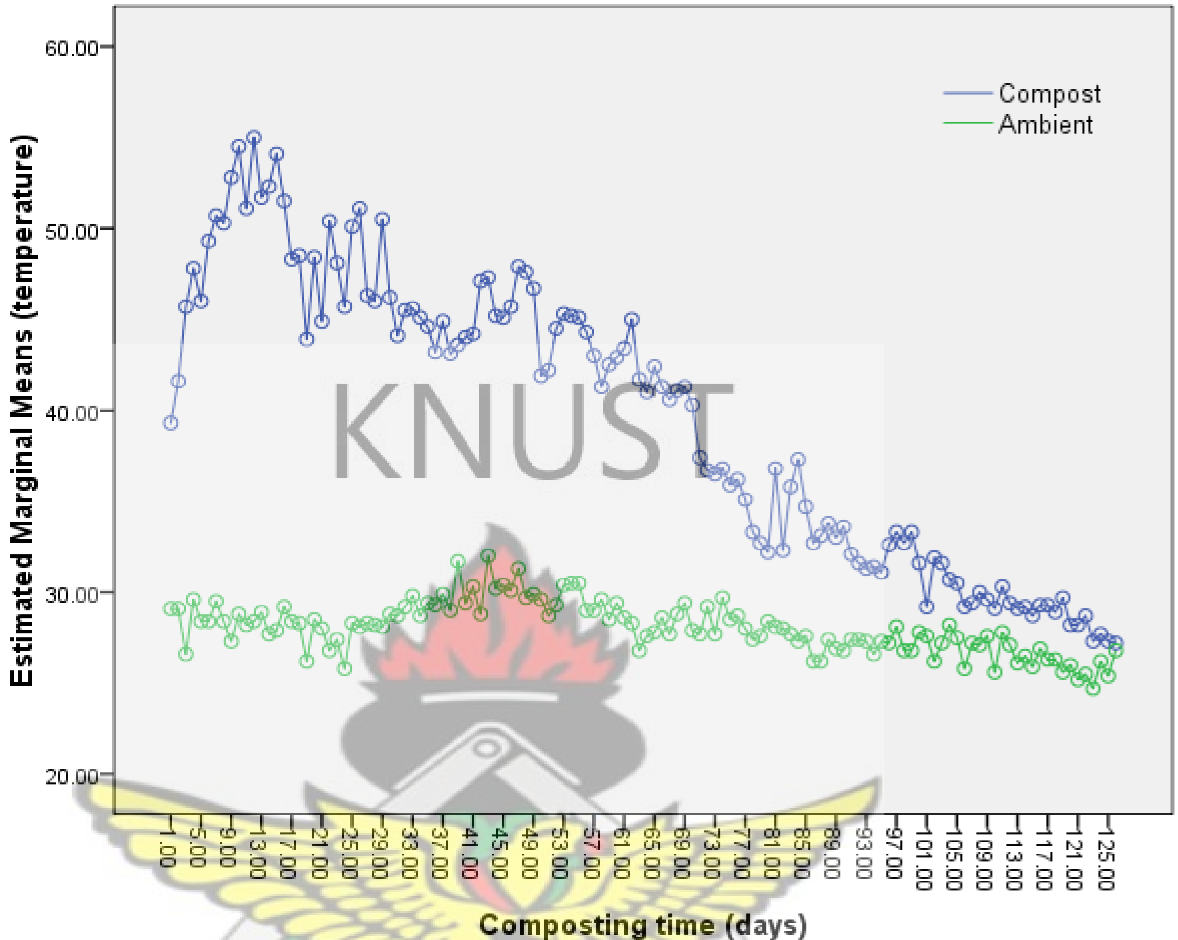

Figure 4.3: Temperature profile for compost produced from source separated organic waste

From figure 4.3, temperature of the composting piles increased gradually from 39.30°C on the first till the seventh day to 50.70°C and peaked at 55.0°C on the 12th day. From the seventh to the sixteenth day, temperatures recorded were above the 55°C therefore the composts produced from this study were free of pathogens. This confirms the study of Cooperband, 2002 who reported that pathogens in a compost pile cannot be sustained after 72 hours in a compost pile with temperature above 55 ^{o}C .Temperature after the sixteenth day fluctuated for some time and then declined till it was almost the same as the ambient temperature.

4.5.2 Nutrient content of compost produced

A quality compost is characterised by the significant levels of nutrient available especially nitrogen, phosphorus and potassium (NPK). The nutrient content in a compost has a link to its suitability in determining the appropriate end use for the compost (Herity, 2003).

According to Zethner et al, (2000) agricultural market demands compost of high quality where as compost low in nutrients is well suited for the landscaping sector and for use as mulch.

Though the NPK content may be low in quantity an important purpose for compost production is conservation of nutrient content of the organic waste and it is appropriate to apply it at greater rates in order for nutrient contribution to be significant (Follet, 1999).

Table 4.3: Nutrient content of compost produced

Nutrient	Mean	Std. Dev.
Nitrogen	0.06	0.002
Phosphorus	0.12	0.024
Potassium	0.35	0.068

In the present work, the data in Table 4.3 shows that the nitrogen conserved in the prepared compost is not appreciable (0.06). Since the C:N ratio of the feedstock (14-16) depicted quite a high nitrogen content, it was expected that the nitrogen content will be higher than the 0.06 recorded but, very little amount of the nitrogen in the organic materials was conserved in the finished compost. This may be as a result of volatilization of nitrogen as ammonia into the atmosphere. Since water serves as solvent or diluents for ammonia, the loss of nitrogen in the piles could be attributed to the high the moisture content in the compost pile hence the volatilization of the nitrogen, as ammonia, into the atmosphere. Therefore, it is possible that, the moisture content of the unfinished compost led to the loss of a significant amount of nitrogen from the compost.

Though both phosphorus and potassium are non-volatile nutrients, their concentrations in the compost were quite low as compared to as described by the Mid scale composting manual, 2007.

Although the level of phosphorus(0.12) and potassium(0.35) in the compost is higher than that reported by Otu (2011) with P(0.04) and K(0.09), all the three macronutrients (NPK) fell far below the range of values for nutrients in most conventional finished compost, as reported by Rothenberger et al (2006) because compost from household waste is known to have low nutrient content compared to compost from other feedstock like agricultural waste by Hogarh et al,(2008).

4.5.3 Heavy metal content in compost produced

Heavy metal concentrations in the compost samples are given in table 4.4. The table shows the minimum, maximum and mean concentrations of the heavy metals as well as standard deviations. The concentration of heavy metals in compost is of serious concern and is one of the main quality criteria which restricts the use of compost. (Pinamonti et al as cited by Herity 2005)

Table 4.4: Heavy Metals content of Compost produced

Heavy Metal	**Mean**	**Std. Dev.**
Nickel	13.1	3.4
Chromium	14.5	3.0
Copper	12.9	0.8
Mercury	0.2	0.1
Lead	12.4	2.9
Zinc	40.5	1.0
Cadmium	<1	

Nickel, Chromium, Mercury, Lead, Zinc and Cadmium were all below the Canadian compost quality guidelines (CCME, 2005). Copper range of 12.1-14.1 was also within range for American Compost quality guidelines. Therefore the compost produced can be said to be of good quality with regards to heavy metal concentrations.

The feedstock of composts was relatively devoid of contaminants such as plastics, printed materials and metals because they were separated at source and there was also further sorting on site. This may have accounted for the much lower concentrations of toxic heavy metals, Cd (<1) and Pb (12.4), in the composts prepared.

4.6 Presence of other foreign material in the compost produced

Because waste was source separated and further segregated on site, there was no presence of foreign materials in the ready compost.

4.7 Addition of Biochar to Compost

The t-test for paired samples was used to statistically examine differences in the different treatments used in this experiment for Nitrogen, Phosphorus and Potassium with biochar having 1.06% nitrogen, 0.29% phosphorus and 0.95% potasium. The null hypothesis H_o : a-b=c suggested in this experiment was that the differences between the before (b) and after (a) the incubation was statistically equal to the difference in the control (c). This was tested both at 1% and 5% levels of significance.

In general, it was observed that, the nutrient content of the compost after it was left for a while and then incubated for 6weeks increased. This could be attributed to the fact that, the activities of the microbes were activated during the incubation period, although there was no significant change in the temperature to indicate microbial activity.

Table 4.5 Test results for Nitrogen

	Before	After	Relative Difference	P(T<=t) one-tail	P(T<=t) two-tail
75C25B	0.335	0.51	52%		
50C50B	0.735	0.79	7%		
25C75B	0.925	0.93	1%		
100C	0.063	0.49	678%	0.004909	0.009818

The summary of the results for Nitrogen in Table4.5 above indicate that there was an overall difference by comparing the different treatments to the control treatment at 100C. The differences observed are significant at both 1% and 5% levels of significance for one (p=0.0049) and two-tailed (p=0.0098) t-test of paired dependent samples. There is a significant difference (678%) in the control treatment as shown in the table. This increase although observed in all the treatments were marginal.

However there was still an increase in nitrogen content in the compost mixed with biochar at different ratios indicating that, the nitrogen content of compost can be boosted with the addition of biochar.

Table 4.6 Test results for Phosphorus

	Before	After	Relative Difference	P(T<=t) one-tail	P(T<=t) two-tail
75C25B	0.125	0.14	12%		
50C50B	0.165	0.12	-27%		
25C75B	0.215	0.125	-42%		
100C	0.09	0.11	22%	0.289181	0.578363

The result for phosphorus as shown in Table 4.6 shows no significant differences by comparing the different treatments with the control treatment. Although only the first treatment (75%C 25%B) displayed some increment in phosphorus with the remaining treatment recording decreases, these changes in the treatments compared with the expected change in the control were not significant both at 1% and 5% levels of significance.

Combining 50% compost and 50% biochar as well as 25% compost 75% biochar reduced the phosphorus content in the mixture. Phosphorus is a non-volatile nutrient which means it is not lost to the atmosphere but it can leach out if the moisture content is too high. If the moisture in the windrow is managed properly no phosphorus should escape thus the end product should contain a greater concentration of phosphorus than the original raw manure due to volume reduction (Nelson, 2002). As shown in Table 4.6, the phosphorus content increased for all treatments right after mixing, but it reduced to o.12 and 0.125 % compositions for 50C50B and 25C75B treatments respectively and that could be as a result of leaching of moisture from the treatments.

Table 4.7 Test results for Potassium

	Before	**After**	**Relative Difference**	**P(T<=t) one-tail**	**P(T<=t) two-tail**
75C25B	0.365	0.66	81%		
50C50B	0.475	0.61	28%		
25C75B	0.7	0.7	0%		
100C	0.27	0.61	126%	0.014868	0.029737

At 5% level of significance, there was a significant difference across all treatments for potassium with the treatment of 75% compost 25% biochar returning the maximum increment in the nutrient. Consistently, this compost and biochar combination recorded the maximum increment for the other nutrients.

5 CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

I. The study showed that a farming community as Ayuom could effectively separate their waste after effective sensitisation and education.

II. Source separation of the waste encouraged recovery, recycling and reuse of the waste fractions generated in the community which are the most favoured in the integrated solid waste management hierarchy. Due to the fact that the largest component of waste was organic, it was sorted and composted for use on the farm of Ayuom as well as the potential for sorted plastics and cans to be sold to bring some income, it can therefore be concluded that an integrated approach in the management of waste was achieved.

III. The study showed a trend that does not correlate to the waste generation per capita rate in low income communities as shown in literature. The largest composition of waste consists of organic waste and the materials typically found in the inorganic waste stream included paper/cardboards, plastics, glass, metals/cans, textile and miscellaneous.

IV. C/N ratios ranging between 14.9 -25.3:1 were obtained, with some conforming to 20-40 as considered as optimum for composting processes and others falling below the optimum condition.

V. The contents of nitrogen, phosphorus and potassium in the compost were not appreciable, that suggests that the C:N ratio (14.9-25.3: 1) for the start may be too low.

VI. NPK content of compost was enhanced by mixing compost and biochar, with 75% compost and 25% biochar being the treatment constantly recording maximum increment of all nutrients

6.2 Recommendations

I. The segregation of solid waste at source is highly recommended so that clean source of raw materials could be obtained for composting and other waste treatment or disposal options.

II. Though the nutrient content may be low, it can be applied in large quantities

III. Further research should be conducted into processing of household waste through composting. In preparing compost, the organic waste materials should be cut or shredded into small pieces and mixed with high carbon materials before composting to improve the nutrient content of the prepared compost to support crop production.

IV. Further studies should be conducted to evaluate the increase in the nutrient content of compost without additives after incubation.

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