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Rotary Drum Composting of Faecal Sludge; Case of Peri-urban Areas in Ashanti Region, Ghana

By

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DOCTOR OF PHILOSOPHY

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DECLARATION

I hereby declare that this submission is my own work towards the PhD 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 any university, except where due acknowledgement has been made in the text.

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ABSTRACT

The main objective of the study was to design and demonstrate the applicability of the rotary drum composter for treating faecal sludge from peri-urban Ghana. The specific objectives were to assess faecal sludge practices and management, assess the perception of peri-urban farmers on faecal sludge compost and its utilization, determine the characteristics of faecal sludge, test the effect of bulking materials and mixing ratios on the quality of peri-urban faecal sludge compost and measure the performance of rotary drum composter on the die off of *Ascaris* and *Trichuris* eggs. The study was conducted in six (6) communities (3 peri-urban and 3 rural used for comparison) randomly selected from Bosomtwe District, Ejisu-Juaben Municipal and Kumasi Metropolitan Assemblies. The study used desk studies, responses from household surveys, key informant interviews, field observations and experiments to address the objectives. The study showed poor faecal sludge management in both peri-urban and rural areas with no designated locations for faecal sludge treatment and disposal. 63% and 76% of peri-urban and rural areas respectively used public toilet as their main mode of defaecation ($p=0.0172$). Majority of farmers (about two-thirds) were not aware of the many advantages associated with the use of faecal sludge to fertilize their farms and the benefits that the reuse of faecal sludge has on sanitation issues. Only 34% of the farmers were aware that faecal sludge is a useful source of fertilizer and only 4% use it to fertilize their farms. Farmers seemed to be more concerned about how society will react towards them if they use faecal sludge compost. Generally, the values for electrical conductivity, chemical oxygen demand, biochemical oxygen demand, ammonia-nitrogen, nitrate-nitrogen, total Kjeldahl nitrogen, nutrients, some heavy metals and microbial quantities analysed in both peri-urban and rural sludge were generally high compared to that found in literature. During the testing of bulking materials in different mixing ratios, all the experimental trials were not adequately exposed to high temperatures (above 45 ^{o}C) for a sufficient period to guarantee pathogen die off. Faecal sludge in peri-urban areas of Ashanti region of Ghana was highly contaminated with *Ascaris* and *Trichuris* eggs. The population of *Ascaris* and *Trichuris* decreased significantly in all the rotary drum experimental set ups during the composting process. The study on the assessment of faecal sludge management showed poor faecal sludge management in both peri-urban and rural areas. From the study, the characteristics of faecal sludge varied between peri-urban and rural areas. Maize cobs as bulking material in 1:2 ratio produced best compost during the testing of bulking materials in different mixing ratios. The type of composter had significant impact on the die off of *Ascaris* and *Trichuris* population with plastic drum with rotating paddle mixer performing best. This research bridges a gap in faecal sludge management as it demonstrates the applicability of the rotary drum technology in faecal sludge composting in peri-urban areas where farming is the main economic activity of majority of the inhabitants.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrophotometer
ADB	Asian Development Bank
CAD	Computer Aided Design
DDT	Dichlorodiphenyltrichloroethane
DEM	Discrete Element Method
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
FS	Faecal Sludge
FSM	Faecal Sludge Management
FST	Faecal Sludge Treatment
GHS	Ghana Cedis
GLSS	Ghana Living Standard Survey
GNA	Ghana News Agency
GPS	Geographic Position System
GSS	Ghana Statistical Service
ID	Infectious Dose
ILO	International Labour Organization
JMP	Joint Monitoring Programme
KNUST	Kwame Nkrumah University of Science and Technology
KMA	Kumasi Metropolitan Assembly
KVIP	Kumasi Ventilated Improved Pit
MDG	Millennium Development Goals
MLGRD	Ministry of Local Government and Rural Development
MPN	Most Probable Number
NEERI	National Environmental Engineering Institute
OSS	Onsite Sanitation Systems
PTS	Public Toilet Sludge
SANDEC	Department of Water and Sanitation in Developing Countries
SDG	Sustainable Development Goals
UNICEF	United Nations Children's Emergency Fund
USD	United State Dollars
VIP	Ventilated Improved Pit
WC	Water Closet
WHO	World Health Organization
WRI	World Resources Institute
WRRI	Water Resources Research Institute

DEDICATION

I dedicate this work to the Almighty God, my wife Barbara, my children Jayden, Jayson and Jessica and my entire family especially Mr. and Mrs. Effah, Chris, Michael and Bernard for their love and continuous support.

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CHAPTER 1: INTRODUCTION

1.1 Background

Basic sanitation is concerned with the means of handling and treating people's urine and excreta in a hygienic way, so that it does not endanger the health of people or the environment. Improving upon basic sanitation services is key to human health and environmental sustainability. In situations where basic sanitation solutions are inadequate or nonexistent, people are often forced to make choices which cause damage to human health and the environment. Inadequate sanitation is a common problem in many developing countries. Increasing population growth, rapid urbanization and increased economic activities also pose serious pressure on the sanitation services. This means that basic sanitation needs of the individuals remains unmet and the human right to sanitation remains unrealized for billions of people worldwide (Eid, 2015).

Governments of developing countries and city authorities face a daunting challenge with respect to sanitation. Despite the spotlight on sanitation challenges and the plight of the poor over the years, the number of people without access to sanitation services continue to increase. Thus the global sanitation problem requires urgent attention (Eid, 2015). At the World Summit on Sustainable Development in Johannesburg in 2002, there was a global commitment to halve by 2015, the proportion of people without access to safe sanitation. To monitor progress of sanitation delivery, the World Health Organisation and UNICEF's Joint Monitoring Programme for Water Supply and Sanitation (JMP) reports every two years on progress towards achieving this target (WHO/UNICEF JMP, 2012). Since 2008, the JMP has defined sanitation access using a sanitation ladder which goes from open defecation, to unimproved, shared and then improved facilities (WHO/UNICEF, 2014). An improved sanitation facility is defined as one that "hygienically separates human excreta from human contact” (WHO/UNICEF, 2014). The definition is based on two main indicators; access to an improved latrine technology type and the number of households sharing the sanitation facility (WHO/UNICEF, 2008). The MDG indicator ‘use of an improved sanitation facility’ focused on hygienic separation of excreta from human contact. Yet, there is the need to go beyond access to a basic facility and address safe management of faecal sludge along the sanitation chain (WHO/UNICEF, 2015).

During the Millennium Development Goals (MDG) period, it was estimated that the use of improved sanitation facilities rose from 54% to 68% globally (WHO/UNICEF, 2015). Despite this huge achievement, the MDG target for sanitation which was to halve the proportion of people without access to basic sanitation by 2015 was missed. The target of 77% was missed by nine (9) percentage points and almost 700 million people. Currently about 2.4 billion people still lack access to basic sanitation (UNICEF/WHO, 2015). Sub-Saharan Africa continues to have the lowest levels of sanitation coverage worldwide where less than 20% of the population have access to improved sanitation and progress has been slow since 1990 (WHO/UNICEF JMP, 2015).

Without proper sanitation people are much more susceptible to sickness, which affects their lives in various ways. The sanitation problem is relevant to adults as well, although children are more easily affected by illnesses. In the developing world, diseases, associated with poor water and sanitation have considerable public health significance. About 1.6 million people die every year from diarrhoeal diseases (including cholera) attributable to lack of access to safe drinking water and basic sanitation and 90% of these are children under 5 years, mostly in developing countries (UNICEF Ghana, 2015a). The cost of inadequate sanitation translates into significant economic, social, and environmental burdens (ADB, 2014).

Globally it is estimated that 82% of the urban population uses improved sanitation facilities compared with 51% of the rural population (WHO/UNICEF, 2015). This was evident as the number of people without access to improved sanitation in rural areas decreased by 15% and open defecation rates decreased from 38% to 25%. Despite the significant progress made during the MDG period, sanitation coverage in rural areas continues to lag behind urban areas. The JMP report indicates that globally seven (7) out of ten (10) people are without improved sanitation and nine (9) out of ten (10) people practising open defecation live in rural areas. In order to achieve goal 6 of the Sustainable Development Goals (SDG)of "*ensuring availability and sustainable management of water and sanitation for all by the year 2030"*, there need to be a concerted effort to provide sanitation and safe excreta disposal facilities.

The sanitation status in Ghana needs improvement. Improving sanitation is of paramount importance to reduce risks of disease transmission in and around the home and to improve the quality of the environment beyond household level (Parkinson & Walther, 2014). It also enables a productive and dignified life. Access to basic sanitation, linked to proper 'use and disposal', can substantially reduce diarrhoeal disease, intestinal worm infections and vector-borne disease. Although access to improved sanitation has been improving steadily over the past two (2) decades, Ghana still lags behind most of the developing countries despite steps by Government and other development partners to address the sanitation challenge. Only 15% of Ghana's population have access to improved sanitation services, well short of the 2015 goal of 54% (Table1-1).

Table 1-1: Ghana Sanitation Coverage

Sanitation Coverage (%)			
	Rural	**Urban**	**National**
Improved	9	**20**	**15**
Shared	45	73	60
Other unimproved	12	**0**	**6**
Open defaecation	34	**7**	**19**

Source: WHO/UNICEF, 2015.

The majority (81%) of the Ghanaian population is served with onsite sanitation systems including latrines, non-sewered public toilets and septic tanks (GSS, 2014). An onsite sanitation is a system of sanitation that can be either a dry system or wet system. According to GLSS 6, the public toilet is the commonest form of toilet facility used by households, accounting for 35.7% (GSS, 2014). Households using WC, Pit Latrine and Kumasi Ventilated Improved Pit (KVIP) constitute 13.9%, 19.1% and 12.1% respectively (GSS, 2014). Between the urban-rural divide, 39% of urban households use public toilets as compared to 14% of rural households. One in five Ghanaians have no access to a toilet and defecate in the open, with open defecation rates over 70% in Northern Ghana, reflecting significant national inequalities (UNICEF Ghana, 2015b). These onsite sanitation systems often only collect or contain the Faecal Sludge (FS) (the contents of septic tanks or pit latrines) and once full there are no systems in place to safely manage or exploit its potential value (through the emptying, transportation, treatment and reuse or disposal (Figure 1-1).

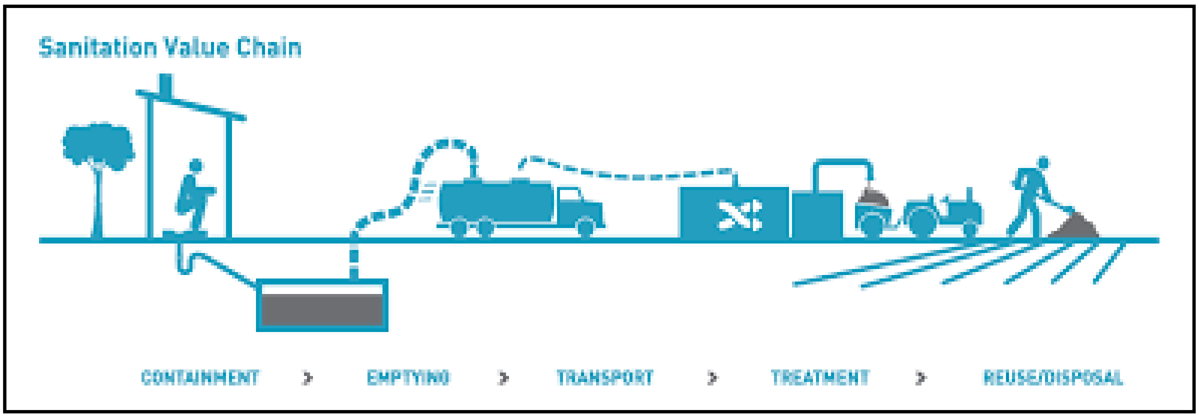

Figure 1-1: The sanitation value chain (Bill and Melinda Gates Foundation, 2010)

Installation of sewerage systems with its high investment cost and need for adequate supply of water has not worked well in Ghana. Onsite sanitation systems is therefore seen as the dominant technology to offer a hygienic and affordable solution to the sanitation crisis. This will serve the growing populations in Ghana for decades to come. As most of the population rely on onsite sanitation, there is a growing challenge for faecal sludge management. This means that provision of access to latrine facilities alone is not sufficient to prevent the faecal threat.

The next challenge is in the mode of treatment and/or safe disposal as addressed in the Sustainable Development Goals 6.2. Faecal sludge needs adequate treatment and disposal to safeguard public health and the environment (EAWAG & SANDEC, 2006). Although there are many options for treating faecal sludge, there is no single best option given the widely varying characteristics of sludge produced in developing countries. Therefore the selection of technologies should be done taking into consideration the characteristics of faecal sludge, existing regulations and end-use of the faecal sludge. Several pilot studies carried out by SANDEC and its partners have found that treatment using biological (natural) processes, including waste stabilization ponds, unplanted sludge drying beds, reed-planted drying beds, constructed wetlands, and composting/co-composting, are among the low cost and effective solutions. One option that has not received much attention in the treatment of faecal sludge is composting which could eventually be channelled back into the life-chain stream for re-use. Composting tends to be an increasingly viable means of faecal sludge management. The use of composting to stabilize faecal sludge and to transform it into a valuable resource is presently experiencing an expanding trend of application in many countries. However, the same cannot be said of peri-urban areas of Ghana where faecal sludge is often buried or sent to disposal sites usually at far distant locations. Composting of faecal sludge is an environmentally sound means of recycling raw organic material into valuable soil amendments with many uses.

It is important, therefore, to critically look at acceptable composting methods which will provide opportunities for peri-urban households to recover resource in the form of organic fertilizer from faecal sludge. In addressing this issue, this study sought to compost faecal sludge from peri-urban Ghana using a rotary drum as this method may provide acceptable option for households to recover nutrients whiles dealing with the faecal threat.

1.2 Problem Statement

The basic objective of sanitation is to protect public health by preventing direct and indirect contact with excreted pathogens such that faecal pathogens do not come into contact with people, animals, insects, crops or water sources' (WRI, IUCN & UNEP,1992). In spite of the importance of good sanitation in improving the health status of the people, sanitation services delivery in Ghana has not been given the needed attention it deserves. While the MDGs have catalyzed increased coverage of access to sanitation facilities, the implementation of this MDG has sadly led to a short-term shift (toilet availability), rather than a long-term outcome (toilet or treatment functionality) (Ross, Abeysuriya & Mitchell, 2015). In other words the MDGs had a strong focus on improving basic sanitation at the household level but not the faecal sludge that will be generated from the latrines. As such faecal sludge management have not received the needed attention even though it is critical to address public health and environmental risk. Thus there are usually no adequate treatment systems in place for the resulting accumulation of faecal sludge which have often resulted in numerous cases of sludge management crisis. It is reported in Ghana, that out of 44 sewage and faecal sludge treatment facilities (including 7 Faecal Sludge and Septage Treatment Plants), only seven are functioning adequately (MLGRD, 2010). These faecal sludge treatment facilities are located in the urban areas of Accra, Kumasi, Tema and Akosombo, which have some form of sewer system.

A nationwide survey conducted by International Water Management Institute (IWMI) in 2010 revealed less than10% of faecal sludge and wastewater generated in urban settlements received some form of treatment (IWMI, 2015). The remaining 90% is left in the environment untreated. Keraita *et al.* (2002), observed that the amount of faecal sludge collected in Kumasi is half of what is expected, while that of Accra is dramatically low. Almost all the rest of the faecal sludge is discharged into the environment untreated (Kuffour *et al.,* 2013). About twenty thousand tons of faecal sludge is estimated to be generated every day from onsite sanitation systems such as unsewered family and public toilets and septic tanks-so-called faecal sludges are disposed of untreated and indiscriminately into the environment posing great risk to human health and the environment (Kuffour *et al.,* 2013).In Accra, only 6% of faecal sludge that accumulates in onsite facilities is being collected and transported to faecal sludge and septage treatment plants for treatment (IWMI, 2015).

The causes for the indiscriminate and clandestine disposal of faecal sludge are multiple: lack of treatment and disposal facilities, long haulage distances to treatment sites, non-affordability, the difficulty for mechanical and manual pit emptying services to gain access to toilets in densely-populated areas and the dumping of solid waste into toilets (Ingallinella *et al.,* 2002; Ahmed & Rahman, 2003; Koné & Strauss, 2004; Koottatep *et al.,* 2012; Bakare, 2014). The unacceptable practice of unapproved disposal of faecal sludge is worse in the peri-urban areas where no appropriate faecal sludge treatment facilities exist. This therefore does not encourage faecal sludge treatment in such areas.

Although composting of faecal sludge is not entirely new in Ghana, there are challenges and hindrances to the wide-scale implementation and acceptance of faecal sludge as an organic fertilizer into crop production in our society. This is as a result of the poor quality of compost or co-compost produced (Adamtey, 2010) and the negative perception farmers and consumers have towards human waste composting and use in crop production.

1.3 Justification

The selection of appropriate faecal sludge treatment option is influenced by the treatment objective. Composting falls under the new paradigm shift of faecal sludge treatment which is towards recycling of wastes of organic origin into useful materials (compost) for crop production. Composting is an appropriate way of treating faecal sludge in peri-urban areas where food farming is largely practiced. Some of the problems associated with most of the current compost practices are (1) uneven mixing (2) bad odour (3) low compost maturity and (4) presence of pathogens. These problems do not promote the application of composting technology for faecal sludge treatment. However, the rotary drum technology is a promising technology to address the problems. Using the rotary drum technology reduces the composting duration whiles rapidly stabilizing the compost (Nayak & Kalamdhad, 2014). It also has the benefit of reducing haulage distance of desludged faecal sludge due to its decentralized nature. Various authors had used rotary drum composter for different types of wastes such as cattle manure, swine manure, municipal bio-solids, brewery sludge, chicken manure, animal mortalities and food residues (Kalamdhad & Kazmi, 2008) but not faecal sludge.

This research explores the possibility of sanitizing faecal sludge whiles promoting its reuse for agriculture and other beneficial purposes by using a rotary drum composter as a decentralized system. Composting of faecal sludge provides a sustainable option for utilising the organic wastes thereby reducing the costs of management/disposal, reducing the waste volume and transport costs while in addition producing a valuable product (Cofie *et al.,* 2008). It is expected that the findings of this study will provide guidelines for the design of an alternative decentralized low cost technology for composting faecal sludge from peri-urban and other low income areas of Ghana and other developing countries with similar sludge characteristics. It will be an option to promote and enhance decentralized treatment of faecal sludge which will be beneficial for agricultural purposes. In general, this study will contribute to the improvement of sanitation, public health, environmental protection and food production through treatment of faecal sludge and application of the compost produced to enrich the soil, thereby contributing to ensuring the well being of people in peri-urban and other low income areas.

1.4 Study Objectives

The main objective of the study was to design and demonstrate the applicability of the rotary drum composter for treating faecal sludge from peri-urban Ghana**.**

The specific objectives were to:

1. Assess faecal sludge management in selected peri-urban areas
2. Assess the perception of peri-urban farmers on faecal sludge compost and its utilization
3. Determine the characteristics of faecal sludge from selected peri-urban areas
4. Test the effect of bulking materials (wood chips and shredded maize cobs) and mixing ratios on the quality of peri-urban faecal sludge compost
5. Measure the performance of rotary drum composter on the die off of *Ascaris* and *Trichuris* eggs

1.5 Hypotheses

The main hypotheses for the study were;

1. Faecal sludge contains high levels of physicochemical and microbial pollutants
2. Peri-urban farmers are not interested in using faecal sludge compost as organic fertilizers
3. The type and ratio of faecal sludge to bulking material has an influence on compost quality
4. The rotary drum composter increases die off of *Ascaris* and *Trichuris* eggs

1.6 Thesis Outline

The report is subdivided into five (5) chapters. Chapter one (1) deals with the introduction which presents the background and problem statement of the study. It also highlights the objectives, hypothesis and justification of the study. The second chapter covers the review of relevant literature to the study. This included review on faecal sludge management, the composting process and design and construction of rotary drum composter. The approach and methodology used to undertake the assignment is also described in chapter three (3). Detail results and discussions of all the study objectives are presented in chapter four (4). This chapter presents the findings and interprets them in the framework of faecal sludge management and composting principles. The conclusions and recommendations from the results and discussions and also from the literature review have been presented in the last chapter, chapter five (5).

CHAPTER 2: REVIEW OF RELEVANT LITERATURE

2.1 Overview of Faecal Sludge Management (FSM)

Faecal sludge comprises all liquid and semi-liquid contents of pits and vaults accumulating in onsite sanitation systems, namely unsewered public and private latrines or toilets, aqua privies and septic tanks (EAWAG & SANDEC, 2003). It is raw or partially digested, a slurry or semisolid, and results from the collection, storage or treatment of combinations of excreta and blackwater, with or without greywater (Strande *et al.,* 2014). The faecal sludge contains varying concentrations of settleable or settled solids and additionally of other non-faecal matter. (e.g. kitchen grease and wastes, plastics, textiles and feminine towels). Public toilet sludge is also referred to as faecal sludge.

Faecal sludge management refers to activities carried out on onsite sanitation systems to avoid faecal sludge crisis. According to Strauss & Montangero (2002), faecal sludge management deals with such important issues as the costing, economics and management of entire FS systems, which would include all relevant infrastructure components and services, through the onsite household-level installations, faecal sludge collection and haulage, faecal sludge treatment and reuse or disposal or of biosolids produced during treatment. Faecal sludge management concerns the various technologies and mechanisms that can be used to treat and dispose of sludge.

2.1.1 Status of faecal sludge management in Ghana

According to the Joint Monitoring Programme, the world has missed the global MDG sanitation target by nine percentage points and almost 700 million people despite the encouraging progress made (WHO/UNICEF, 2015). About 68% of the global population use improved sanitation facilities, whiles the remainder use shared, unimproved sanitation facilities or practice open defaecation. The Joint Monitoring Programme defines improved sanitation facilities as facilities that ensure hygienic separation of human excreta from human contact. They include flush or pour-flush toilet/latrine, piped sewer system, septic tank, pit latrine, ventilated improved pit (VIP) latrine, pit latrine with slab, composting toilet. Unimproved sanitation facilities is defined as facilities that do not ensure hygienic separation of human excreta from human contact. Unimproved facilities include pit latrines without a slab or platform, hanging latrines and bucket latrines. Other forms of sanitation practices include the use of shared (public/communal) sanitation facilities which is of an otherwise acceptable type shared between two or more households. Shared facilities include public toilets. These toilets are not considered improved. Open defaecation is also the defaecation in fields, forests, bushes, bodies of water or other open spaces, or disposal of human faeces with solid waste.

Ghana's population is becoming increasingly urbanized. The census or statistical definition of an urban centre in Ghana is any settlement with a population of 5,000 or more persons. Today more than four out of every ten Ghanaians live in a city or town of more than 5,000 people. The rapid urbanization characterized by sharp population growth and unplanned settlements have been posing serious challenges on public health and environmental status of low income countries. As urban migration increases, available latrines are receiving more and more users. However, while latrine coverage may remain insufficient, the safe collection and treatment of faecal sludge from systems that do exist is arguably the weakest link in the sanitation value chain. These have led to a substantial increase in the quantity of faecal sludge generated daily. This increase has put pressure on some urban infrastructure since the rate of urbanization does not match the rate of sanitation infrastructural provision. This has led to growing interest in approaches for safe emptying, transport and end use or disposal of faecal sludge (Montangero & Strauss, 2004).

Contrary to wastewater management, the development of strategies and treatment options adapted to the conditions prevailing in developing countries to cope with faecal sludges (the by-products of onsite sanitation installations) has long been neglected (Kone & Strauss, 2004). Only about 3.4% of the people in Ghana use sewered sanitation (GSS, 2012). Ghana statistical service report shows that in 2012, about 81% of Ghanaians depended on onsite sanitation technologies consisting mostly of pit latrines, KVIPs and septic tanks (GSS, 2012). The few faecal sludge treatment facilities available are not able to treat the large tons of sludge generated. As a consequence, growing quantities of faecal sludge will have to be managed.

The situation of faecal sludge management is more serious in the rural and peri-urban settlements of Ghana as these areas lack access to adequate faecal sludge facilities, thus relying more on unimproved approaches. This is as a result of the absence of proper arrangements and locations for the treatment and disposal of the sludge (Appiah-Effah *et al.,* 2014). This is corroborated by a recent study on Technology assessment for basic sanitation delivery in rural and peri-urban areas of Ghana where households using onsite sanitation systems have no idea on any Faecal sludge management option when their pits get full (KNUST/UNICEF GHANA, 2015). The current practice for the very few who try some form of management from onsite sanitation systems (OSS), collect and dispose of untreated and indiscriminately into drainage ditches, inland waters and the sea, mainly due to lack of affordable treatment systems (Heinss *et al.,*1998). Suitable sites for treatment and final disposal of faecal sludge are located at farther distances outside the communities as a result of no cesspit emptying operators and facilities in the communities (Appiah-Effah *et al.,* 2014).

2.1.2 Faecal sludge collection and haulage

Despite the widespread promotion of onsite sanitation systems in reaching the MDGs' sanitation target, most toilet provision programs and city agencies do not address the issue of what people do with the faecal sludge that accumulates inside the onsite sanitation systems. When an onsite sanitation system is full there are two options according to Pickford & Shaw (1997), that is either latrine is abandoned and new one constructed or it is emptied. The lack of available space or the costs of constructing a new onsite sanitation system often, means that desludging may be the only practical alternative (Muller & Rijnsburger, 1994). While desludging frequencies vary, it is typically considered best practice to desludge tanks once every three to five years, or when the tank becomes one third full. Studies have shown that after this period, sludge decomposes, solidifies, and can no longer be removed by suction alone (Bosch & Schertenleib, 1985). Frequent desludging also helps reduce the pollution levels in the liquid effluent, which typically enters waterways untreated.

Desludging can be done manually or mechanically by using a machine. Manual desludging is a traditional practice which usually involves removing the sludge by using a bucket tied to a rope and the content transferred into pits and buried. Manual emptying is often done at night and is associated with clandestineness. The challenges associated with manual desludging are that the method is not aesthetically pleasing, the toilet cannot be used while desludging, it usually takes about 3–5 days, operators normally lack appropriate equipment, and the attendant health risks associated with it. Emptying by hand poses serious health risks to the emptiers, especially if no protective clothing is worn. Mechanical desludging involves the use of mechanized technologies such as conventional vacuum tankers to small hand-operated pumps that have been used or piloted in urban areas in developing countries.

Once the sludge is collected, it has to be hauled to a treatment or disposal site (Thye *et al.,* 2011). According to Strauss & Montangero (2002), faecal sludge collection and haulage are particularly challenging in metropolitan centres which are often large and very densely built-up. In low-income districts where emptying vehicles may not have access to pits, suction hoses must be laid through neighbours yards and homes. Long haulage distances and traffic congestion aggravates the problem and renders haulage to designated discharge or disposal sites uneconomical and financially unattractive, leading to uncontrolled dumping of collected FS at shortest possible distance from the area of collection.(Strauss & Montangero, 2002).

2.1.3 Faecal sludge treatment and disposal

Faecal sludge treatment and disposal can be done onsite or offsite. The onsite system, treatment and/(or) disposal takes place at the point of faecal sludge generation without transportation while offsite approach involves the transportation of faecal sludge from the point of generation to another location. The main purpose of treating faecal sludge should be to render the sludge harmless for discharge into the environment (including landfilling), or to produce biosolids, which may be safely used for beneficial purposes including agriculture. Generally, proper faecal sludge treatment and disposal facilities are absent in peri-urban areas of Ghana. The fact that there are no designated treatment and disposal facilities in peri-urban areas renders haulage of faecal sludge to designated treatment and disposal sites very expensive, leading to illegal dumping of collected sludge at the shortest possible distance where they may cause environmental and health risks (Klingel *et al.,* 2002).

There are many options for treating faecal sludge as there is no single best option given the widely varying characteristics of sludge produced in developing countries. The selection of appropriate treatment option is also influenced by the treatment objective. Several pilot studies carried out by SANDEC and its partners have found that treatment using biological (natural) processes, including waste stabilization ponds, unplanted sludge drying beds, reed-planted drying beds, constructed wetlands, and composting, are the most cost-effective solutions. However it is important to take into consideration the cost of land, the capacity of staff to operate and maintain the system and the location of the treatment facility with respect to OSS.

In 2002, Strauss and Montangero proposed an overview of options for faecal sludge treatment, which can be implemented by using modest to low-cost technology (Figure 2-1).

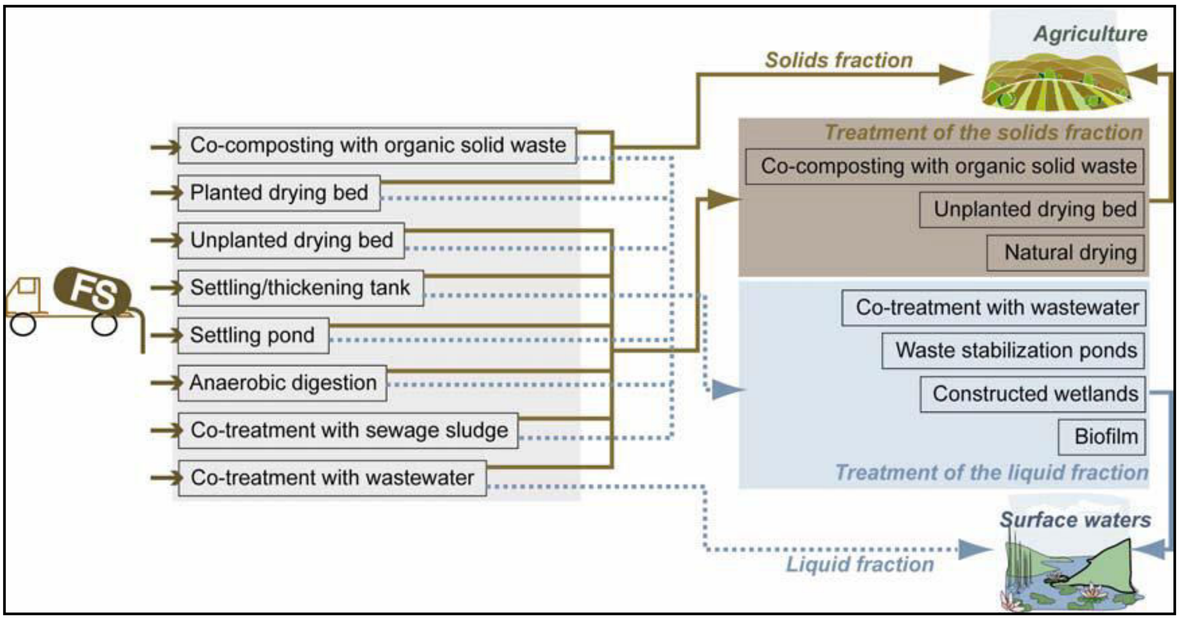

Figure 2-1. Overview of potential, modest-cost options for faecal sludge treatment

Source: Strauss and Montangero, 2002.

Currently, a great deal of research are being conducted on innovative faecal sludge management technologies which also addresses the issue of resource recovery. These technologies include

- Vermicomposting
- Using Black Soldier Fly
- Ammonia Treatment
- Thermal drying and pelletizing
- Solar drying

These technology options ensures recycling and use of faecal sludge and are the preferred options for sustainable development. They have also been proven to achieve high removal of pathogens which is necessary to secure sludge use on land. With treatment focus on resource recovery, there is an increasing need to use advanced treatments to provide assured pathogen removal

2.2 Faecal Sludge Quantities and Characteristics

Estimating the quantities of faecal sludge generated and determining their characteristics are important steps in designing faecal sludge (FS) treatment technologies. The collected or collectable daily per capita faecal sludge quantities are dependent on the technology type, desludging practices, how the technology is used, groundwater levels and on infiltration, and soil absorption capacities (Strauss *et al.,* 1997). All of these variables result in a significant difference in faecal sludge characteristics within cities, and within the same type of containment technology in different locations (Strande *et al.,* 2014).

2.2.1 Faecal sludge generation and quantities

Faecal sludge is either generated from on-site sanitation systems and/or through open defecation. According to IWMI (2003), much of the faecal sludge produced, collected and disposed of in urban centres remains as yet unaccounted for. As reported by Strauss *et al.*(1997), the per capita quantities reported in the literature vary widely. The amount of faeces excreted daily by individuals vary considerably depending on water consumption, climate, diet and occupation (Torondel, 2010). However Vinnerås (2001), reports that the amount of faeces produced by a person depends on the composition of the food consumed. For example, foods low in fibres such as meat, result in smaller amounts (mass and volume) of faeces than foods high in fibre (Vinnerås, 2001).The only way to obtain an accurate determination of the amount at a particular location is direct measurement (Franceys *et al.,* 1992). Approximately 30-45 kg (wet weight basis) of faecal sludge is produced per person every year in developed countries corresponding to 10-15 kg of dry matter (Lentner & Wink, 1981; Feachem *et al.,* 1983; Schouw *et al.,* 2002; Jonsson & Vinneras, 2004). In 1999, Del Porto & Steinfeld reported an average faecal sludge generation rate of 50 grams per person per day based on compilation of several studies.

A study in Accra reported that the volume of faecal sludge generated per capita per day is 1 litre, 2 litres and 0.2 litres for septic tank sludge (septage), public toilet sludge and pit latrine sludge respectively (Heinss *et al.,* 1998). Based on the volume of faecal sludge generated daily, faecal sludge quantities produced in urban and rural areas of Ghana are estimated as shown in Table 2-1 below;

Table 2-1: Estimate of faecal sludge from urban and rural areas of Ghana

Toilet Type	Percentage Population using option	Population using toilet option	Volume of FS/cap/day, litres	Estimated Faecal Sludge/cap/day, m^3
URBAN				
Septic tank	23.30%	2,923,038.36	1	2,923.04
Pit latrine system	30.30%	3,801,204.39	0.2	790.24
Public toilet	35.70%	4,478,646.75	2	8,957.29
Other	0.40%	50180.92	1.5	75.27
Total				**12,715.84**
RURAL				
Septic tank	2.30%	278,600.20	1	278.60
Pit latrine system	32.40%	3,924,628.85	0.2	784.93
Public toilet	32.10%	3,888,289.69	2	7,776.58
Other	0.30%	36,339.16	1.5	54.51
Total				**8,894.61**
GRAND TOTAL(URBAN + RURAL)				**21,610.45**

Source: Adapted from Heinss et al. (1999)

Table 2-1 above, shows that a significant proportion of faecal sludge generated in both urban (70%) and rural (87%) areas comes from the public toilet. About 30% and 3% of faecal sludge from urban and peri-urban areas respectively comes from septic tanks.

2.2.2 Classification and characteristics of faecal sludge

Faecal sludge according to Strauss *et al.* (1997) and Mara (1978) can be classified as Type "A" (High strength faecal sludge) and Type "B" (Low strength faecal sludge) considering its physical properties. High strength sludges are mostly public toilet sludge (PTS) that is fresh and undigested, generated from unsewered public toilets. Meanwhile low strength sludges are septage that is partially digested, generated from septic tanks (Strauss *et al.* (1997); Mara, 1976).

The fresh and undigested (unstable) sludges contain a relative large share of recently deposited excreta stored for days or weeks only. These high strength sludges exhibit high concentrations of organics, ammonium and solids which is described to be 10 -100 times as high as sewage (Montangero & Strauss, 2000; Koné & Strauss, 2004). They originate from non-flush or pour flush family and public toilets. Partially digested (Stable) sludges are those, which have been retained in on-plot pits or vaults for months or years and which have undergone biochemical degradation to a variable degree.

The quantity and nature of faecal sludge produced from an onsite toilet facility depends on the efficiency of the facility. The characteristics of faecal sludge are highly variable from country to country and within the same country, depending on the type and origin of sanitation facility being used (Kone *et al.,* 2010) but their characterization based on history only gives qualitative information (Montangero & Strauss 2002). As noted by Pescod (1971), Pradt (1971), Um & Kim (1986), Guo *et al.* (1991) and Strauss *et al.* (1997), the characteristics of collected faecal sludges vary greatly and depends on, among others, on the season, type of the on-site sanitation system (e.g. water closet/septic tank system, "dry" aqua privy, watertight vented pit latrines), the emptying frequency (i.e. is the retention time in the facility), the extent of stormwater or groundwater infiltration into the sanitation facility, and on user habits. The composition of faecal sludge will determine the type of treatment that is possible and the end-use possibilities.

To determine the characteristics of faecal sludge, physical, chemical and biological parameters are measured. Physical parameters give general information on sludge processability and handleability. Chemical parameters are relevant to the presence of nutrients and toxic/dangerous compounds, so they become necessary in the case of utilization in agriculture. Biological parameters give information on microbial activity and organic matter/pathogens presence, thus allowing the safety of use to be evaluated. The Table 2-2 below presents the characteristics of faecal sludge in some selected developing countries in Africa, Asia and South America.

Table 2-2. Faecal sludge (FS) characteristics in selected cities in developing countries

Parameters	**Accra (Ghana)**	**Accra (Ghana)**	**Yaoundé (Cameroon)**	**Bangkok (Thailand)**	**Alcorta (Argentina)**
Type of FS	*Public-toilet [a]sludge*	Septage [b]Septage	*Septage*	*Septage mean (range)*	Septage mean (range)
TS (mg/l)	52,500	12,000	37,000	15,350 (2200–67,200)	(6000–35,000) (SS)
TVS (% of TS)	68	59	65	73	50 (VSS)
COD (mg/l)	49,000	7800	31,000	15,700(1200–76,000)	4200
BOD5 (mg/l)	7,600	840	N/A	2300 (600–5,500)	(750–2600)
TN (mg/l)	N/A	N/A	1100	1100 (300–5,000)	190
NH4-N (mg/l)	3300	330	600	415 (120–1,200)	150
Ascaris (Eggs number/gTS)	N/A	(13–94)	2813	(0–14)	(0.1–16)

Source: Kone and Strauss, 2004.

TS: total solids; SS: suspended solids; TVS: total volatile solids; VSS: volatile suspended solids; COD: chemical oxygen demand; BOD5: biochemical oxygen demand; TN: total nitrogen .[a]Sludge collected from latrines shared by a high-density population or latrines with very high emptying frequency (weeks,months).[b]Sludge collected from septic tanks after two to five years. Septage is well digested and less concentrated in solids and nitrogen than public-toilet sludge.

2.2.3 Microorganisms in faecal sludge

The solid fraction or biosolids component of sludge contains microorganisms, including some that are potentially harmful, toxic metals, macro- and micronutrients (Shanahan *et al.,* 2010). The actual species and density of pathogens existing in sewage and for that matter faecal sludge depend on the health status of the local community and the sewage sludge treatment processes (Sasakova *et al.*, 2005). Similarly, Niwagaba (2007), reported that the faeces of a healthy person contain large numbers of bacteria of many non pathogenic species. The presence of some pathogenic microorganisms (Gastrointestinal pathogenic microorganisms) in faecal sludge is an indication of infection amongst the population contributing to the faecal sludge (Table 2-3). The reason is that Gastrointestinal pathogenic microorganisms do not occur as a natural part of normal intestinal microbiota (Feachem *et al.*, 1983).

Low-cost treatment options rely on natural means that is using microorganisms to decompose faecal sludge. The most common microorganisms present in faecal sludge are bacteria, fungi, actinomycetes and algae. These microorganisms are often heterotrophic in nature and thus rely on a carbon source derived from organic matter as food. Furthermore, the survival or die off of pathogens in the faecal sludge depends upon a number of factors, such as temperature, moisture content and competition from indigenous microflora (Öğleni & Özdemir, 2009). Other factors, such as predation, pH, sunlight, oxygen and texture also influence the pathogen die off.

Table 2-3: Pathogenic microorganisms in faecal sludge and related disease symptoms

Group	Pathogen	Disease symptoms
Bacteria		
	Aeromonas spp.	Enteritis
	Campylobacter jejuni/coli	Campylobacteriosis - diarrhoea, cramping, abdominal pain, fever, nausea, arthritis, Guillain-Barre syndrome
	Escherichia coli (EIEC, EPEC, ETEC, EHEC)	Enteritis. For EHEC there are also internal haemorrhages that can be lethal
	Salmonella typhi/paratyphi	Typhoid/paratyphoid fever – headache, fever, malaise, anorexia, bradycardia, splenomegaly, cough
	Salmonella spp.	Salmonellosis – diarrhoea, fever, abdominal cramps
	Shigella spp.	Shigellosis – dysentery (bloody diarrhoea), vomiting, cramps, fever; Reiters syndrome
	Vibrio cholera	Cholera – watery diarrhoea, lethal if severe and untreated
Virus		
	Adenovirus	Various; respiratory illness, here added due to enteric types
	Enteric adenovirus types 40 and 41	Enteritis
	Enterovirus types 68-71	Meningitis; encephalitis; paralysis
	Hepatitis A	Hepatitis – fever, malaise, anorexia, nausea, abdominal discomfort, jaundice
	Hepatitis E	Hepatitis
	Poliovirus	Poliomyelitis – often asymptomatic, fever, nausea, vomiting, headache, paralysis
	Rotavirus	Enteritis
Parasitic protozoa		
	Cryptosporidium parvum	Cryptosporidiosis – watery diarrhoea, abdominal cramps and pain
	Cyclospora histolytica	Often asymptomatic; diarrhoea; abdominal pain
	Entamoeba histolytica	Amoebiasis – often asymptomatic, dysentery, abdominal discomfort, fever, chills
	Giardia intestinalis	Giardiasis – diarrhoea, abdominal cramps, malaise, weight loss
Helminths		
	Ascaris lumbricoides	Generally no or few symptoms; wheezing; coughing; fever; enteritis; pulmonary eosinophilia
	Taenia solium/saginata	Taeniasis
	Trichuris trichura	Trichuriasis - Unapparent through to vague digestive tract distress to emaciation with dry skin and diarrhoea
	Hookworm	Itch; rash; cough; anaemia; protein deficiency
	Schistosoma Spp. (blood fluke)	Schistosomiasis, bilharzias

Source: Adapted from Schönning and Stenström, 2004.

2.3 Faecal Sludge Composting

Composting is the biological breakdown of decomposable waste under controlled conditions to a state that is sufficiently stable for nuisance-free storage and handling and is satisfactorily matured for safe use in agriculture". Composting is a successful strategy for the sustainable recycling of organic wastes (Fermor, 1993; Tuomela *et al.*, 2000) and also faecal sludge. It is a controlled biological process in which succession of microbial populations convert waste material into a biologically stable product. Composting can either be an aerobic or anaerobic process (Jovičić *et al.,* 2009). In an aerobic composting process, that is occurring in the presence of oxygen, the microorganisms (bacteria, fungi, actinomycetes) that decompose faecal material require oxygen and water. Products of the composting process include compost and carbon dioxide, heat and water vapour which are released into the air. The CO_2 and water losses can amount to half the weight of the initial materials, thereby reducing the volume and mass of the final product (Pace & Farrel-Poe, 1995). However, anaerobic composting takes place in the absence of oxygen. Anaerobic conditions are often undesirable and cause compost piles to smell badly (Hirrel & Riley, 2004). Composting is among the best-known processes for the biological stabilization of faecal sludge and organic wastes. Tweib *et al.* (2011), reported that composting is one of the most promising technologies to treat wastes in a more economical way. Epstein *et al.* (1976), explained that compost can be used to improve the soil structure, increase its retention of water, and provide nutrients for plant growth.

Composting involves the accelerated degradation of organic matter (and or faecal sludge) by microorganisms under controlled conditions, in which organic matter (and or faecal sludge) undergoes a characteristic thermophilic stage that allows sanitization of the waste by the destruction of pathogenic microorganisms (Lung *et al.,* 2001). The process is essential for the conversion of potentially degradable waste into a beneficial product, disinfection of material that might be contaminated with pathogens; and bioremediation of hazardous waste (Steger, 2006).

The technology used for composting involves the following three phases: (1) preparation of the feedstock (also known as "pre-processing"), (2) the compost process itself, and (3) the grading and upgrading of the final product (or "post-processing") (Pichtel, 2005). The pre-processing step involves screening out of unwanted materials and also reduction of surface area of materials to enhance microbial reactions. The second step involves the actual decomposition of the compost by microorganisms. In the final stage the compost product is cured. During the composting process itself, two phases can be distinguished: (i) the thermophilic stage, where decomposition takes place more intensively and which therefore constitutes the active phase of composting; and (ii) a maturing stage which is marked by the decrease of the temperature to the mesophilic range and where the remaining organic compounds are degraded at a slower rate (Lazcano *et al.,* 2008). An odourless innocuous and stable organic amendment can be obtained by composting, and its use for improving soil structure and soil organic matter has been reported worldwide (Laos *et al.,* 2002). If done properly, composting can turn faecal sludge into a product that is aesthetically acceptable, essentially free of pathogens, and easy to handle (Epstein *et al.,* 1976). However, there are some challenges associated with the method of waste management process. Box 1 presents advantages and disadvantages of composting as outlined by Beffa (2002);

Box 1: Advantages and Disadvantages of composting

Advantages

- *reduction of the amount of waste that has to be incinerated or put in landfills and therefore reduction of incinerator ash to be disposed of, and of landfill space;*
- *completely enclosed composting systems are now near those for incineration;*
- *recycling of humus and nutrients into the soil;*
- *protecting and improving the microbiological diversity and quality of cultivated soils,*
- *bog conservation, because compost can be used as peat substitute*
- *beneficial role of compost microorganisms in crop protection, in as much as they compete with plant pathogens*
- *beneficial role of compost microorganisms in bioremediation (biodegradation of toxic compounds and pollutants).*

Disadvantages

- *the most common complaint about composting installations are odor nuisances;*
- *proliferation and dispersion of potentially pathogenic and/or allergenic microorganisms*
- *soil pollution if the heavy metal content of the compost is too high. This can be avoided if the starting material is free of these contaminants (source separation of the organic waste; use of sewage sludge only from non-industrial origin)*
- *groundwater pollution if composting is carried out on a surface that is not made up properly or where the runoff water is not collected.*

2.3.1 Composting process

Composting is a biological method of treatment where faecal sludge come into contact with bacteria (cells), which feed on the organic materials in the faecal sludge, thereby reducing its BOD content. There are two fundamental types of composting and these are aerobic and anaerobic (Tweib *et al.,* 2011). These two types of biological treatments are directly related to the type of bacteria or microorganisms that are involved in the degradation of organic impurities in a given sludge and the operating conditions of the bioreactor.

Aerobic: In the process of aerobic digestion, aerobic bacteria live and multiply in the presence of free oxygen. The aerobic treatment processes in the presence of air utilize those microorganisms (also called aerobes), which use molecular/free oxygen to assimilate organic impurities that is convert them in to carbon dioxide, water and biomass (Mittal, 2011). This can be used to treat any type of organic waste but, effective composting requires the right blend of ingredients and conditions which include moisture contents of around 60-70% and carbon to nitrogen ratios (C/N) of 30/1 (Tweib *et al.,* 2011). To ensure an adequate supply of oxygen throughout, ventilation of the waste, either forced or passive is essential (Guanzon & Holmer, 1993). Aerobic composting requires more physical work than anaerobic composting but does not produce the same foul stench (Rynk *et al.,* 1992).

Anaerobic: Anaerobic is a series of process in which microorganisms break down biodegradable material in the absence of oxygen. Here anaerobic bacteria utilize the organic material present in the sludge as a food source and produce carbon dioxide and methane gas. During the digestion period, typically 15 to 28 days, conditions suitable to maximize the biological activity of the anaerobic bacteria are maintained. There are two types of anaerobic digestion namely mesophilic and thermophilic. Mesophilic digestion uses bacteria that are active at body temperature (35-37 °C) whiles thermophilic digestion uses bacteria that are active at considerably higher temperatures (50-57 °C). Anaerobic digestion involves four key processes; hydrolysis, acidogenesis, acetogenesis and methanogenesis (Veenstra & Polprasert, 1997). This type of composting results in a foul-smelling odour because the organic materials get broken down into carbon dioxide and methane, according to the United USEPA (1995).

2.3.2 Composting systems

The old method of composting was to pile organic materials and let them stand for a year, at which time the materials would be ready for use. This method is referred to as passive composting. Generally two main systems of composting can be distinguished which are open systems such as windrows and static piles and closed "in-vessel" systems. In-vessel or "reactor" systems can be static or movable closed structures where aeration and moisture are controlled by mechanical means and often requires an external energy supply (IWMI, 2003). Most often closed "in-vessel" systems are usually investment intensive and also more expensive to operate and maintain. There are various forms of composting, such as windrow type, trench and pit type and closed in-vessel composting. A study by Fauziah & Agamuthu (2009), listed static pile, windrow, in-vessel, vermi-composting and bin composter as the methods of composting. According to Fitzpatrick (2005), the windrow system is the most popular example of a non-reactor, agitated solid bed system.

2.3.2.1 Open systems

These are the most common, most familiar composting technologies around. They include open windrow, aerated static pile, bin and trench or pit composting. The compost piles restrict the dissipation of heat, leading to an increase in temperature (Zibilske, 1998) and this is essential for the open systems.

Open windrow system composting is the most common of the technologies currently used in most developing countries. In this system, windrows (long narrow piles) of mixture of raw materials for composting are turned on a regular basis to maintain aerobic conditions. The composting process depends upon a good supply of oxygen, therefore air must be able to move through the windrow. Windrow aeration is accomplished through the natural chimney ventilation effect of warm air rising through the pile and by mechanical turning. Mechanical turning is usually done with a front-end loader or a machine specifically designed for turning windrows. The size of the heaps ensures sufficient heat generation and aeration is ensured by addition of bulking materials, passive or active ventilation or regular turning. The size and shape of the windrows is based on the characteristics of feedstock and the type of equipment used for turning. If a windrow is too large or dense, anaerobic conditions may occur and this will release odours when the windrow is turned. On the other hand, small windrows lose heat quickly and may not achieve high enough temperatures to kill pathogens to produce a sanitized compost. Windrows operate most effectively at a height of 1.5 to 1.8 m (Jovičić *et al.,* 2009). Jovičić *et al. (*2009), however cautioned that windrow heights may vary based on the feedstock. Banegas *et al.* (2007), ensured a heap size of $3m^3$ during composting of sewage sludge and sawdust to ensure sufficient heat generation. Advantages of this composting system are the possibility to manage large volumes of wastes, a good stabilization of the end product, and relatively low-capital investments (Rynk *et al.,* 1992).

Aerated static pile method is relatively complicated in terms of operation than turned windrow piles. Aerated pile composting involves the provision of aeration either by natural phenomena or by using a blower to supply air to the pile. This method of composting can be classified as passive or active also known as forced air. In the case of passive process, the windrow is allowed to remain undisturbed and aeration is by natural phenomena where no mechanical input is required. However, the active process involves the introduction of air through the windrows. The capacity of the blowers and the characteristics of the feedstock dictate the size of the piles (Rynk *et al.,* 1992). This gives a greater degree of control over the composting process. The composting material is placed on top of a perforated pipe or platform. Once the pile is formed, it will require no turning or agitation and provided that the air supply is sufficient and uniformly distributed, the active composting period may be completed in approximately 3 to 5 weeks. The pile may be covered or uncovered, a factor which has important implications for the circulation of air within the pile.

2.3.2.2 In vessel systems

In-vessel composting refers to a group of composting systems, which range from enclosed halls to tunnels and containers or bins. It also include rotating drum, tank and bunker systems. This method of composting relies upon mechanical aeration and turning to enhance and decrease the duration of the composting process. In-vessel systems attempt to create optimum conditions for the microorganisms thereby giving improved control of the composting process and accelerating decomposition. In vessel systems normally process material through the active composting phase and through to stabilization which typically takes 14 days. The maturation phase is normally carried out in piles or windrows, which requires suitable hard-standing areas. The most advanced technique, the in-vessel composting system can be operated with less air than the open system, due to the possibility of air recirculation and preconditioning of the supply air (Gruneklee, 1998). The goal of in-vessel composting systems is to combine various composting techniques into one controlled environment, which utilizes the strengths and minimizes the weaknesses inherent to other forms of composting.

2.3.2.3 Rotary drum composting systems

The technology used for composting is a relevant factor (Rodríguez *et al.,* 2012) towards achieving a well stabilized and hygienized compost. Reactor composting systems attempt to optimize conditions for the microorganisms thereby giving improved control of the composting process and accelerating the rate of decomposition. That notwithstanding, most studies on sewage and faecal sludge composting have been carried out using open systems such as windrows and static piles.

Rotary drum composters which is a reactor system are considered to be an efficient and promising technology as this type of composter provides agitation, aeration and compost mixing in order to produce a consistent and uniform end product without any odour or leachate related problems (Kalamdhad *et al.,* 2009). Using the rotary drum technique reduces the composting duration whiles rapidly stabilizing the compost (Nayak & Kalamdhad, 2014). In several studies, different types of wastes (cattle manure, swine manure, municipal biosolids, brewery sludge, chicken manure, animal mortalities and food residues) have been effectively composted in rotary drums (Kalamdhad & Kazmi, 2008).

High rate composting studies on vegetable wastes and tree leaves were conducted on a demonstration-scale (3.5 m^3) rotary drum composter by evaluating changes in some physico-chemical and biological parameters during the composting process (Kalamdhad *et al*., 2009). The study suggested that rotary drum composting was found suitable in delivering fine grained, better quality matured compost within 20 days of maturation period. Nayak & Kalamdhad (2014), was able to achieve optimal degradation of sewage sludge during composting with cattle manure and sawdust using a rotary drum.

Mixing of compost feedstock is very important in composting providing both homogenization and aeration to the waste mixture (Rodriguez *et al.,* 2012). It controls the composting mixture temperature and also therefore, the kinetics of the process and the end product sanitation (Smith *et al.,* 2006). Difficulties will appear due to the diversity of products in terms of size-particles or granules, shape-irregularly shaped particles, moisture and surface nature-cohesive or non cohesive powders (Gyebis & Katai, 1990). This is an indication that the mode of mixing is very critical and should be considered when designing a rotary drum for composting. However, most of composting studies using rotary drum has been silent on the mode of mixing and drum design. The rotary drum design depends on the desired retention time, the amount of waste to be treated, and the drum's slope and rotational speed.

2.3.3 Microorganism interactions and process reactions during composting

Microorganisms such as bacteria, fungi and actinomycetes which are the preferred microorganisms account for most of the decomposition, as well as the rise in temperature that occurs in the composting process (Hirrel & Riley, 2004). These microorganisms are preferred since they provide the most rapid and effective composting. Aerobic organisms thrive at oxygen levels greater than 5% (air is about 21% oxygen). During the process of aerobic digestion, aerobic bacteria will multiply in the presence of free oxygen. The aerobic treatment processes in the presence of air utilize those microorganisms also called aerobes (Mittal, 2011).

Microorganisms predominantly bacteria breakdown faecal sludge under aerobic conditions (in the presence of oxygen). In essence, the activity of microorganisms causes both an increase in temperature, hence the pathogen destruction, and a release of energy, CO_2, H_2O, NH_3 and other gases, while consuming oxygen. During the process, both external and internal enzymes breakdown food (substrates) into readily usable forms to be used by the bacteria for the maintenance and propagation of life.

The energy produced is used by the bacteria for their reproduction. Bacteria increases at an exponential rate until there is short supply of oxygen. The metabolism of the bacteria then slows down to a conventional rate and eventually become stationary when the oxygen supply is shortened. In this mode sufficient substrate exists only to maintain life, not to promote growth.

A good composting process depends upon the activity of microorganisms and their metabolism which can be dramatically affected by the presence of toxic material in the faecal sludge (Pace *et al.,* 1995). Constituents such as organic and inorganic solvents and heavy metals can inhibit the biological activity during the composting process.

2.3.4 Stability and maturity of compost

Compost stability and maturity are essential for its successful application, particularly in high value horticultural situations (Gómez-Brandón *et al.,* 2008; Wang *et al.,* 2004). The composting process is normally taken to be complete when the active decomposition stage is over and the C/N ratio is around 20. Maturity and stability indicators that have been used in other composting studies include C/N ratio, microbial activity, germination index, cation exchange capacity (CEC), humic substances, compost concentration of WSC, dissolved organic matter, NH^{+}_{4}-N and NO^{-}_{3}-N; ratios of NO^{+}_{4}-N=NO^{-}_{3}-N, WSC/TN and WSC/organic-N (Harada & Inoko, 1980; Zucconi *et al.,* 1981; Iglesias Jiménez & Pérez-García, 1992; Hue & Liu, 1995; Bernal *et al.,* 1998; Paredes *et al.,* 2000; Eggen & Vethe, 2001; Benito *et al.,* 2003; Smith & Hughes, 2004; Goyal *et al.,* 2005; Tang *et al.,* 2006; Pullicino *et al.,* 2007). Some of the recommended compost maturity indicator values include C/N<12; WSC<1.7%; WSC/TN < 0.7; WSC/organic-N 0.7; NH^{+}_{4}—N=NO^{-}_{3}—N<0.16; NH^{+}_{4}—N<400 mg/kg; CEC>60 meq /100g and germination index >50%. In some studies, compost maturity was estimated by measuring temperature and CO_2 emission from windrows.

A study by Cofie *et al.* (2009), presented the potentials and performance of combined treatment of faecal sludge (FS) and municipal solid waste (SW) through co-composting, and reported a co-composting duration of 12 weeks (90 days) was indicated by the cress seed test, NO_3-N/NH_4-N and the C/N ratios to achieve a mature and stable product. Fang & Wong (1999) evaluated the maturity of compost by using a cress seed test and found that lime-amended sludge reached maturation after 63 days of composting. Finstein & Miller (1985) reported that declining NH^{+}_{4} and increasing NO^{-}_{3} concentrations is indicative that a composting material has achieved maturity and is suitable for use. Tumuhairwe *et al.* (2009), however, cautioned that no single maturity indicator can be applied to all composts because of differences in feedstock used.

2.3.5 Pathogen die off during faecal sludge composting

The actual species and density of pathogens existing in sewage and for that matter faecal sludge depend on the health status of the local community and the sewage sludge treatment processes (Sasakova *et al.,* 2005). Present in faecal sludge are enteric organisms including bacteria, viruses, protozoa, and helminths which are of particular concern (Wichuk, 2007) as they can present a hazard to both human health and the environment (de Bertoldi *et al.*, 1988). Table 2-4 shows average amount of some selected pathogens present in faecal sludge and the ID_{50} for these pathogens (i.e. the doses required to infect half those exposed) in a tropical developing country.

Bacteria, viruses, protozoa and helminths (pathogens) have varying resistance against die off and worm eggs are among the most resistant with *Ascaris*eggs surviving longest in the extra-intestinal environment (Strauss *et al.,* 2002). The survival or die off of pathogens in faecal sludge depends upon a number of factors, such as temperature, moisture content, and competition from indigenous microflora. Other factors, such as predation, pH, sunlight, oxygen, soil type, and texture, also influence the pathogen die off. Data from literature reports that Helminth eggs can survive 10-12 months, under tropical climate, upon excretion (Feachem *et al.*, 1983; Cross and Strauss, 1985; Schwartzbrod, 1994). This means that bad disposal practices poses the danger of pollution of water, soil and air and high potential for epidemic. Kone (2004), in his study concluded that composting of faecal sludge is a good tool to convert faecal sludge into a hygienically safe product that can be used as a fertilizer in agriculture. During that study helminth eggs were reduced from 25-83 /g TS to a, < 1-3 viable eggs/g TS level, allowing a safety reuse in agriculture.

Table 2-4. Average amount of pathogens in faeces and their infective dose

Pathogen		**Average number of organisms per g of faeces**	**Median infective dose (ID_{50})**
Viruses			
	Enteroviruses	10^6	Low ($<10^2$)
Bacteria			
	Pathogenic E. coli	10^8	High ($>10^6$)
	Salmonella spp	10^6	High ($>10^6$)
	Vibrio cholerae	10^6	High ($>10^6$)
Protozoa			
	Entamoeba histolytica	15×10^4	Low ($<10^2$)
Helminth			
	Ascaris lumbricoides	10^4	Low ($<10^2$)
	Hookworms	800	Low ($<10^2$)
	Schistosomia mansoni	40	Low ($<10^2$)
	Taenia saginata	10^4	Low ($<10^2$)
	Trichuris trichiura	2×10^3	Low ($<10^2$)

Source: Gallizzi K. 2003.

2.3.6 Compost quality and sanitization

Compost quality is measured by several criteria, including moisture content, nutrient content, heavy metal, stability, particle size distribution, pathogen levels and product consistency over time (James, 2008). Presence of pathogens and content of heavy metals are limitations in using sludge compost for agricultural purposes (Rehm & Reed, 2000). Faecal sludge's usually contain harmful microbes, heavy metals and toxic organic matter that if applied in agricultural lands can cause dangerous condition for humans, animals and plants (Bazrafshan *et al.,* 2006), thus, the sanitization of compost is very essential.

Researchers have also paid a great deal of attention to the heavy metal content of the compost made from these sludges (Zorpas *et al.,*2000; Cai *et al.,* 2007; Smith, 2009), and guidelines and regulations regarding the application of the compost to farmland have been introduced in many countries (Nakasaki *et al.,* 2010). A study on evaluation of microbiological and chemical parameters during wastewater sludge and sawdust co-composting revealed that microbial parameters such as total and faecal Coliforms and *Salmonella* decreased significantly at the end of composting period and covered A class standards of EPA for its application in agricultural lands (Bazrafshan *et al.,* 2006). Also in the final compost no *Ascaris* ova was observed. In a study conducted by Mena *et al.* (2003), the composting process provided an acceptable degree of bioremediation for sanitizing products such as sewage sludge from municipal water treatment plants. In an experiment conducted during composting of source separated human faeces using an insulated reactor, *E. coli* and total coliforms were reduced to below detection in composts that maintained sanitising temperatures for at least six days (Niwagaba *et al.,* 2007). A study conducted by Cofie & Koné (2009), observed a well sanitised compost as a result of high temperatures during co-composting of faecal sludge and organic waste for agriculture.

2.3.7 Potential and socio-economic benefits of composting faecal sludge

Composting is seen as an environmentally acceptable method of waste treatment (Guanzon & Holmer, 1993). It is a suitable method for the sanitization and the hygienization of raw organic materials (Juriš *et al.,* 2000; Sidhu *et al.,* 2001; Christensen, 2002; Vinneras *et al.,* 2003; Vinneras, 2007). It allows recycling of nutrients into agriculture thereby closing the nutrient loop (Cofie & Koné, 2009). Van-Camp *et al.* (2004), explained that composting helps to optimise nutrient management and the land application of compost may contribute to combat soil organic matter decline and soil erosion. Land application of compost completes a cycle whereby nutrients and organic matter which have been removed in the harvested produce are replaced (Diener *et al.,* 1993).

Composting is also seen as an alternative method to reduce the volume of materials to be managed, to reduce odour problems, pathogens and ground water pollution (Tirado &

Michel, 2010), as well as to improve the handling and physicochemical properties of the bulk fraction for soil improvement (Brito *et al.,* 2012). A study conducted by Fauziah & Agamuthu (2009), reported that composting makes waste easier to handle and transport and often allows for higher application rates because of the more stable, slow release, nature of the nitrogen in the compost.

2.4 Process Conditions Suitable for Composting

Successful compost stabilization process of sludge depends on maintaining a suitable environment for process control including: (a) moisture content (b) oxygen concentration (c) carbon-nitrogen ratio (d) temperature that must be considered under all aspects of external conditions, heat production within the matrix as a consequence of biological activity, heat transfer and heat management (e) potential hydrogen-pH (f) Physico-chemical characteristics of the material being composted and (g) macro and micronutrients (Bazrafshan *et al.,* 2006). These factors relate to the composition of compostable materials, including *e.g.* C/N ratio, pH, oxygen, moisture content and temperature (Miller, 1993; Haug, 1993; Del Porto & Steinfeld, 1999). According to Kalamdhad & Kazmi (2008) however, Carbon (C), nitrogen (N), oxygen (O_2) and moisture (H_2O) are the essential elements required for the operation of microorganisms to achieve a successful compost process. Similarly Sandeen & Gamroth (2003), also stated that effective composting is affected by four major factors which are aeration, nutrient balance, moisture content and temperature. They further reported that if any of these essential elements are lacking, or if they are not provided in the proper proportion to one another, the microorganisms will not flourish and will not provide adequate heat to achieve a sanitized compost. Pare´ *et al.* (1998) and Garcı´a *et al.* (1993), reported that during the composting process, organic compounds are transformed through successive activities of different microbes to a more stable and complex organic matter. The rate and extent of the transformations will depend primarily on the compost process conditions and also the nature of the starting materials (Banegas *et al.,* 2006).

Under favourable conditions, earthworms and microbes act symbiotically to accelerate and enhance the decomposition of the organic matter in the sludge (Morgan & Burrows, 1982; Xing *et al*., 2005). Bulking materials play a role in providing these favourable conditions which include adequate aeration, moderate temperature, neutral pH (7.0), appropriate carbon/nitrogen (C/N) ratio of the feed material and adequate supply of calcium (Sinha *et al.,* 2009). Bazrafshan *et al* .(2006), also suggested moisture content, oxygen concentration, carbon-nitrogen ratio, temperature that must be considered under all aspects of external conditions, heat production within the matrix as a consequence of biological activity, heat transfer, and heat management; pH, physico-chemical characteristics of the material being composted and macro and micronutrients as suitable conditions for good compost.

2.4.1 Moisture content

Moisture content is an important parameter required for the proper functioning of the compost process. Moisture is needed for bacterial decomposition. It provides a medium for the transport of dissolved nutrients required for the metabolic and physiological activities of microorganisms (Stentiford, 1996; McCartney & Tingley, 1998). Several research studies have recommended varying quantities of moisture as appropriate during composting. A moisture content of 40-60 % provides adequate moisture without limiting aeration (Epstein, 2003). Too much moisture causes nutrients to leach out, odours are produced and decomposition slowed. A “squeeze” test is an easy way to gauge moisture content. The material should feel damp to the touch, with just a drop or two of liquid expelled when the material is squeezed tightly. Turning a “too wet” compost pile allows air to circulate. Adding dry material can fix excess moisture problems. Piles too dry can be watered while turning

(Hirrel & Riley, 2004). This phenomenon was corroborated by Atkinson *et al.,*1996 who recommended the addition of water to dry compost to prevent premature drying.

A moisture content of 40% to 60% is the optimum for biological activity in aerated systems and has been used in composting studies (Bernal *et al.,*1998; Zhu *et al.,* 2004; Goyal *et al.,* 2005). This moisture content range has also been recommended by Dickson *et al.* (1991) and Dougherty (1998). A study by Bazrafshan *et al.* (2006), suggests a moisture content of 50% to 60% based on as received weight and therefore should be regulated by spraying water on some piles. Other literature also recommend that water content of the substrates should be 55–65% at the start of the process, with the higher values recommended for composting with turning or based on any other mechanical mixing of the substrate biomass. In an experiment conducted by Yadav *et al.* (2011), a moisture content of 60–65% was maintained by regularly sprinkling water over the entire period of the experiment. Adequate moisture provision is necessary to maintain microbial activity throughout the duration of the composting processes to achieve a stable end-product (Liang *et al.,* 2003), but the decline in moisture content due to evaporative water losses often requires additional moisture inputs to prevent process inhibition (Brito *et al.,* 2012). However, when moisture supply is too high, aeration is poor and may produce anaerobic conditions through water logging, which prevents and halts compost activities (Schulze, 1962; Tiquia *et al*., 1996). Also, NO^{-}_{3} can be denitrified and N_2 lost when moisture content is high (Tumuhairwe *et al.,* 2009). It is therefore important to optimize the moisture content of a compost mixture in order to achieve the best result (Beck, 1997, Bueno *et al.,* 2008).

2.4.2 Carbon-nitrogen ratio

When combining bulking materials to make compost, the carbon-to-nitrogen (C/N) ratio is important. It is considered among the important factors affecting the compost process and compost quality (Michel *et al*., 1996) as it has an impact on the maturity and quality of compost. Microorganisms in compost digest carbon as an energy source and ingest nitrogen as a protein source. A C/N ratio of 15 to 30 is recommended because in this range, nitrogen is present in excess and no rate limitation should be imposed (Haug, 1993). Hirrel & Riley (2004), recommended that the C/N proportion should be approximately 30 parts C to 1 part N by weight for a composting material. Most materials available for composting do not fit the ideal 30:1 ratio, so blending of different materials is needed. When the compost substrates have low C/N ratios outside the recommended value, nitrogen loss occurs through ammonia volatilisation at high pH and temperature (de Bertoldi *et al*., 1983; Eklind *et al*., 2007) leading to loss of nitrogen thereby reducing the value of the compost as a fertilizer. Conversely, when the C/N ratio is too high, there is too little nitrogen and decomposition slows. Therefore the composting process can be optimised by combining materials with complementary nitrogen contents. Huang *et al.* (2004), investigated the effect of C/N on composting of pig manure with sawdust and concluded that composting at a low initial C/N (15), would require a period large than 63 days to reach compost maturity than when the initial substrate had an initial C/N of 30.

The C/N ratio is used by many authors as one of the indicators of compost quality (Cofie *et al.,* 2009). However, several authors have suggested a wide range of C/N values. A study conducted by Cofie *et al*. (2009), obtained a C/N ratio of a matured compost to be 13 and was considered satisfactory as it was slightly higher than another limit of 12 suggested by Bernal *et al.*(1998). Fuchs *et al.,* (2001) recommended a C/N ratio below 16 for the use of compost to avoid nitrogen blockade due to competition between microorganisms and plants. Wong *et al.* (2001), also found a C/N value of around or below 20 to be satisfactory. According to Allison (1973), a well humified soil has C/N ratio close to 10 and the addition of materials with a C/N ratio below 15 may not alter the microbiological equilibrium of the soil. de Bertoldi *et al.* (1983), suggested that C/N of the starting substrate should be about 25.

2.4.3 Temperature

Temperature is probably the most important factor affecting microbial metabolism during composting. For the survival of microorganisms, there is a minimum temperature below which no growth occurs, an optimum temperature at which growth is most rapid and a maximum temperature above which growth is not possible (Madigan & Martinko, 2006). These three temperatures are often referred to as the cardinal temperatures (Niwagaba, 2007). Sufficient temperature range is a key factor in composting. Temperature increase from the start of composting process, is as a result of microbial metabolism. Temperature changes selectively affect the presence, succession and activity of microorganisms (Hassen *et al.,* 2001) and can thus be used to track the progress of the composting process. Composting will essentially take place within two temperature ranges known as mesophilic (20-45 ^{o}C) and thermophilic (over 45 ^{o}C). Niwagaba (2007), based on temperature development identified three phases (mesophilic, thermophilic and curing) during a composting process. The mesophilic phase is characterised by increasing temperatures up to about 40-45 °C. The thermophilic phase is defined by temperatures from 45 °C -70 °C (Miller, 1996) and the curing phase which involves cooling and maturation is characterised by temperatures again sinking below 40-45°C (Chiumenti *et al.*, 2005).

Experts have reported different temperature ranges for effective composting process. The optimal temperature for composting is in the range of 55 to 60 ^{o}C (Finstein *et al.*, 1983). Pace *et al.*(1995), reported that maintaining temperatures between 43 ^{o}C and 66 ^{o}C allow effective composting. A temperature range between 45-59 ^{o}C has been suggested for effective composting of organic matter by Richard (2002). Temperatures above 60 ^{o}C have the effect of sanitizing compost (Zucconi & de Bertoldi, 1987; Ellorietta *et al.,* 2003). Hirrel & Riley (2004), suggested temperatures (above 60 °C) kill most pathogenic organisms and weed seeds and that the most effective decomposing bacteria are those that grow at moderate temperatures, 21 °C -38 °C. This is due to the fact that several types of bacteria thrive between the temperatures of 13 °C -68 °C (Hirrel & Riley, 2004). Niwagaba *et al.* (2006), during composting of source separated human faeces for treatment and sanitation had temperature reaching a maximum of 67 ^{o}C for a sanitized compost. The thermophilic temperatures are desirable during the composting process because they destroy more pathogens, weed seeds and fly larvae in the composting materials. Previous studies have reported that temperature during composting develops independently irrespective of the technology when the right size and management of the pile is achieved (Zucconi & de Bertoldi, 1987). Temperatures below 20 °C have been demonstrated to slow or even stop the composting process (Mosher & Anderson, 1977).

2.4.4 Potential Hydrogen(pH)

This is the concentration of hydrogen ions in solution and indicates the level of acidity or alkalinity of an aqueous solution. Composting is affected by pH through selective microbial activity of acidophiles and alkalophiles and their succession, for which reason it has been suggested as an indicator of composting progress (Tumuhairwe *et al.,* 2009). pH varies within a compost pile, but there is a general trend for the pH to decrease (become more acidic) during the early stages of decomposition and then to increase (Finstein & Morris, 1975). In the early stages of composting, the pH decreases to 5.3-5.7 (Stuetzenberger *et al.*, 1970). The pH decline is usually due to the formation of organic acids and this is especially so if the moisture content is high and the substrate contains lots of easily degradable organics. (Niwagaba, 2007).

Literature reveals that the optimum pH range for a successful compost process is between 5.5 and 8.0. Also, the initial pH values in the range 4.2 to 7.2 or 7.0 to 7.5 have been recommended by Tchobanoglous *et al.* (1993) and Dickson *et al.* (1991). Hoitink & Kuter (1986), reported the optimum pH for decomposition is 6.5-8.5 but in order to avoid excessive ammonia losses in aerated compost systems, the pH should be less than 7.4. Microbes driving compost stabilization operate best in the range of pHs between 6.5 and 8.0 (Bazrafshan *et al.,* 2006). Bernal *et al.* (2009), suggested that pH value of the composting mixture should generally be in the range of 6.7–9 to support microbial activity during composting. Composting of source separated human faeces for treatment and sanitation by Niwagaba *et al.* (2007), revealed that a pH range of 6.9-9.4 was reached to attain a sanitized compost. During the co-composting of faecal sludge and organic solid waste for agriculture by Cofie *et al.* (2009), pH values of 7.8 and 8.1 were observed at the end of maturation of compost.

In a study conducted by Mckinley & Vestal (1985), they hypothesised that increased pH could be used as an indirect indicator of high microbial activity. Acidic conditions (pH < 6) reduce activity, while higher pH is associated with ammonification (Smårs *et al.,* 2002; Sundberg *et al.,* 2004). The Figure 2-2 shows temperature and pH variation during the natural composting process.

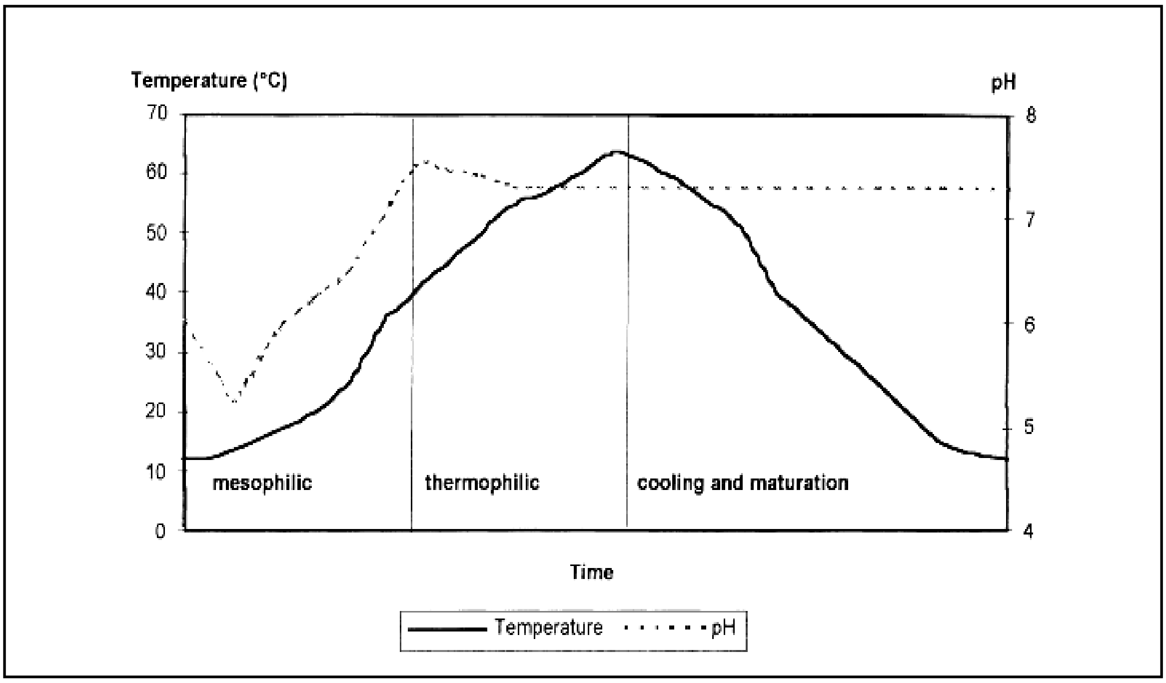

Figure 2-2. Temperature and pH variation during the natural composting process. Source: Golueke, 1991; Tuomela et al., 2000.

2.4.5 Oxygen concentration

The process of composting depends upon a good supply of oxygen, therefore air must be able to move through the mixture. Aerobic composting consumes large amounts of oxygen, particularly during the initial stages because it is used as electron receptor in metabolism by the aerobic microorganisms. That is, the oxygen gets depleted during the decomposition and has to be continuously replenished. Rapid aerobic decomposition occurs only when there is enough oxygen present. Air movement throughout the compost pile is affected by spaces between particles in the compost pile and by moisture content (Hirrel & Riley, 2004). If the material becomes water saturated, pore size of compost decreases thereby decreasing the air movement within the compost. It is therefore recommended that structure creating materials which increase the proportion of free airspace be used during composting.

Minimum oxygen concentration of 5% within the pore spaces of the compost is necessary for aerobic composting (Pace *et al.,* 1995). Epstein *et al.* (1976), also suggested a range between 5% and 12% oxygen levels to be suitable for composting as compost piles do not produce any detectable odours. Tchobanoglous *et al.* (1993), reported that aerobic composting requires the oxygen within the pile to be kept at a concentration at least half that of the ambient air. A detailed measurement of turned and aerated piles conducted by Wang *et al.* (2007), found oxygen concentration below 1.5% in the air within non-aerated compost piles whereas the oxygen level was always above 4% in the aerated piles. Beck-Friis *et al.* (2003), compared compost aeration at different oxygen concentrations (1%, 2.5% and 16%) and observed prolongation of the mesophilic phases and reduction of microbial activities at lower oxygen concentration (1% and 2.5%).

Oxygen can be supplied to composts by mechanical aeration, convective air flow (passive aeration), diffusion and physical turning of the compost mass (Epstein, 1997). Regular mixing or turning of compost pile fluffs up the material and increases air movement which enhances aeration and decreases compaction. Turning or mixing of compost can either be done mechanically or manually. If the supply of oxygen is limited, the composting process may turn anaerobic, which is a much slower and odorous process. Whilst it is important to maintain adequate oxygen for aerobic microbial activity, it should be noted that excessive aeration can increase emissions of polluting nitrogenous gases such as NH_3 or N_2O (de Guardia *et al.,* 2008; Kader *et al.,* 2007; Liang *et al.,* 2006). A higher aeration rate reduces methane and nitrous oxide emissions but increased ammonia volatilization (Maeda & Matsuda, 1997; Tamura *et al.,* 1999).

2.4.6 Turning of compost during composting process

Turning aerates the compost that is replaces oxygen-deficient air in the centre of the compost pile with fresh air. Turning releases trapped heat, water vapour and gases and also mixes the materials, breaks up large particles and restores the pore spaces eliminated by decomposition and settling. During the turning, it is necessary to bring inner mass to the outer surface and to transfer the outer waste to the inner portion. Turning of compost feedstock is reported to significantly decrease temperature build-up during composting (Elorrieta *et al.,* 2003; Zhu *et al.,* 2004; Tognetti *et al.,* 2007; Tosun *et al.,* 2008).

Available literature does not specifically give the number of times a compost pile should be turned. Several experts, during the composting process used wide variations of turning frequencies. Studies at the National Environmental Engineering Research Institute (NEERI) have shown that the optimum turning interval which will reduce the cost and simultaneously maintain aerobic conditions is 5 days. Banegas *et al.* (2007), during the composting of aerobic and anaerobic sewage sludge used a turning frequency of every 4-5 days for 90 days. A study conducted by Cofie *et al.* (2009), recommended a turning frequency of every 10 days as it saves labour and still produces safe compost with good nutrient content. The study further suggested that turning frequency of compost does not have any significant impact on the quality of the matured compost (Cofie *et al.,* 2009).

2.5 Role of Bulking Material during Composting

Bulking materials (BM) play a very important role in faecal sludge treatment during composting and also in vermiculture. The role it plays depend on the intended use either for composting, as a bedding material for waste digesters in vermiculture and also provide an enabling environment for the activities of microorganisms. Bulking materials are mostly organic in nature and are added to compost primarily to reduce the bulk weight and increase air voids, allowing for proper aeration. Bulking materials when added to compost improve the process structurally or chemically and/or to add energy for the process (Niwagaba, 2007). Haug (1993), reported that successful thermophilic composting of raw materials (substrates) usually requires mixing them with amendments, a process called feed conditioning. Bulking materials are of great importance to the root environment when compost is used as substrate and also the microbial population during the previous composting process. This means that benefits of bulking material should also be seen only to play the role of supplying nutrients (N, P, secondary nutrients, and micronutrients), improving of soil physical conditions and elevating of soil organic matter level whiles providing an enabling environment it produce to speed up the aerobic decomposition of faecal sludge.

Banegas *et al.* (2006), reports that results from the study of bulking materials have not been consistent. A study on the composting of cattle manure with various bulking materials (rice straw, sawdust, waste paper and vermiculite) by Tang & Katayama (2005), indicated that the bulking material was not degraded within the first 14 days of composting and did not affect microbial succession. However, Nakasaki *et al.* (1986), found that larger amounts of rice husks added as bulking material to sewage sludge yielded a higher CO_2 evolution rate and a larger number of thermophiles per unit dry mass of raw sludge.

2.5.1 Types and sources of bulking materials

Different types of bulking materials have been used during composting process. Common bulking materials are fibrous carbonaceous materials with low moisture content (Morisaki *et al.,* 1989; Sesay *et al.,* 1997; Milne *et al.*, 1998; Miner *et al.,* 2001). These usually are dry materials and help keep compost aerated. The many types of bulking materials include sawdust, wood shavings, rice husk, coconut fruit fibre, maize cob, dried grass, hay or straw, organic solid waste and many more. Bulking materials often used in composting operations include sawdust, straw, peat, rice hulls, cotton gin trash, manure, refuse fractions, yard wastes, wood chips and a variety of other wastes (Haug, 1993). Similarly Diener *et al.* (1993), suggested faecal (sewage) sludge, industrial wastes (e.g. food, pulp and paper), yard and garden wastes, municipal solid wastes (up to 70% organic matter by weight), soft prunings, clippings and leaves, kitchen waste like fruit peelings, egg shell and paper shredded, mixed with grass cuttings and used sparingly as materials that can be composted. Inorganic materials such as lime or ash can be added to faecal sludge to raise their pH to improve composting.

Relatively smaller particles of bulking materials have more surface area for soil organisms to work on. In general, the smaller the particle size, the faster the raw materials will be transformed into compost. To speed up the composting process, one should grind, cut, chop, or smash the raw materials to reduce the particle size.

2.5.2 Mixing ratio for composting with bulking materials

Literature on faecal sludge to bulking material ratios during co-composting process is diverse. The quality of biosolids is largely influenced by the proportions of sludge and bulking material that is used. Studies by group of researchers during the composting of filter cake raw sludge (23% solids) with wood chips produced a compost mix at a ratio of 1:3 on a volume basis (Epstein *et al.,* 1976). The usage of a 2.5-3 parts of wood chips to every 1 part of sludge mixture was found to provide optimum porosity without excessive heat loss which is necessary for pathogen kill and sludge stabilization (Ceschan, 1981). Oleszkiewicz & Mavinic (2001), recommended that bulking material for composting should be 40–50% TS. Banegas *et al* .(2006), in a study on composting anaerobic and aerobic sewage sludges using two proportions of sawdust suggested mixing ratios of 1:1 and 1:3 sludge:sawdust (v:v). For the aerobic composting, sludge was subjected to periodic turning.

In Evaluation of microbiological and chemical parameters during wastewater sludge and sawdust co-composting, Bazrafshan*et al.* (2006), suggested five different ratios: 8:1, 8.5:1.5, 1:0.6, 1:0.5, and 1:0.4 (W: W) of sewage sludge and sawdust use as bulking materials during composting. Zubillaga & Lavado (2003), in a study of stability indices of sewage sludge composts used the ratios of 1:2, 2:1 and 1:1 (v:v). Molla *et al.* (2004), used a 1:1 (w:w) ratio in a study to evaluate the feasibility of the solid bioconversion processes in the biodegradation of wastewater sludge. Bousselhaj *et al.* (2004), in studying the nitrogen fertilizer value of sewage sludge co-compost, mixed sewage sludge with different bulking materials (domestic solid waste, olive cakes and sawdust) using also a 1:1 (w:w) ratio. Eftoda & Mc Cartney (2004), employed wood chips as bulking material, assaying the ratios of 1:1, 1:2, 1:3 and 1:4. Hay *et al.* (1988), composted sewage sludge with either straw or sawdust in a sludge:bulking material ratio of 1:2 and 1:1 (v:v) respectively. They observed that both mixtures effectively destroyed indicators and pathogenic microorganisms, yielding final compost products well-stabilized, humus-like in texture and devoid of objectionable odours.

2.6 Research Gaps

A review of existing literature reveals composting as a promising and suitable method for effective treatment of high strength faecal sludge into hygienically safe and economically profitable product which is a low cost treatment method with minimal impact on the environment. This method has not been given much attention in the peri-urban areas of Ghana where majority of inhabitants are mostly farmers.

Bassan *et al.* (2013), reports that the design of faecal sludge treatment method requires accurate data on faecal sludge characteristics and quantities to properly size and select treatment technologies and operational parameters. However, results of faecal sludge characterization studies that have been conducted are extremely variable (Heinss *et al.,* 1999; Jenkins & Scott, 2007; Koottatep *et al.*, 2005; Veenstra & Polprasert, 1997) and may not be applicable in certain circumstances. Consequently not much recent work has been done to characterize faecal sludge from peri-urban areas in a bid to address the lack of treatment option for such areas.

Bulking materials sometimes referred to as bulking agents play a very important and effective role in composting by controlling the air supply, C/N ratio, moisture and other important composting parameters. Inasmuch as BM are necessary for composting, improper type and insufficient amounts (ratio) in a composting matrix could cause poor aeration and moisture transfer resulting in the release of odorous gases and production of poor compost quality. However, literature on FS to BM ratios during composting process is diverse. The ratio of FS and BM is an important consideration in optimizing the composting process (CWMI, 2004). The quality of compost is also largely influenced by the proportions of sludge and BM that is used. Due to complexity of composting parameters, requirements and processing costs, it is of utmost importance to further explore the type and most optimal ratio of the BM in a composting mixture.

In contrast to the conventional outdoor composting technologies such as open windrow system and aerated static piles, the rotary drum composter has been considered to be an efficient and promising technology. This technology has been widely used for solid waste composting, however, not much work has been done in the area of faecal sludge composting. Although there has been some effort to evaluate the dynamics of composting in terms of physicochemical, biological and stability analysis, results on the die off of *Ascaris* and *Trichuris* eggs has not been satisfactorily answered. Furthermore, to date, reported data about the design material and configuration of rotary drums for faecal sludge composting is rather scarce.

This thesis sought to address these identified research gaps by designing and demonstrating the applicability of the rotary drum composter technology for treating faecal sludge from peri-urban Ghana. To achieve this, it also sought to assess faecal sludge management, characterize faecal sludge and test the effect of bulking materials and mixing ratios on the quality of selected peri-urban faecal sludge compost.

CHAPTER 3: STUDY AREA AND METHODOLOGY

3.1 Study Area

The study was conducted in six (6) communities (3 peri-urban and 3 rural) randomly selected from Bosomtwe District Assembly (BDA), Ejisu-Juaben Municipal Assembly (EJMA) and the Kumasi Metropolitan Assembly (KMA). The three (3) rural communities were considered for the purposes of comparison. Peri-urban areas were those located on the periphery of cities and functioned as a transition between urban and rural areas. Rural areas were considered as communities characterised by low population densities, small size and relative isolation from cities, agricultural production as the major economic activity. The Figure 3-1shows a map of three selected districts showing geographic position system (GPS) locations of study communities.

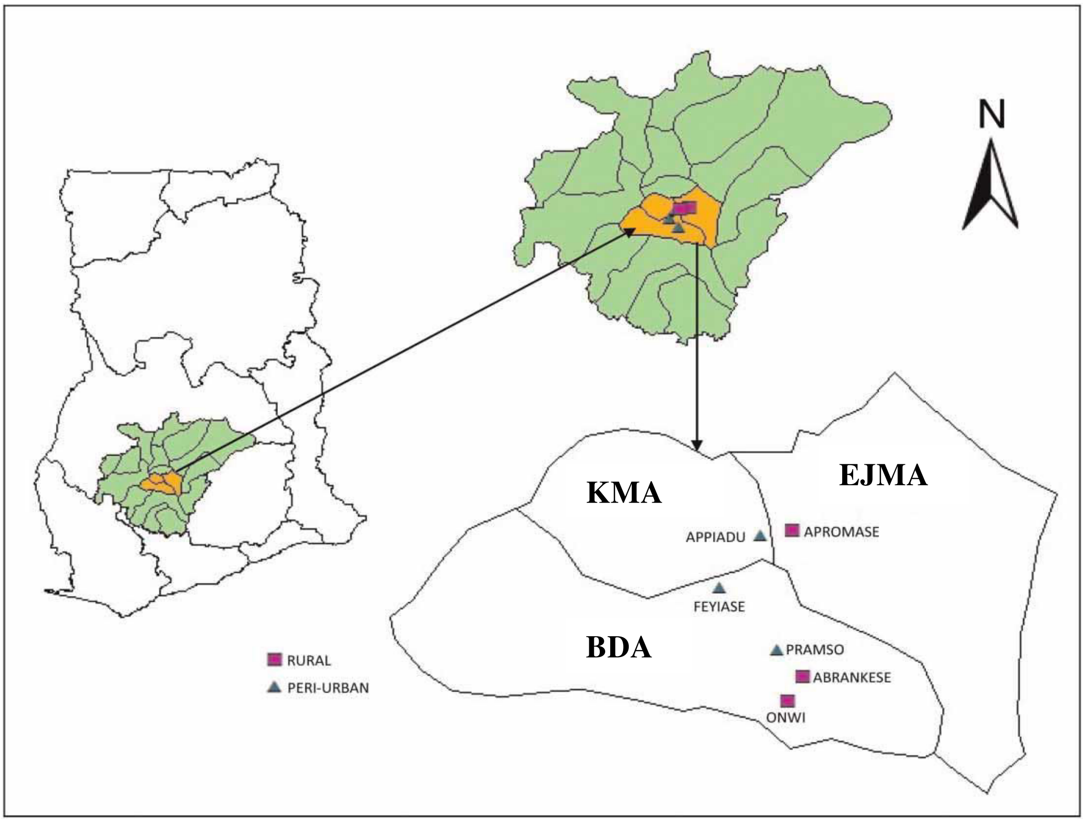

Figure 3-1: A map of Ghana (Left), map of Ashanti Region (Top Right) and map of three selected districts showing GPS locations of study communities.

3.1.1 Kumasi Metropolitan Assembly

The Kumasi Metropolitan is one of the 30 administrative districts in the Ashanti Region. It is located between Latitude 6.35 ^{o}N and 6.40 ^{o}S and Longitude 1.30 ^{o}W and 1.35 ^{o}E and elevated 250 m to 300 m above sea level. The Metropolis shares boundaries with Kwabre East and Afigya Kwabre Districts to the north, Atwima Kwanwoma and Atwima Nwabiagya Districts to the west, Asokore Mampong and Ejisu-Juaben Municipality to the east and Bosomtwe District to the south. It has a surface area of approximately 214.3 km^2. The Kumasi Metropolis had a population of about 1,730,249 in 2010 representing 36.2% of the total population of Ashanti Region (GSS, 2012). It comprises of 826,479 males (47.8%) and 903,779 females (52.2%). It has 440,283 households with an average household size of 3.8 persons per household.

The Metropolis falls within the wet sub-equatorial type. The average minimum temperature is about 21.5 ^{o}C and the maximum average temperature is about 30.7 ^{o}C. The average humidity is around 84.16% at sunrise and 60% at sunset. The metropolis has a moderate temperature and humidity and the double maxima rainfall regime of 214.3 mm in June and 165.2 mm in September. The Metropolis lies in the transitional forest zone specifically within the moist semi-deciduous South-East Ecological Zone. The Metropolis is traversed by a major river (Owabi) and streams like Subin, Wiwi, Sisai, Aboabo and Nsuben. These water bodies, especially Owabi, serve as the main source of drinking water to residents not only within the Metropolis but the region as a whole. The Kumasi Metropolitan area is dominated by the Middle Precambrian Rock.

The main toilet facilities used in the metropolis are the water closet with septic tanks, public toilet facilities, pit latrines system (VIP and KVIP) and bucket/pan latrine. WC with septic tanks are used by 43.3% of the households in the Metropolis. Public toilet facility, the second most common type of toilet facility, is used by 36.2% of households. The use of pit latrine facility by households ranks third in the Metropolis (11.1%) followed by KVIP (7.2%). About two percent (2.4%) of the households do not have toilet facilities therefore use the bush or field or other open spaces. Even though the use of bucket/pan latrine has been outlawed in the Metropolis, 1,064 households (0.2%) report its use.

3.1.2 Bosomtwe District Assembly

The Bosomtwe District, is located in the central part of the Ashanti Region and lies within Latitudes 6° 24' S and 6° 43' N and Longitudes 1° 15' E and 1° 46' W. It is bounded in the north by Kumasi Metropolitan Assembly, in the east by Ejisu-Juaben Municipal, the south by Bekwai Municipal and Bosome-Freho District, and in the west by Atwima- Kwanwoma District. The District has 66 communities, which have been zoned into three area councils namely, Jachie, Kuntanase and Boneso. Bosomtwe District had a total population of 93,910 in 2010 with male population representing 47.7% and that of the female 52.3% (GSS, 2012). The District has a land size of 422.5 km^2.

The Bosomtwe District falls within the equatorial zone with rainfall regime typical of the moist semi-deciduous forest zone of the country. There are two well-defined rainfall seasons: the main season, which occurs from March to July and the minor season, which starts from September to November with a peak in October. The main dry season occurs in December to March during which the desiccating harmattan winds blow over the area. Temperature of the area seems to be uniformly-high and throughout the year with a mean of around 24 ºC. The highest mean temperature occurs just before the major wet season in February whilst the mean minimum occurs during the minor wet season. The vegetation of the entire District is the Semi Deciduous Forest type. The District is underlain by Precambrian rocks of the Birimian and Tarkwaian formations.

The Bosomtwe District has the following sources of water supply. They are open hand-dug wells, boreholes, pipe borne water and mechanized bore holes, rain water, small town water system, streams and lakes. 48.1% of households use the public toilets. Another 25.3% of households use pit latrines, and 9.3% use the WC facility.

3.1.3 Ejisu-Juaben Municipal Assembly

The Ejisu-Juaben Municipality lies within Latitudes 1^o 15′ N and 1^o 45′ N and Longitude 6^o 15′ W and 7^o 00′ W, occupying a land area of 582.5 km^2. The Municipality lies in central part of the Ashanti Region, sharing boundaries with six Districts in the Region. The Districts are Sekyere East and Afigya Kwabre to the Northeast and North-West respectively; the Bosomtwe and Asante Akim South Districts to the South; the Asante Akim North to the East and the Kumasi Metropolis to the West. The district capital is sited at Ejisu. The population of the Municipality was 143,762 comprising 68,648 (47.8%) males and 75,114 (52.2%) females in 2010 (GSS, 2012). It has an average household size of 4 persons which is similar to the regional average.

The Municipality has bi-modal rainfall pattern. The major rainfall period begins from March to July with average annual rainfall of 1,200 mm–1,500 mm per year. The minor rainfall period also begins in September and tapers off in November with an average minor annual rainfall of 900 mm-1,120 mm per year. December to February is usually dry, hot and dusty. Mean annual temperatures in the Municipality are lowest around 25 ^oC in August and highest around 32 ^oC in March. Relative humidity is moderate but quite high during the rainy season.

The Municipality lies in the semi-deciduous forest zone of Ghana. The topography of the Municipality area is generally undulating, dissected by plains and slopes with heights ranging between 240 metres and 300 metres above sea level. The geology of the Municipality is precambrian rocks of the Birimian and Tarkwaian formations that is generally suitable for agriculture. The Oda, Anum, Bankro, Hwere and Baffoe Rivers are the major rivers in the area.

Borehole is the main source of drinking water for 60.9% of the households in the Municipality, followed by pipe-borne water (24.2%). Sachet water is also used by 2.3% of households in the Municipality. 48.8% of households in the Municipality use public toilet, 21.5% use pit latrine and 12.2% use Water closet (W.C.) toilets. About one-tenth (10.4%) of households also use Kumasi Ventilated Improved Pit Latrine (KVIP). The proportion of households that do not have toilet facilities is 6.4% and is higher in rural areas (6.7%) than urban areas (5.8%).

3.2Methodology for Qualitative Data Collection

3.2.1 Assess faecal sludge management in selected peri-urban areas

The study was designed to assess faecal sludge management in selected peri-urban areas in relation to selected rural areas in three districts of the Ashanti Region of Ghana in the period of 2013. The assessment specifically considered the toilet technologies and household sanitation practices of households, households' perception of hygiene practices and faecal sludge reuse; and current faecal sludge management practices in terms of desludging, treatment and disposal. The study used desk studies, responses from household surveys, key informant interviews and field observations as qualitative data collection techniques to address the objective.

3.2.1.1 Desk study

Literature and other relevant documents were reviewed for this study in order to fully understand the concept of faecal sludge management and composting as approaches for hygienization of sludge as well as recovery of resource. The literature were sourced from a variety of different sources such as published articles, reports, the national environmental sanitation strategy and action plan and other government agencies documents and thesis from Kwame Nkrumah University of Science and Technology (KNUST) library. To complement the document review, relevant information from internet websites were collected. The literature explained some of the key terminologies used in the study. The whole faecal sludge management chain covering collection, haulage, treatment, disposal and reuse was reviewed. Issues bothering on faecal sludge generation and characteristics were also looked at. Also, the key principles and factors affecting the process of faecal sludge composting were thoroughly reviewed. The outcome of the desk study provided insight to the study objectives and thegaps that existed.

3.2.1.2 Questionnaire surveys

The study employed the use of questionnaires to collect both quantitative and qualitative data (Appendix A). Open-ended questionnaires aided in qualitative data while close ended questionnaires gave quantitative date. Closed ended questions were made of multiple or set of answers with a small box next to answer where the respondents were asked to choose among them. It was ticked on the appropriate box when a respondent gave an answer. Open-ended questions did not contain boxes to tick but instead left a blank section in which the answer provided was written. According to De Vaus (2001), questionnaires can be administered through the survey strategy in various ways including: face-to-face administration by trained interviewers; by telephone with or without trained interviewers; and unsupervised or self-administration where the questionnaire is normally received and returned through the mail by the respondent. During the assessment of faecal sludge management, face-to-face administration of questionnaires to households was adopted in order to ensure high response rate, quick return of response and offer the trained interviewers the opportunity to explain the questionnaires, where needed, to the households and farmers (Nkansah, 2009).

A total of 45 household questionnaires were administered in each of the six communities in the study area. In all, household questionnaires were administered to 270 households which were randomly selected. The purpose of the household survey was to determine the socioeconomic profile of the respondents (including sex, age, marital status, educational level and reported monthly household income), perception of sanitation practices, faecal sludge reuse and faecal sludge management (desludging, treatment and disposal).

Asante Twi, the main local language spoken within the study areas, was used during the household interviews.

3.2.1.3 Key informant interviews

Face-to-face interviews were conducted with key informants (stakeholders) who matter in the area of sanitation and for that matter faecal sludge management. Gillham (2000) suggests, that a semi-structured interview, which is in between the two interview extremes, that is, structured and unstructured, offers the interviewees the opportunity to say their views in an unstructured manner that adds some new discoveries and understanding to the research investigators. Based on this recommendation, this study used semi-structured interviews to obtain data from the key informants who were Assembly men (elected officials and government appointees at the District Assembly), public toilet attendants and the Water and Sanitation Management Teams (Appendix A). The aim of the interview with the key informants was to examine their views on a wide range of information regarding the faecal sludge management situation of their communities (Table 3-1). The duration for the interview varied for different informants due to the scope and content of the questions. The interview was also a tool to establish the validity and reliability of some of the secondary data collected from various sources.

Table 3-1: Key informants and data collected

Key Informant	Number interviewed	Data collected
Assemblymen	2 per community	Community demography, general sanitation situation and challenges with FSM issues
Public toilet Attendants	2 per community	Description and cleanliness of public toilet, toilet user fees, and other FSM issues
Water and Sanitation Management Teams	1 team per community (7–11 members per team)	General sanitation situation, main toilet technologies, FSM issues

3.2.1.4 Field observations

The study methodology also employed visual inspection and observations by transect walk to observe the faecal sludge management situation in the communities. This approach was intended to help bring out information that households may not wish to disclose during interviews or may not be asked about in surveys (Roche, 1999). This activity was also undertaken to have a fair idea about the general hygiene practices and also ascertain some of the secondary data collected and assertions made by households and key informants from the interview. Observations were carried out early in the mornings and in the evenings when households were at home and use of household and public toilets were at their peak. A stick was used to check whether toilets were full or not. According to Trochim (2006), technology is a useful part of observation. Therefore, during these visits, pictures of faecal sludge disposal, household and public latrines and other sanitation facilities in the communities were taken with a digital camera.

3.2.2 Assess the perception of peri-urban farmers on faecal sludge compost and its utilization

Attitudes and perceptions play an important role in the use of sanitized faecal sludge for agricultural purposes (Mariwah & Drangert, 2011). Against this background, the study therefore sought to investigate the perception of peri-urban farmers on faecal sludge compost and its utilization in the period of 2014. Specifically, this study sought to: (1) investigate the farming practices and type of fertilizer used by farmers; (2) assess farmers knowledge on faecal sludge compost and its utilization; and (3) investigate the socio-cultural and health issues relating to faecal sludge compost. The study used semi-structured questionnaires which were administered face-to-face with a farmer.

3.2.2.1 Semi structured questionnaire surveys

In the case of the peri-urban farmers, the study also employed a random sampling approach to select 150 farmers, fifty from each of the selected three communities based on a listing of farmers. Selected farmers mostly cultivated vegetable with few into food crop farming. The main aim of the survey with the farmers was to generate both qualitative and quantitative data to assess the views of peri-urban farmers on the utilization of faecal sludge compost. The questionnaire was divided into five (5) main sections. Section one focused on the socio-economic characteristics of a farmer's profile. Sections two and three contained information on farming practices and the use of inorganic fertilizers by the farmers. Assessment of farmers' knowledge on faecal sludge compost and its utilization were outlined in section four. Cultural and social acceptability and health risks posed by using faecal sludge were contained in the fifth (and last) section of the questionnaire.

During the assessment of the perception of peri-urban farmers, face-to-face administration of questionnaires to farmers was adopted in order to ensure high response rate, quick return of response, and offer the trained interviewers the opportunity to explain the questionnaires, where necessary, to the households and farmers (Nkansah, 2009). Asante Twi, the main local language spoken within the study areas, was used during the farmers interviews.

3.3 Methodology for Experimental Design

3.3.1 Determine the characteristics of faecal sludge from selected peri-urban areas

Knowledge about the constituents of faecal sludge is important for treatment as exposure to excessive amounts may have adverse effects on public and environmental health. Thus, the characteristics of raw faecal sludge was determined in terms of its physicochemical, heavy metals and microbial constituents. This study compared results from the peri-urban areas to that of the rural areas to determine the existence of any significant difference between them. This was done as there are no discharge standards for faecal sludge discharge. The physicochemical, heavy metals and microbial constituents were measured in the laboratory using various methods outlined in Standard Methods for the Examination of Water and Wastewaters (APHA-AWWA-WEF, 2005).

3.3.1.1 Sampling of faecal sludge for characterization

Faecal sludge was sampled within the periods of July, August and September, 2013. Faecal sludge samples were collected from public toilets located in the study communities. Samples were collected in 1-l air-tight sterile plastic containers rinsed thoroughly with distilled water. Sample containers were completely filled to remove air. Four (4) samples of public toilet sludge were collected from each of the selected communities per visit. At the end of a visit, samples were mixed to form a composite sample each for peri-urban and rural sludges, respectively. Faecal sludge samples were collected twice a month for a period of three months (July, August and September 2013). A total of 12 composite samples were collected from the peri-urban (6 composite samples) and rural areas (6 composite samples).

Faecal sludge samples were securely transported to the Environmental Quality Laboratory of the Kwame Nkrumah University of Science and Technology and analyzed for physico-chemical, heavy metals and microbial constituents. Physico-chemical parameters measured were pH, electrical conductivity (EC), total solids and volatile solids (TS and TVS), chemical oxygen demand (COD), biochemical oxygen demand (BOD), NH_3-N, NO_3-N and TKN. Nutrients like total nitrogen, phosphorus and potassium were also determined. Copper (Cu), iron (Fe), lead (Pb), cadmium (Cd), zinc (Zn), manganese (Mn) and arsenic (As) were also analysed for heavy metals. Microbial parameters such as total coliform, faecal coliform, *Escherichia coli*, *Salmonella* spp., hookworm, *Ascaris, Schistosoma haematobium, Schistosoma mansoni* and *Trichuris trichiura* were also determined.

Faecal sludge sampling protocol was followed carefully to prevent contamination during sampling and transportation which may affect the results. The protocols used in the study were approved by the Departmental Ethics Committee.

3.3.2Test the effect of bulking materials and mixing ratios on the quality of peri-urban faecal sludge compost

The study was designed to test the effect of bulking materials and mixing ratios on the quality of peri-urban sludge compost. Due to complexity of composting parameters, requirements and processing costs, it is of utmost importance to determine the type and most optimal ratio of the bulking material (BM) in a composting mixture (Malinska & Zabochnicka-Światek 2013). Therefore this study examined the suitability of two common bulking materials (BMs) used in composting faecal sludge as well as investigate the effect of bulking materials and mixing ratio on faecal sludge compost mixture on selected compost parameters. Compost feedstocks were prepared in volume by volume ratio as follows; 1 part of FS to 1 part of BM, 1 part of FS to 2 parts of BM and 2 parts of FS to 1 part of BM and FS only as control. The bulking materials used for the experiment were wood chips and maize cobs. Temperature, pH, Moisture Content (MC), Organic Matter Content (OMC), Total Solids (TS), Ash Content, Organic Carbon, Nitrogen, C/N ratio, Phosphorus and Potassium in compost samples were measured at the laboratory using methods as explained under section 3.5

3.3.2 .1 Design and construction of bench scale experimental set up

Seven (7) cylindrical plastic reactors were used for the composting experiment. Each reactor was sized 27 litres measuring 32 cm in diameter and 33cm in length (Figure 3-2). A hole of 5 inches was drilled at about 10 cm from the bottom of the reactor to provide an inlet for cold air expected to flow by convection into the composting mixture and, once warmed, to exit through (Adhikari *et al.,* 2009) another 5 inches hole on the top opening (4 No.) which is about 5 cm from the top end of the reactor. The reactors were put on a platform raised above ground level under a shed done to provide shelter and protect the composting process from severe environmental conditions of rain (Appendix-Plate 2) .

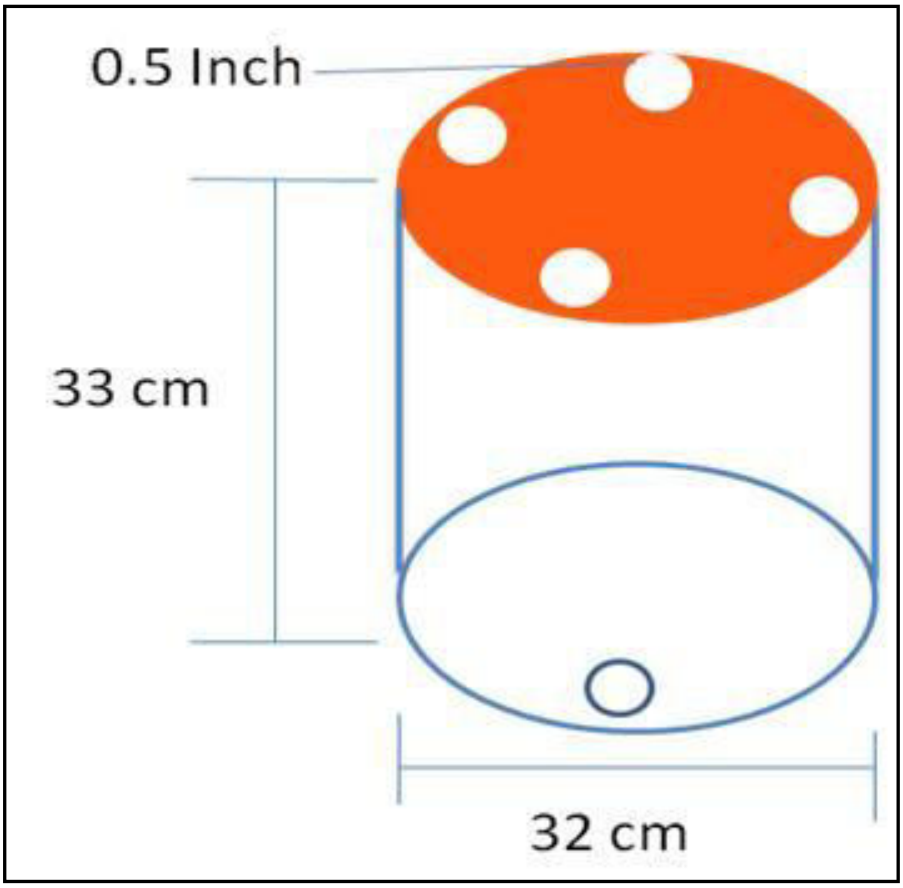

Figure 3-2: Schematic drawing of cylindrical reactor for bench scale composting

3.3.2 .2 Sampling and preparation of faecal sludge compost materials

Raw faecal sludge and bulking materials (wood chips and maize cobs) were sampled from three peri-urban communities in the Ashanti region of Ghana for this study in the period of 2014. The sludge and bulking materials were transported to KNUST campus for composting. The raw faecal sludge was semi-solid in nature. The wood chips already offered a small particle size (2 mm-10 mm) whereas the maize cobs were chopped into smaller similar particle sizes ranging from 2mm-10mm in length and 1-2 mm in width.

Compost materials were prepared by manually mixing the raw faecal sludge and the bulking materials using a shovel in the following weight by weight ratio; 1 part of FS to 1 part of BM, 1 part of FS to 2 parts of BM and 2 parts of FS to 1 part of BM and FS only measured volume by volume). A control of only faecal sludge was also monitored. Turnings were performed once every three days during the first 14 days of active composting to ensure the restructuring and maintain a uniform decomposition of the compost. Turnings were later performed at regular intervals once every week till the end of the compost period which lasted for 60 days. Throughout the active phase of composting period, moisture was maintained within the range 40–55% by periodically sprinkling the composts with water.

For sampling, the compost in each reactor was divided into three layers along the depth (upper, central and lower layers). Grab samples weighing 10 g were randomly collected from these three locations within the plastic reactor. All the grab samples were mixed together to obtain homogenised samples which were taken to the Environmental Quality Engineering laboratory for immediate analyses. In this study temperature, pH, Moisture Content (MC), Organic Matter Content (OMC), Total Solids (TS), Ash Content, Organic Carbon, Nitrogen, C/N ratio, Phosphorus and Potassium of samples were measured at the Environmental Quality Engineering laboratory of KNUST.

Table 3-2: Description of experimental labels

Experiment	**Label**	**Replicate**		
		1	2	3
Faecal Sludge only	Control	$Control_1$	$Control_2$	$Control_3$
Faecal sludge and wood chips (2:1 ratio by volume)	Wood (2:1)	$Wood_1$ (2:1)	$Wood_2$ (2:1)	$Wood_3$ (2:1)
Faecal sludge and wood chips (1:1 ratio by volume)	Wood (1:1)	$Wood_1$ (1:1)	$Wood_2$ (1:1)	$Wood_3$ (1:1)
Faecal sludge and wood chips (1:2 ratio by volume)	Wood (1:2)	$Wood_1$ (1:2)	$Wood_2$ (1:2)	$Wood_3$ (1:2)
Faecal sludge and Maize cobs(2:1 ratio by volume)	Maize cob (2:1)	Maize cob_1 (2:1)	Maize cob_2 (2:1)	Maize cob_3 (2:1)
Faecal sludge and Maize cobs(1:1 ratio by volume)	Maize cob (1:1)	Maize cob_1 (1:1)	Maize cob_2 (1:1)	Maize cob_3 (1:1)
Faecal sludge and Maize cobs(1:2 ratio by volume)	Maize cob_1(1:2)	Maize cob_1 (1:2)	Maize cob_2 (1:2)	Maize cob_3 (1:2)

3.3.3 Measure the performance of rotary drum composter on the die off of Ascaris and Trichuris eggs

The technology used for composting is a relevant factor (Rodríguez *et al.,* 2012) towards achieving a well stabilized and hygienized compost. This study designed and constructed a rotary drum using the discrete element method (DEM) elaborated under section 3.4.3. Two different composters namely rotary baffle and paddle composters were constructed from plastic and galvanized metal. With the rotary paddle composters, the paddle blades scoop, lift and tumble compost feedstock in a gentle thorough mixing action. In the case of rotary baffle composters, the baffles act as obstructing vanes or panels which are long flat plates that attach to the sides of the composter to prevent swirling and promote top to bottom movement of compost feedstock. The rotary drums were used to compost faecal sludge and their performance on the die off of *Ascaris* and *Trichuris* investigated. The concentration of *Ascaris* and *Trichuris* eggs in compost sample was determined using a combination of the floatation and sedimentation method developed by Schwartzbrod *et al.* (2003).

3.3.3.1 Design and construction of rotary drum composter

The objective was to make a 3D model of a rotary drum composter and study the blending time, mixing efficiency and volumetric efficiency by performing discrete element analysis. A 3D Model concept of a rotary drum was created using a Computer Aided Design (CAD) software (PTC Creo Parametric 3.0). The 3D model served as a geometric definition which depicted the topology of the design concepts.

CD Adapco Star CCM+ (DEM Software) was used to simulate the mixing of the faecal sludge in the rotary drum. The 3D Model of the rotary drum was imported into the DEM software and a mesh was created around the rotary drum for easy analysis. The physical properties of the faecal sludge and shredded maize cobs as well as boundary conditions of the drum were assigned in the software. The model was used to simulate the mixing of faecal sludge and shredded maize cobs (bulking material). The output of the model simulation included the blending time, mixing efficiency, average force required to turn the drum and volumetric efficiency which informed the final design of the rotary drum technology. After the results were obtained from the DEM simulation, the 3D CAD model of the rotary drum was adjusted to generate final manufacturing drawings for fabrication (Figure 3-4 and Figure 3-5). The process from the conceptual to the design of the rotary drum technology is shown in the flow diagram in Figure 3-3 with details presented under Annex C.

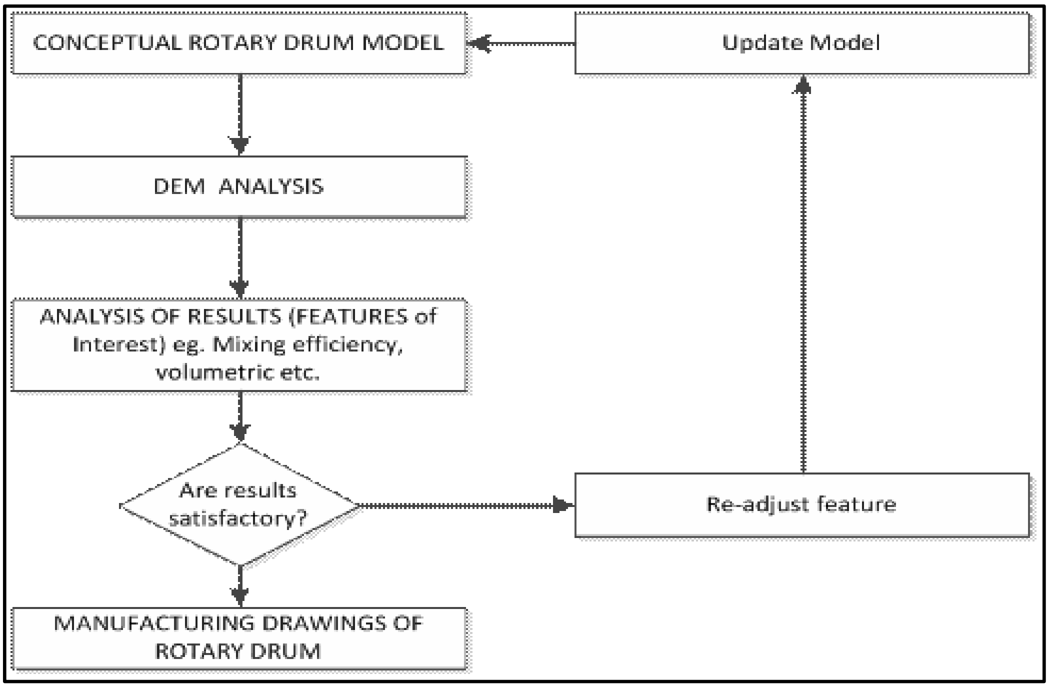

Figure 3-3: Diagram of overall flow for design and construction of rotary drum composter

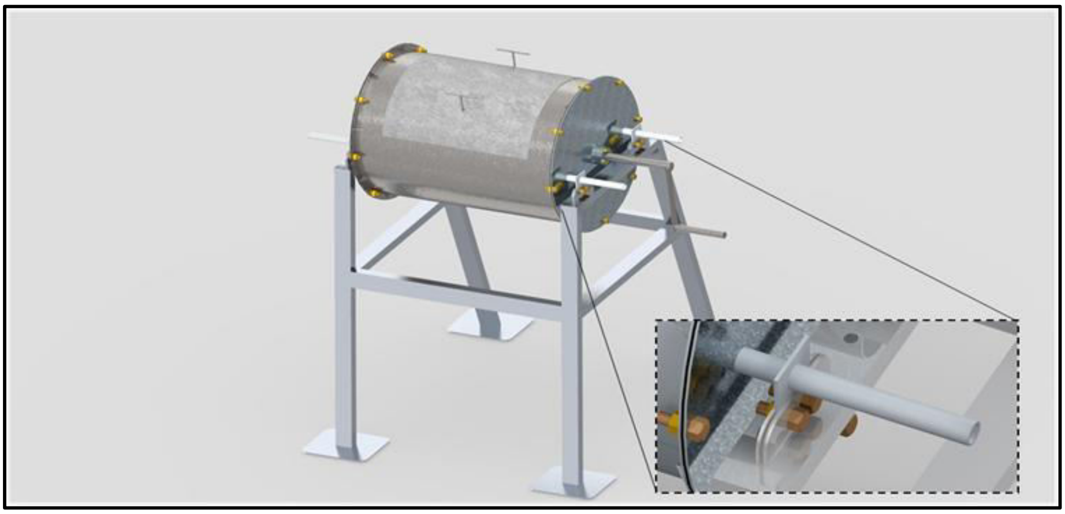

Figure 3-4: Manufacturing drawing of rotary drum composter

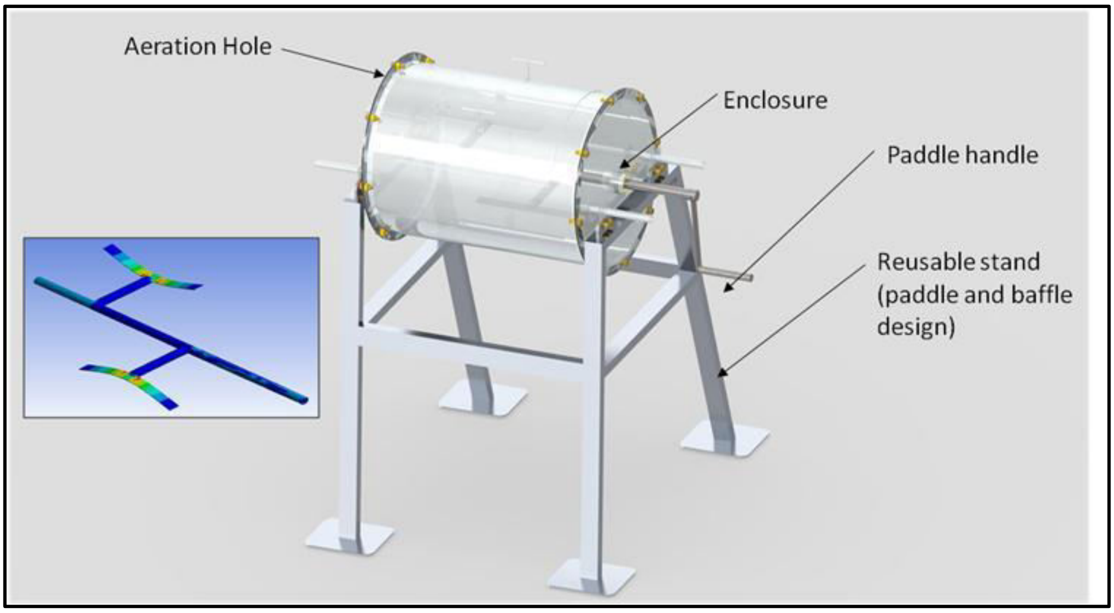

Figure 3-5: Manufacturing drawing of rotary drum composter detailing paddles for mixing

<u>*3.3.3.2 Sampling and preparation of faecal sludge compost materials*</u>

The faecal sludge used in the experiment was collected from three public latrines located in three peri-urban communities in the Ashanti region of Ghana in the period of 2015. These latrines have an estimate of between 120-200 visits daily by users in the respective communities. None of the latrines had been emptied for about 2 to 5 months prior to the sampling of faecal sludge. The faecal sludge was a mixture of faeces, urine and anal cleansing materials. Maize cobs were shredded using maize milling machine to achieve about 1 to 4 mm particle size for better aeration and moisture control (Kalamdhad & Kazmi, 2008). The compost material was prepared by mixing the freshly collected faecal sludge with shredded maize cobs in a ratio of 1:2 (1 part of faecal sludge to 2 parts of shredded maize cobs) on volume by volume basis. A total of two experimental trials were monitored, trial 1 from March to May 2015 and trial 2 from September to November 2015. Composting was carried out in four different pilot scale rotary drum composters for each of the experimental trials as detailed in Table 3-3.

Table 3-3: Description of rotary drum composting experimental set up labels

S/N	Experiment	Label
1	Metal Rotary Composter with Paddles	Metal Paddle
2	Metal Rotary Composter with Baffles	Metal Baffle
3	Plastic Rotary Composter with Paddles	Plastic Paddle
4	Plastic Rotary Composter with Baffles	Plastic Baffle

The rotary drum composter had a volume of 130 litres for the composting process which was batch-mode operated. The composter was fabricated with plastic and galvanised metal sheet of thickness 5mm. The main units of the composter is the drum (metal and plastic) and a mixer (rotating paddle). The drum had dimensions of 60cm in length and an inner diameter of 40cm with the mixer spanning the entire length of the drum. The mixer was to provide an effective mixing of the compost feedstock. The rotary drum was coated with black paint and also covered with black polythene material to prevent excessive heat loss from compost. In order to allow for proper aeration of the compost, two openings each of diameter 10 mm was created at the upper part of the circular sides and another at the longitudinal side. The rotary composter was mounted onto a metal stand and it was manually rotated according to schedule.

Manual turning of up to five complete rotation of drum was done on the first day and subsequently every three days for the first three weeks of the compost process. After the first three weeks, manual turning was done every 10 days till the end of the compost process. Turning was done to ensure that the materials on the top portion moved to the central portion, where it was subjected to higher temperature (Nayak & Kalamdhad, 2014). A 12 weeks (84 days) composting period was selected for the proper degradation and hygienization of the compost (Hartz & Giannini, 1998).

3.4 Laboratory Analyses of Faecal Sludge Samples

3.4.1 pH and EC

A digital PC 300 Waterproof Handheld pH meter was used. The electrode was first calibrated against pH buffer 4, 7, and 10. The sample under test was vigorously shaken before the insertion of the probe. There was a digital read-out when the probe was inserted in the sample indicating the pH value of the sample. This reading was recorded when it stabilized. The "MODE" button which allows switching to other parameters was then used to read the values of EC.

3.4.2 Total volatile solids (TVS)

The total volatile solids (TVS) was analysed based on the method described in the Standard Methods of water and wastewater analyses, APHA-AWWA-WEF, (2005) (Appendix B).

3.4.3 Total solids (TS)

The total solids (TS) was analysed based on the method described in the Standard Methods of water and wastewater analyses, APHA-AWWA-WEF, (2005) (Appendix B).

3.4.4 Five day biochemical oxygen demand (BOD_5)

The BOD_5 was analysed based on the method described in the Standard Methods of water and wastewater analyses, APHA-AWWA-WEF, (2005) (Appendix B).

3.4.5 Chemical oxygen demand (COD)

The chemical oxygen demand (COD) was analysed based on the method described in the Standard Methods of water and wastewater analyses, APHA-AWWA-WEF (2005) (Appendix B).

3.4.6 Ammonia-nitrogen (NH_3-N)

The ammonia nitrogen (NH_3-N) was determined using Cadmium Reduction Method, which makes use of Ammonia Salicylate Powder Pillows, as described in the manual of, HACH DR/2400 Portable Datalogging Spectrophotometer (Appendix B).

3.4.7 Nitrate-nitrogen (NO_3-N)

The nitrate nitrogen was determined using Cadmium Reduction Method, which makes use of NitraVer 5 Nitrate Reagent Powder Pillows, as described in the manual of, HACH DR/2400 Portable Datalogging Spectrophotometer (Appendix B).

3.4.8 Phosphorus and Potassium

The Phosphorus was determined using Cadmium Reduction Method, which makes use of Phos Ver 3 (Ascorbic Acid) Method using Ammonia Salicylate Powder Pillows, as described in the manual of, HACH DR/2400 Portable Datalogging Spectrophotometer. Trace amounts of Potassium was determined in a direct reading type of flame photometer at a wavelength of 766.5 nm and a slit width of 2 nm (Appendix B).

3.4.9 Heavy metals

The heavy metals included Copper (Cu), Iron (Fe), Lead (Pb), Cadmium (Cd), Zinc (Zn), Manganese (Mn) and Arsenic (As) were measured based on floatation and sedimentation method by Schwartzbrod (1998). A 2g of a ground compost sample was weighed and placed into 300 ml volumetric flask and 10 ml of di-acid mixture of HNO_3 and $HClO_4$ with ratio 9:4 was added and the contents well mixed by swirling thoroughly. The flask with contents was then placed on a hot plate in the fume chamber and heated, starting at 85 ^{o}C and then temperature raised to 150 ^{o}C. Heating continued until the production of red NO_2 fumes ceased. The contents were further heated until volume was reduced to 3–4 ml and became colourless or yellowish, but not dried. This was done to reduce interference by organic matter and to convert metal associated particulate to a form (the free metal) that can be determined by the Spectrophotometer (AAS). Contents were cooled and volume made up with distilled water and filtered through acid-washed Whatman No.1 filter paper. The resulting solution was preserved at 4^{o}C, ready for Spectrophotometric determination of the metal analysis. A blank was similarly prepared but without the compost sample. A standard solution for atomic absorption spectrophotometry was prepared from commercial stock metal standards of Lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn), Chromium (Cr) and Arsenic (As). Their concentrations in the final solutions were determined by Atomic Absorption

3.4.10 Total coliform

Total coliforms were estimated using the Most Probable Number method (MPN) according to Standard Methods (Anon, 1992). Ten grams of each compost sample was weighed into a stomacher bag and pulsified in 90 ml of 0.9% NaCl MQ-water for 30 sec using a pulsifier (PUL 100E). Serial dilutions of 10-1 to 10-10 were prepared by picking 1 ml from the stomacher bag. One millilitre aliquots from each of the dilutions were inoculated into 5ml of MacConkey Broth with inverted Durham tubes and incubated at 37 ^{o}C for 24 hours. Tubes showing acid and gas production after 24 hours were confirmed by plating on MacConkey No.3 agar and examined for typical colonies. Counts per 100 ml were calculated from MPN tables and expressed as MPN 100 ml-1 (Collins *et al.*, 1989).

3.4.11 Faecal coliform determination

Faecal coliforms were determined following the same procedure for total coliforms in 3.4.10 above. However, tubes were incubated at 44 ^{o}C for 24 hours. Tubes showing acid and gas production after incubation for 24 hours were confirmed by plating on MacConkey No.3 agar and examined for typical colonies. Counts per 100 ml were calculated from MPN tables and expressed as MPN 100 ml-1 (Collins *et al.*, 1998).

3.4.12 Escherichia coli

Escherichia coli were determined following the same procedure for total coliforms in 3.4.10 above. Tubes showing acid and gas production were subjected to further analysis with EC broth (Merck). The EC tubes were incubated at 44°C for 24h. EC positive tubes were confirmed for the presence of *E. coli* by indole production into tryptone water (Merck). Gas and indole production were considered to be positive for the presence of *E. coli* (APHA-AWWA-WEF, 1995).

3.4.13 Salmonella spp

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

3.4.14 Helminth eggs

The helminth eggs enumerated included hookworm, *Ascaris, Schistosoma haematobium, Schistosoma mansoni* and *Trichuris trichiura.* Helminth eggs were enumerated using a combination of the floatation and sedimentation method (Schwartzbrod, 1998). Samples of slurry were diluted into a 2-L container and allowed to stand overnight to enable the eggs to settle completely. As much supernatant as possible was sucked up using a vacuum pump and the sediment placed into tubes and centrifuged for 3 min at 1500 rpm. The supernatant was poured off and the sediment re-suspended with Zinc Sulphate of 1.3 density and homogenized with a spatula. It was again centrifuged for 3 min at 1500 rpm. The Zinc

Sulphate supernatant was poured into a fresh 2 litre bottle and diluted with 1 litre of water. The container was allowed to stand for 3 hours. As much supernatant was sucked up and the sediment re-suspended by shaking and emptied into centrifuge tubes, the bottle was rinsed twice with deionized water and placed into the tubes with the sediment. The tubes were centrifuged for 3 min at 1750 rpm. The sediments were regrouped into one tube and centrifuged again for 3 min at 1750 rpm. The sediment was again re-suspended in about 5 ml acid/alcohol (H_2SO_4+C_2H_5OH) buffer solution and 2 ml ethyl acetate solution. It was shaken and occasionally opened to let out gas. It was then centrifuged for 3 min at 2000 rpm. Much of the supernatant was sucked up leaving less than 1ml of liquid. The deposits were read on a slide using a light microscope. The helminths eggs were identified on the basis of their shape and size compared with the aid of bench aids for the Diagnosis of Intestinal Parasites (WHO, 1994). The counting was done under a light microscope in both chambers of a haemocytometer at X40 magnification.

3.5 Laboratory Analysis of Compost Samples

3.5.1 Temperature

Temperature of compost was recorded in situ at mid mornings at three different locations that is the centre, and the two opposite ends of the composter at varying depths with a long stem mercury in glass thermometer with a temperature range of 0 °C to 100 °C. The thermometer was rinsed in ethanol solution between readings. The mean of all the three individual measurements was recorded as average daily temperature. Average ambient air temperature was also recorded daily. Readings were taken daily for the entire composting period.

3.5.2 pH

The potential hydrogen (pH) ions of the compost sample was measured as described under section 3.4.1.

3.5.3 Total solids

Total dry solids content was determined by weighting 10 g of each sample into a Petri dish and designated W1, oven dried for 24 hours at 105 ^oC and then reweighed, W2. The percentage of total dry solid is then calculated using the formula;

% Total Solids (T S) = $\frac{W2}{W1}\ X\ 100$

This was determined at the end of every week for 8 weeks.

3.5.4 Organic matter and ash content

10 g of compost sample was put into dry porcelain crucible and dried for 24 hours at 105 ^oC. Samples were then transferred into an ignition furnace where the temperature was gradually increased to 550 ^oC and then maintained for 8 hours. The crucibles containing a grayish white ash were removed and cooled in a desiccator and reweighed. The percentage ash and organic matter were then calculated by the differences in weight of the crucibles before and after combustion as follows;

% Ash content = $\frac{W3-W1}{W2-W1}\ X\ 100$

% Organic matter = 100 - ash %

Where W1 = weight of empty dry crucible

W2 = weight of dry crucible containing sample

W3 = weight of dry crucible containing sample after ignition

W3 – W1 = weight of the ash

3.5.5 Moisture content

Ten grammes (10g) of the compost samples were weighed using an electronic precision balance. The samples were dried in an oven for 24 hours at a temperature of 105 ^oC and reweighed. The difference in weight expressed the amount of water in the sample taken. The percentage (%) moisture content was then calculated using the formula:

% Moisture Content = $\frac{W1-W2}{W1}\ X\ 100$

Where:

W1 is the initial weight of sample before drying

W2 is the final weight of sample after drying.

3.5.6 Total organic carbon

The total carbon (TOC) was calculated from volatile solids according to the following equation by Thompson, 2001; Abdullah & Chin, 2010;

%TOC = $\frac{\%VS}{1.8}\ X\ 100$

where VS= volatile solids

3.5.7 Total nitrogen

Total Nitrogen was measured using the Kjeldahl method. 10g air dried compost sample of each pile was weighed into 500ml long-necked Kjeldahl flask and 10ml distilled water added to moisten the sample. One spatula full of Kjeldahl catalyst (mixture of 1 part selenium + 10 parts $CUSO_4$ + 100 parts Na_2SO_4) was added, followed by 20ml conc. H_2SO_4. This was digested until a clear colourless solution was obtained. The flask was allowed to cool, and the fluid decanted into a 100ml volumetric flask and make up to the mark with distilled water.

An aliquot of 10ml fluid from the digested sample by means of a pipette was transferred into Kjeldahl distillation flask. 90ml of distilled water was added to make it up to 100ml in the distillation flask. 20ml of 40% NaOH was added to the content of the distillation flask. Distillate was collected over 10 ml of 4% boric acid and 3 drops of mixed indicator in a 200ml conical flask. The presence of nitrogen gave a light blue colour. Collected distillate (about 100 ml) was titrated against 0.1N HCl till the blue colour changes to grey and then suddenly flashes to pink. A blank determination was carried out without a sample. Weight of sample used, considering the dilution and the aliquot taken for distillation. Nitrogen content was calculated using the formula;

$$\%N = \frac{14\ x\ (V1 - Vo)x\ N\ x\ 100}{1000\ x\ 0.2}$$

Where,

V1=volume of standard HCl used in sample titration

Vo= volume of standard HCl used in blank titration

N=normality of standard HCl

3.5.8 Phosphorus

A standard Phosphate solution was prepared by dissolving 0.2195 g of analytical grade KH_2PO_4 in 1 litre of distilled water with the resultant concentration of 50 µg P/ml. This was used to prepare a standard curve using 0, 1, 2, 3, 4, 5 and 10 ml of the standard solution (50 µg P/ml) in 50 ml volumetric flasks. 10 ml of vanadomolybdate reagent was added to each flask and topped up to the volume to obtain Phosphorus concentrations of 0, 1, 2, 3, 4, 5 and 10µg P/ml respectively. The standard curve was prepared by measuring these concentrations on a spectrophotometer (at 420 nm) and recording the corresponding absorbances.

Using a di-acid digestion method, 0.25 g of each compost samples placed in 100 ml digestion flask and 2.5 ml of the acid mixture (HNO_3 and $HClO_4$ in the ratio 9:4) was added and the contents swirled to mix. The flask with its content was heated on a hot plate under a fume chamber until the production of red NO_2 fumes ceased and the mixture turned colourless. The volume was made up to 100 ml by adding distill water. 5ml of each digest was placed in a 50 ml volumetric flask containing 10 ml of vanadomolydate (Ammonium molybdate). Distilled water was added to make up the volume. The mixture was shaken thoroughly and left to stand for 30 minutes undisturbed. A yellow supernatant solution was read at 420 nm on an

Atomic Absorption Spectrophotometer (AAS). Absorbance observed was used to determine the Phosphorus, P, content as in Potassium above. Thus the concentration of Phosphorus, P, for absorbance obtained for each sample was used to calculate the Phosphorus, P, content as shown below:

Thus, Phosphorus, P, content (μg) in 1 g of sample = C× df

Hence P content (g) in 100g sample (%) = $\frac{C\ x\ df\ x100}{1000000}$

Where:

C = concentration of P (μg/ml) as read from the standard curve

df = dilution factor, which is 400 × 20 = 8000 (because 0.25 g of sample made up to 100 ml; that is 400 times and 5 ml of sample solution made to 100 ml; that is 20 times).

Factor for converting μg to g = 1,000,000.

3.5.9 Potassium

1.907 g of potassium chloride previously dried for 2 hours at 105 °C was accurately weighed. This was dissolved in 1 litre of distilled water. 100 ml of the solution was transferred in a 1 litre volumetric flask to give 100 μg K/ml. This served as the stock solution. 5, 10, 15 and 20 ml of the stock solution was transferred into 100 ml volumetric flasks and distilled water added to make up the volume giving 5, 10, 15 and 20 μg K/ml respectively. Well air-dried and ground of each sample was passed through a 2 mm sieve. 0.25 g of each sample was placed into a 100 ml digestion flask and 2.5 ml of an acid mixture (HNO_3, H_2SO_4 and $HClO_4$ in the ratio 9:4:1) was added and content swirled to mix. The flask with its content was heated on a hot plate under a fume chamber until the production of red NO_2 fumes ceased and the mixture turned colourless. The volume was made up to 100 ml by adding distill water.

A blank was prepared the same without the sample. 5 ml of the aliquot was taken for estimation and made up to 100 ml. Samples were atomized on a calibrated Atomic

Absorption Spectrophotometer (AAS) on which a Potassium standard solution graph had been prepared. The absorbance was recorded for each sample. Thus the concentration of Potassium (K) for absorbance obtained for each sample was used to calculate the Potassium (K) content as shown below:

K content (µg) in 1 g sample = C× df

Thus potassium content (g) in 100g sample (%) = $\frac{C\ x\ df\ x100}{1000000}$

Where:

C = concentration of K (µg/ml) as read from the standard curve

df = dilution factor, which is 400 × 20 = 8000 (because 0.25 g of sample made up to 100 ml; that is 400 times and 5 ml of sample solution made to 100 ml; that is 20 times).

Factor for converting µg to g = 1,000,000

3.5.10 Helminth eggs (Ascaris and Trichuris eggs)

The method used for the determination of *Ascaris* and *Trichuris* eggs in compost sample is as described under section 3.4.14.

3.6 Statistical Analysis

Questionnaires were entered manually using Microsoft Excel 2007. All the data entered were cross-checked manually with the corresponding questions to ensure that data entered were accurate and of high quality. Descriptive statistics using percentages and Chi-square test were used to establish associations between categorical variables. Two tailed tests were used with $p<0.05$ considered significant. In some cases mean differences were compared using Analysis of Variance (ANOVA). The data were tested at 95% confidence level. The study also expressed measured results in terms of means and standard deviation.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Assessment of Faecal Sludge Management in Peri-urban Areas

4.1.1 Demography of respondents

Respondents to the questionnaires consisted of males and females with ages from 20 to 89 years with 28.5% being 30–39 years. The majority of these were married (63.3%), had education at least up to junior high school level (42.6%) with a small proportion (4.4%) engaged by private organizations. Within the study population, 48.5% of the respondents also had a household size of 4–6 with a proportion of these (29.6%) earning less than GHS 100 per month (Table 4-1). Respondents demographic data, when stratified by location, showed that 49.6% of peri-urban dwellers had education up to junior high school level compared to 35.6% of respondents from rural communities ($p=0.0194$) (Table 4-1). Of the respondents, 6.7% of peri-urban dwellers had no formal education compared to their counterparts in rural areas (15.6%) ($p=0.0201$). When the employment status was stratified by settlement type, the results showed that a fewer proportion of respondents in peri-urban areas (11.9%) were subsistence farmers compared to 65.9% in the rural dwelling ($p<0.0001$) (Table 4-1). However, there were more traders in the peri-urban areas (71.1%) compared to 24.4% in the rural ($p<0.0001$). There were about 8% of respondents in peri-urban communities who earned their living working with private organizations compared to less than 2% from rural communities (Table 4-1). The study showed that 41.5% of respondents in the rural areas earned less than GHS 100 per month compared to 17.7% of their peri-urban counterparts ($p<0.0001$).

Table 4-1: Respondents demographic data stratified by type of settlement

Variables	Total 270(%)	Peri-urban, 135(%)	Rural, 135(%)	*p*-value
Sex				
Male	104(39)	49(36)	55(41)	0.2265
Female	166(61)	86(64)	80(59)	0.4530
Age (years)				
20–29yrs	57(21.1)	30(22.2)	27(20.0)	0.6546
30–39	77(28.5)	43(31.9)	34(25.2)	0.2251
40–49	61(22.6)	33(24.4)	28(20.7)	0.4668
50–59	37(13.7)	16(11.9)	21(15.6)	0.3762
60–69	27(10.0)	10(7.4)	17(12.6)	0.1556
70–79	10(3.7)	3(2.2)	7(5.2)	0.1974
80–89	1 (0.4)	0(0)	1(0.7)	0.3164
Marital Status				
Single	63(23.3)	28(20.7)	35(25.9)	0.3138
Married	171(63.3)	93(68.9)	78(57.8)	0.0582
Divorced	7(2.6)	4(3.0)	3(2.2)	0.7017
Separated	8(2.9)	4(3.0)	4(3.0)	
Living-in	3(1.1)	0(0)	3(2.2)	0.0816
Widowed	18(6.7)	6(4.4)	12(8.9)	0.0716
Educational Level				
No formal education	30(11.1)	9(6.7)	21(15.6)	0.0201
Basic	79(29.3)	31(23.0)	48(35.6)	0.0230
Junior high school	115(42.6)	67(49.6)	48(35.6)	0.0194
Senior high school	31(11.4)	20(14.8)	11(8.1)	0.0858
Tertiary	15(5.6)	8(5.9)	7(5.2)	0.7905
Employment Status				
Subsistence farming	105(38.9)	16(11.9)	89(65.9)	<0.0001
Trading	129(47.8)	96(71.1)	33(24.4)	<0.0001
Public service	24(8.9)	13(9.6)	11(8.1)	0.66890
Private organization	12(4.4)	10(7.4)	2(1.5)	0.01820
Household size				
1–3	74(27.4)	31(23.0)	43(31.9)	0.10160
4–6	131(48.5)	69(51.1)	62(45.9)	0.39400
7–9	47(17.4)	27(20.0)	20(14.8)	0.26120
10–12	13(4.8)	6(4.4)	7(5.2)	0.77620
>12	5(1.9)	2(1.5)	3(2.2)	0.65170
Household income(GHS/month)				
<100	80(29.6)	24(17.7)	56(41.5)	<0.0001
100–199	79(29.3)	38(28.1)	41(30.4)	0.68820
200–299	50(18.5)	27(20.0)	23(17.0)	0.53090
300–399	18(6.7)	13(9.6)	5(3.7)	0.05100
400–499	17(6.3)	15(11.1)	2(1.5)	0.00110
>/=500	26(9.6)	18(13.3)	8(5.9)	0.03910

p: *p*-value $p<0.05$ is significant, $p>0.05$ is not significant. Values in parenthesis within the main table represent various %. NA: Question not applicable to respondent, GHS is Ghana cedis. 1 USD= GHS 2.00 (2013).

From the study, female respondents dominated male respondents in both peri-urban and rural areas and this may be due to the high percentage of females in the Ashanti region (GSS, 2012). The age group of majority of respondents suggest the population of the study areas is young and falls within the economically active group (KMA, 2006). The situation of early marriages and early births, mostly in rural and peri-urban communities, cause children to come of age early and start their own families (Adubofour *et al.,* 2012) and this might have impacted on the high percentage of married respondents. The majority of respondents in rural areas involved in subsistence farming compared to peri-urban respondents could have influenced the high proportion of no formal education in the rural communities. These household demographics are consistent with the Ghana Statistical Service report (GSS, 2012). The Ghana Living Standard Survey defines poverty (in terms of economic index) as households subsisting on a monthly income less than GHS 102. The survey found about 18% and 42% of households from peri-urban and rural areas, respectively, as being poor. This, however, did not come as a surprise because the majority of respondents from both peri-urban and rural areas were employed in the informal sector that is either subsistence farming or trading. This assertion is true as the International Labour Organization reported that informal sector employees seldom attract substantial incomes to cater for the needs of their families (ILO, 2004).

4.1.2 Household sanitation practices

The results of household sanitation practices showed that the majority of rural respondents (76.3%) relied on public toilets as their main toilet option compared to 63.0% from the peri-urban areas ($p=0.0172$). The percentage of respondents in the peri-urban communities who used their own toilet (37%) was higher than their counterparts in the rural areas who used their own toilet (15.6%) ($p<0.0001$). Nobody from the peri-urban communities defecates openly, as compared to 8.1% of respondents from the rural communities ($p=0.0007$) (Table

4-2). The study also showed that majority of respondents from peri-urban areas (63.0%) patronized KVIP latrine as compared to the rural respondents (27.4%) ($p<0.0001$). Of the respondents who used a ventilated improved pit (VIP) latrine, 24.4% were from the peri-urban areas while only 7.4% were from rural areas (Table 4-2). The majority of respondents from the rural areas (52.6%) used the traditional pit latrine. Of the respondents from the peri-urban areas, 15.6% had toilet facilities aged from 4–6 years compared to 7.4% of respondents from the rural areas ($p=0.0042$). The results of the study further showed that 63.0% of respondents from peri-urban areas paid some form of user fees before accessing public toilets compared to 7.0% of their rural counterparts ($p< 0.0001$).

Table 4-2: A comparative analysis of respondents household sanitation practices based on location

Variables	Total 270(%)	Peri-urban 135(%)	Rural 135(%)	p-value
Mode of discharge of toilet				
Public toilet	188(69.6)	85(63.0)	103(76.3)	0.01720
Private/household toilet	71(26.3)	50(37.0)	21(15.6)	<0.0001
Open defaecation	11(4.1)	0(0)	11(8.1)	0.00070
Toilet type				
VIP	43(15.9)	33(24.4)	10(7.4)	0.00010
KVIP	122(45.2)	85(63.0)	37(27.4)	<0.0001
Traditional pit latrine	71(26.3)	0(0)	71(52.6)	<0.0001
WC with Septic tank	23(8.5)	17(12.6)	6(4.4)	0.01650
NA	11(4.1)	0(0)	11(8.1)	0.00070
Age of toilet				
1–3	32(11.9)	20(14.8)	12(8.9)	0.13200
4–6	27(10.0)	21(15.6)	6(4.4)	0.00230
7–9	5(1.9)	3(2.2)	2(1.5)	0.65170
10–12	4(1.5)	4(3.0)	0(0)	0.04390
>12	3(1.1)	2(1.5)	1(0.7)	0.56150
NA	11(4.1)	0(0)	11(8.1)	0.00070
Don't know	188(69.6)	85(63.0)	103(76.3)	0.01720
Number of people using toilet				
1–3	15(5.6)	7(5.2)	8(5.9)	0.79050
4–6	36(13.3)	26(19.3)	10(7.4)	0.00420
7–9	18(6.7)	16(11.9)	2(1.5)	0.00060
10–12	3(1.1)	1(0.7)	2(1.5)	0.56150
>12	0(0)	0(0)	0(0)	
NA	11(4.1)	0(0)	11(8.1)	0.00070
Don't know	188(69.6)	85(63.0)	103(76.3)	0.01720
Frequency of visit to toilet in a day				
Once	178(65.9)	91(67.4)	87(64.0)	0.60750
Twice	79(29.3)	43(31.9)	36(26.0)	0.34910
Three times	4(1.5)	1(0.74)	3(2.0)	0.31370
NA	11(4.1)	0(0)	11(8.0)	0.00070
Payment of user fees				
Yes	94(34.8)	85(63.0)	9(7.0)	<0.0001
No	111(41.1)	0(0)	111(82.0)	<0.0001
NA	65(24.1)	50(37.0)	15(11.1)	<0.0001
Cost of public toilet user fee (Gp)				
5	0(0)	0(0)	0(0)	
10	69(25.6)	60(44.4)	9(7.0)	<0.0001
20	25(9.4)	25(18.6)	0(0)	<0.0001
NA	175(64.8)	50(37.0)	125(93.0)	<0.0001

Gp is Ghana pesewas.

Onsite sanitation systems and open defecation were the main mode of toilet discharge in both peri-urban and rural areas. The proportion of peri-urban respondents with household toilets was higher compared to the rural respondents, who used public toilets and other unimproved means of defecation. Similarly, the usage of KVIP and VIP latrines were more in the peri-urban compared to the rural areas. This could be partly due to the availability of more KVIP and VIP latrines in the peri-urban than the rural areas. There was no reported case of open defecation in the peri-urban areas compared to 8.1% in the rural areas. These findings were inconsistent with the results of research carried out by Antwi-Agyei *et al.* (2011), who reported that 4% of people in Madina (peri-urban community) practised open defecation. Education, awareness creation and enforcement of sanitation bye laws might be relevant in addressing the problem of open defecation in rural areas. Adubofour *et al.* (2012), reported that it takes an average of 4.2 years for each toilet pit in Kumasi to fill up, dependent on pit volume and the number of people using it. Interviews and field observations, however, showed that household toilets (KVIP, VIP and WCs with a septic tank) take about 6–10 years to fill up. This study established the low frequency of visits to the toilet by both peri-urban and rural respondents, which is once a day, which could have influenced the variation in pit fill up rate. The toilet user fees charged could partly be the reason for the significant number of rural areas practising open defecation. This confirms the findings of other studies (Keraita *et al.,* 2003) in communities of similar characteristics. Majority of peri-urban respondents paid user fees before accessing public toilets compared to their rural counterparts. This was not surprising as the income levels of participants from the peri-urban communities were higher compared to their rural counterparts. Interviews with some key informants also confirmed that most of the rural areas were poor and could not afford the toilet user charges. These results emphasize the need to provide targeted subsidies for the poor in communities to provide them the opportunity to access public toilets.

4.1.3 Hygienic behaviour and faecal sludge reuse

Analysis of results of hygienic behaviour and FS reuse showed that the majority of respondents in the peri-urban areas (60%) used toilet tissue (Table 4-3). Of peri-urban respondents, 77.8% had their toilets regularly cleaned compared to 16.3% in the rural areas (p<0.0001). About 92% of the respondents reported that they practise hand washing with soap each time after visiting the toilet, compared to 76.3% from the rural areas (p=0.0005). The results showed that none of the respondents reused FS for any beneficial purpose, including agriculture. However, these respondents reported that they would be willing to reuse FS when it is treated for agriculture (Table 4-3).

Table 4-3: Respondents' hygienic behaviours and sludge reuse stratified by settlement type

Variables	Total 270(%)	Peri-urban 135(%)	Rural 135(%)	p-value
Type of anal cleansing material used				
Paper	148(54.8)	54(40.0)	94(69.6)	<0.0001
Toilet tissue	122(45.2)	81(60.0)	41(30.4)	<0.0001
Cleanliness of toilet				
Regular	127(47.0)	105(77.8)	22(16.3)	<0.0001
Not regular	99(36.7)	16(11.9)	83(61.5)	<0.0001
No cleaning	33(12.2)	14(10.3)	19(14.1)	0.35290
NA (open defaecators)	11(4.1)	0(0)	11(8.1)	0.00070
Hand washing with soap after visiting toilet				
Yes	227(84.1)	124(91.9)	103(76.3)	0.00050
No	43(15.9)	11(8.1)	32(23.7)	0.00050
Reuse of sludge for agricultural purposes				
Yes	0(0)	0(0)	0(0)	
No	66(24.4)	50(37.0)	16(11.9)	< 0.0001
NA (no household toilets)	204(75.6)	85(63.0)	119(88.1)	< 0.0001
Willingness to reuse sludge for agricultural purposes				
Yes	221(81.9)	103(76.3)	118(87.4)	0.01790
No	49(18.1)	32(23.7)	17(12.6)	0.01790

Regular: cleaning done twice a day; not regular: cleaning done but not as arranged; no cleaning: no arrangements made for cleaning.

SWASH+ (2009), reported that toilet tissue is the preferred anal cleansing material. A higher proportion of the peri-urban respondents reported using toilet tissue compared to those in the rural areas. People are reluctant to use toilet facilities when the sanitary conditions of the toilets are poor. The proportion of rural dwellers who defecated into the open compared with none from the peri-urban communities could be partly as a result of the lack of regular cleaning of the facilities, which creates bad sanitary conditions. This was also confirmed during key informant interviews in the rural areas. The bad sanitary conditions could be managed by ensuring regular and adequate cleaning of toilets before peak times (usually in the early mornings and evenings). Education and awareness creation could also be essential in addressing the bad sanitary conditions. Hand washing is one of the most effective means of preventing diarrhoeal diseases (Curtis & Cairncross, 2003). Only a few of the respondents from the peri-urban areas risk contracting any diarrhoeal disease since the majority of them reported that they wash their hands with soap each time after visiting the toilet compared to their rural counterparts.

Faecal sludge is reused as compost in low and middle income countries, mainly for the benefits of recycling plant nutrients and enhancing soil characteristics. The study surprisingly showed that none of the households interviewed reused faecal sludge as compost for any beneficial purpose such as agriculture. This is in contrast with previous studies conducted in some households in five farming communities in the Tamale Municipal area where most of the households used faecal sludge as fertilizer on their farms (Cofie, Kranjac-Berisavljevic & Dreschel, 2004). In both the peri-urban and rural areas, respondents indicated that they would be willing to reuse treated faecal sludge for agriculture. The willingness to reuse faecal sludge as compost agrees with the proposal in the Ghana Environmental Sanitation Policy (MLGRD, 2001), which recommends composting as an appropriate faecal sludge treatment method for daily sludge volumes less than 50 cubic metres.

4.1.4 Faecal sludge treatment and disposal

Assessment of faecal sludge management practices revealed that there were no designated disposal and treatment site in the study districts. In the peri-urban areas, only 3.7% of the respondents had desludged their toilets whilst 33.3% have never desludged their toilets. However, of the 33.3% who had never desludged their toilets, 10.3% add chemicals, particularly dichlorodiphenyltrichloroethane (commonly referred to as DDT) and calcium carbide to their faecal sludge. In the rural areas, out of 15.6% respondents with household toilets, none had desludged their toilet whilst 2.2% add chemicals such as DDT and calcium carbide to their faecal sludge (Table 4-4).

Table 4-4: Methods of faecal sludge treatment and disposal stratified according to settlement type

Variables	Total 270(%)	Peri-urban 135(%)	Rural 135(%)	*p*-value
Place of sludge disposal				
Sludge sent to disposal site outside community	5(1.9)	5(3.7)	0(0)	0.02400
Bush	0(0)	0(0)	0(0)	
Buried in pits	0(0)	0(0)	0(0)	
No designated disposal site in community	61(22.6)	45(33.3)	16(11.9)	<0.0001
NA	204(75.6)	85(63.0)	119(88.1)	<0.0001
Treatment of sludge				
Yes	22(8.1)	19(14.0)	3(2.2)	0.00040
No	44(16.3)	31(23.0)	13(9.6)	<0.0001
NA	204(75.6)	85(63.0)	119(88.2)	<0.0001
Method of sludge treatment				
Treatment site/WSP	5(1.9)	5(3.7)	0(0)	0.02400
Chemicals	17(6.3)	14(10.3)	3(2.2)	0.00590
No treatment	34(12.6)	31(23.0)	3(2.2)	<0.0001
NA	214(79.3)	85(63.0)	129(95.6)	<0.0001
Desludging of toilet facilities				
Yes	5(1.9)	5(3.7)	0(0)	0.02400
No	66(24.4)	45(33.3)	21(15.6)	0.00070
NA	199(73.7)	85(63.0)	114(84.4)	<0.0001
Mode of desludging				
Manual labour	0(0)	0(0)	0(0)	
Mechanical	5(1.9)	5(3.7)	0(0)	0.02400
NA	265(98.1)	130(96.3)	135(100.0)	0.02400

Faecal sludge treatment and disposal is a principal component of environmental sanitation. There were no designated locations for the disposal and treatment of faecal sludge in both rural and peri-urban areas. However, none of the respondents disposed of faecal sludge indiscriminately into the environment, which was also confirmed by field visits and interviews with the assembly men. A few of the peri-urban respondents dispose of faecal sludge at an approved location, 40 km outside the communities. This is because there are no cesspit emptying operators in the communities. Although results from the study showed that about one-third of peri-urban dwellers had not desludged their household toilet facilities, field observations revealed that 31% of those who had their toilets full (VIP toilets) required immediate desludging. Similarly, 42% of rural dwellers who had not desludged their household toilets actually had their toilets full. The few peri-urban respondents who used a WC with septic tank desludged their toilets mechanically. Households who had not desludged their toilets did not consider either manual or mechanical desludging as an immediate remedy. Rather, they preferred to close and abandon the toilet and resort to the use of public toilets at a fee (peri-urban 63%; rural 11%) or practise open defecation (peri-urban 37%; rural 89%). Potentially decentralized FS treatment facilities could be located close to the poor communities to reduce the cost of desludging. Households complained of high mechanical desludging fees of GHS 200–400 per trip, as a result of which they resorted to using public toilets at a fee or abandoned the toilet. Moreover, manual desludging was not a preferred option for all the households due to its associated challenges, though it was a cheaper option compared with the mechanical method. The challenges were that the method was not aesthetically pleasing, the toilet cannot be used while desludging, it usually takes about 3–5 days, operators normally lack appropriate equipment, and the attendant health risks associated with it. For manual FS removal, the sludge is removed by using a bucket tied to a rope and the content transferred into pits and buried. Desludging is done usually by 2–4 men who charge GHS 150–300 for household VIP toilets. The public toilet attendants from the study areas indicated that the toilets were desludged on an average frequency of 1–2 year intervals, dependent on user population and rate. Although accessibility to public toilet facilities was not a problem, mechanical desludging operators could not operate effectively due to the disposal of materials such as plastics, bottles and stones into the pit which clogs the pipes and hoses of the emptying trucks and often cause it to breakdown. Majority of public toilets (6/8) were therefore manually desludged and the process usually lasted for 8–14 days per toilet facility. During this period, the toilet is closed to public use and individuals are left to find other means of defecation. Manual operators charge fees of GHS 800–1,800 for desludging one public latrine compared to GHS 1,200–2,100 for mechanical desludging. It takes about 4–7 trips for trucks to fully empty a public toilet. The mode of desludging largely depended on the characteristics of the sludge, whether dry or wet. Disposal of unapproved materials into toilet pits could be addressed by educating users on the effects of the act and enforcement of sanitation bye laws. The cost of desludging (either manual or mechanical) was not fixed as it depended on the location of the toilet relative to the disposal site, difficulty of sludge removal and the volume of the truck. The trucks usually used for the mechanical desludging had a capacity of 5–8 cubic meters. With regards to the treatment of faecal sludge, respondents preferred to use chemicals, particularly dichlorodiphenyltrichloroethane (commonly referred to as DDT) and calcium carbide which they claim reduce sludge volume, thus reducing the filling up rate and extending the life of the pit. According to Bakare *et al.* (2010), there is a lack of theoretical evidence for the efficacy of chemical additives for the treatment of sludge although respondents claim that their experience in the field has proven their worth. The use of chemical additives, however, affects a wide range of naturally occurring bacteria which feed on the faecal sludge thereby slowing the rate of sludge decomposition. A meaningful research into the performance of toilet additives is needed to inform its users.

4.2 Perception of Peri-Urban Farmers on Faecal Sludge Compost and its Utilization

4.2.1 Socio-economic characteristics of farmers

Results of the socio-economic characteristics of farmers are presented in Table 4-5. All of the respondents were males, which is not surprising considering the fact that agriculture in Ghana is dominated by males (GSS 2012). Majority of farmlands (90%) were owned by men with the remaining 10% being owned by females. The results support the study by Masterson (2007) who noted that in many parts of the world women have the least probability of owning land. The study showed that majority of farmers (55%) were within the age range of 25–40 years. This age was found to be lower than the national average of 45 years for farmers in Ghana (Nimo *et al.,* 2014). This age group indicates that the majority of the farmers are young and fall within the economically active group. The level of education among the farmers was low, with 4% and 24% having no formal education and basic/primary education, respectively. The corresponding figures for secondary education, junior high school (JHS) and senior high school (SSS) were 19% and 16%, respectively, with only 2% having some form of tertiary education. This was, however, not surprising as farming in Ghana is perceived to be the work of the less educated who are into small scale farming as a way of living (Anyidoho *et al.,* 2012). The study revealed that majority of the farmers (82%) were the main breadwinners of their family, whereas the remainder were not the breadwinners. This variation may be promoted by culture of the communities that enjoins males to assume headship of families (Owusu-Boateng & Amuzu, 2013). Farming in the peri-urban areas are classified under the informal sector as individual household's farm using primitive tools. Consequently, profits per planting season were low for most farmers, ranging from GHS 100–199 (27%), GHS 200–500 (32%), to more than GHS 500 (41%) (Table 4-5). The farmers (88%) claimed that the profits earned were below their expectation of not less than GHS 1000 per planting season. It is worth noting that the rate of increase in the profit margins increased with increasing size of the farm. The profits made by the farmers, however, is consistent with the report by the International Labour Organization, which has shown that informal sector employees seldom attract substantial incomes to cater for the needs of their families (ILO, 2004).

Table 4-5: Respondents demographic characteristics

VARIABLE	FREQUENCY (n=150)	PERCENTAGE (%)
Sex of Respondent		
Male	150	100
Females	0	0
Age (Years)		
<25	46	30.7
25-40	83	55.3
>40	21	14
Educational Level		
No formal education	59	39.3
Basic/Primary	36	24
JHS	29	19.3
SSS	24	16
Tertiary	2	1.3
Main breadwinner of family		
Yes	123	82
No	27	18
Total Income per planting Season (GHS)		
100-199	41	27.3
200-500	48	32
>500	62	41.3

GHC 3.22 is equivalent to USD 1

4.2.2 Farming practices and type of fertilizer used by farmers

Majority of respondents (farmers) in the study were either into vegetable (82%) or both vegetable and food crop (18%) farming and had been farming for more than 4 years (63%). The farm land ownership scheme in the study area was mainly of the leasehold type (temporary ownership) and farmers often cultivated lettuce and cabbage with other vegetables depending on which vegetable was mostly patronized within the area. A larger proportion of these farmers were farming on small (67%) to medium (31%) farm land. This could be partly due to the lack of adequate financial resources and also the scarcity of land in these areas as a result of urban sprawl. All of the farmers interviewed applied some form of organic or inorganic fertilizer on their farms. The choice of type of fertilizer was guided by its effectiveness in increasing the yield of crops. Fertilizers were purchased from poultry farms, cesspit emptiers (organic fertilizers), and chemical retail shops (inorganic fertilizers).

The results showed that 28% and 51% of farmers used organic and inorganic fertilizers, respectively, while 21% of the farmers used both organic and inorganic fertilizers on their farms. Vegetable crop yields were higher for farmers who used inorganic fertilizers compared to those using only organic and both organic and inorganic fertilizers. This result is corroborated by Blatt (1991) and Lee (2010), who reported that crop yields in fields treated with organic fertilizer are lower than in those treated with inorganic fertilizers. Yields of vegetable crops in the areas studied ranged from less than 6–55 bags for small to large farms. The percentage of annual vegetable crop yield per acre of farmland recorded for each type of fertilizer used is presented in Figure 4-1. The farmers claimed that, from experience, applying a lot of inorganic fertilizer although may increase crop yield, it however reduces the storage time of crops. This assertion is consistent with the conclusion reached by Granstedt & Kjellenberg (1997), in a research where they treated plants (summer wheat, clover/grass, potatoes and beets) with organic fertilizer and other plants with inorganic fertilizer. At the end of the experiment, the plants treated with organic fertilizer had a greater ability to tolerate stressful conditions and long-term storage in comparison with those treated with inorganic fertilizer. The analysis of choice of fertilizer by the number of years of farming showed some variations. For farmers with 3 years of experience, 50% use only organic sources of fertilizer, 16.7% use both organic and inorganic sources of fertilizer, and 33.3% apply only inorganic sources of fertilizer to their farms. Majority of farmers (62.5%) with 4 years of experience use only inorganic sources of fertilizer, 12.5% use only organic sources of fertilizer, and the remaining 25% use both organic and inorganic sources. The use of inorganic fertilizer is predominately seen to be adopted by farmers with farming experience from 2 years or more years ($P=0.015$) (Figure 4-2). This could probably be a result of farmers' previous experience with using organic fertilizers in the form of poultry droppings, which they claim produce a lower yield compared to inorganic fertilizers. The choice of type of fertilizer could be influenced by the level of formal education of the farmer. This was evident as further questioning showed that farmers who had no or little formal education (40%) used inorganic fertilizer upon the advice of agriculture extension officers. These farmers held the extension officers in very high esteem. The reason is that they consider the agricultural extension officers to be experts, and as such follow their advice with the hope that they bring them up to date with all new technologies in farming. The cost involved in applying a particular type of fertilizer was analyzed. According to the farmers who use organic fertilizers, the average cost incurred during their application on small- to medium-scale farms is mostly the transportation cost, which ranged from GHS 20–40. Meanwhile, majority of the farmers who apply inorganic fertilizer to their farms spend more than GHS100 on the purchase of inorganic fertilizer (Figure 4-3).

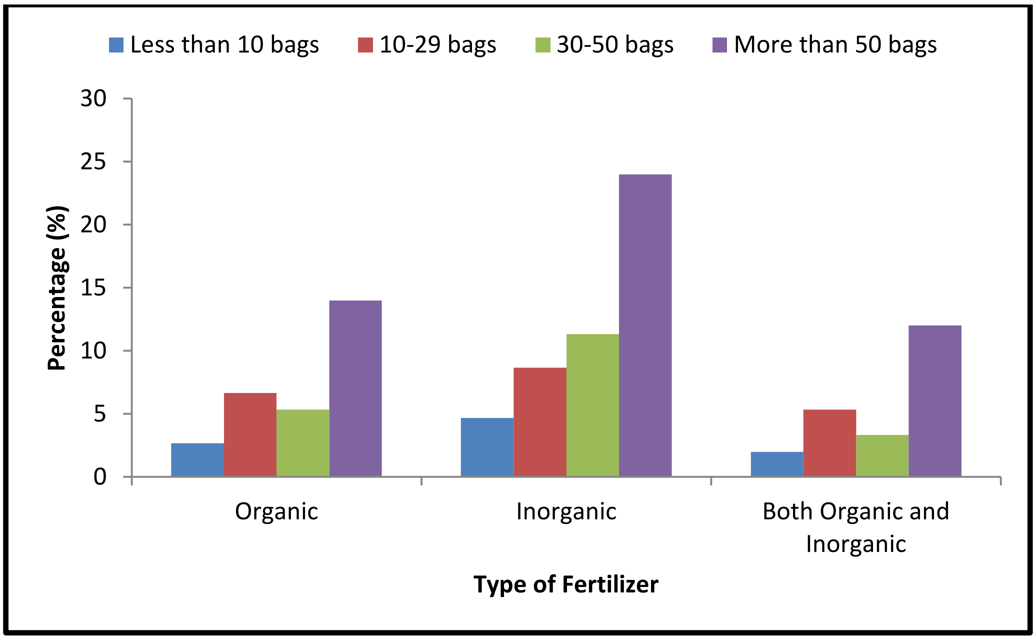

Figure 4-1: Annual vegetable crop yield by type of fertilizer per acre of farm land. A bag is equivalent to 50Kg

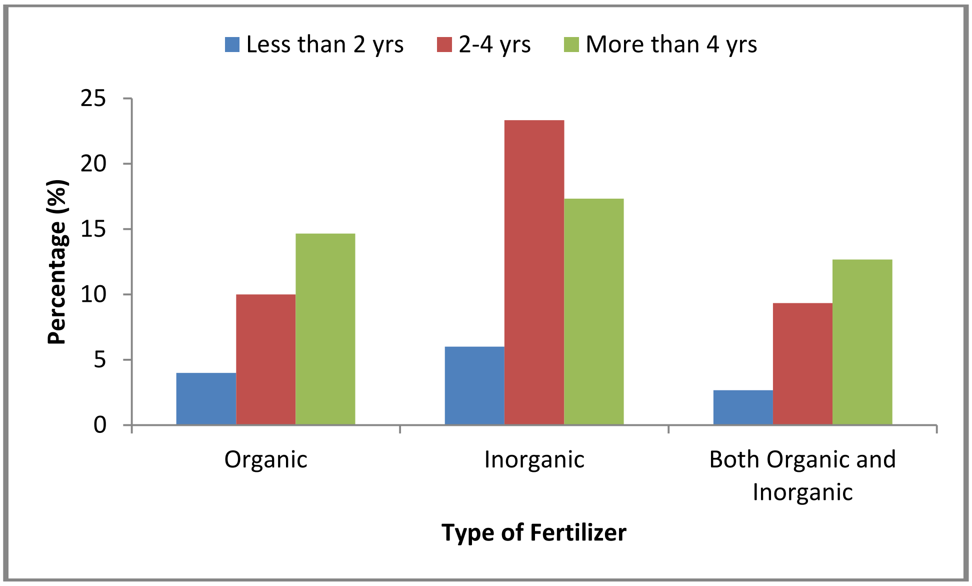

Figure 4-2: Choice of fertilizer by years of farming

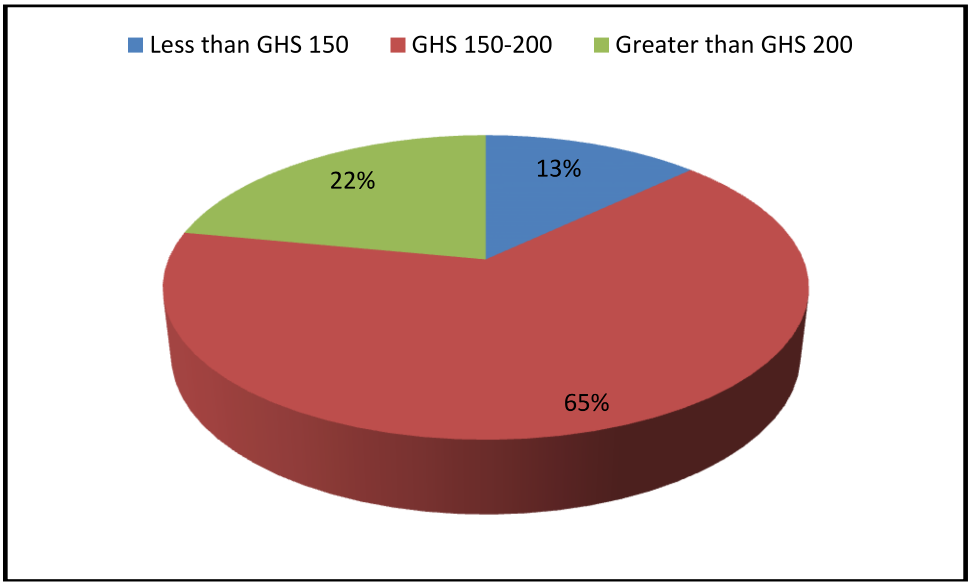

Figure 4-3: Cost of applying inorganic fertilizer per acre of farm land

4.2.3 Assessment of farmers' knowledge on faecal sludge compost and its utilization

Farmers' knowledge on the use of faecal sludge as compost were assessed during the study. Only 34% of the farmers responded that they were aware that faecal sludge is a useful source of fertilizer. Majority of farmers (65%) obtained information on faecal sludge compost from fellow farmers, while (8%) of them obtained information from Agric extension officers who visited their farms once in a while. The remaining 27% of the farmers obtained information on faecal sludge compost from the media (especially television and print media). The lower percentage of farmers' awareness on using faecal sludge compost suggested that the capacity of farmers could be built to promote the use of organic fertilizers in a proper and safe manner. Only 4% of the farmers who used organic fertilizers used faecal sludge to fertilize their farms. The preferred type of faecal sludge in use was the partially stabilized sludge from septic tanks. The motivation for the use of this type of organic fertilizer was its effect in improving the productive capacity of the soil leading to higher crop yields. Meanwhile, some of the farmers (20%) used other forms of organic fertilizer (poultry droppings, cow dung) to fertilize their farms. However, 32% of the farmers who were aware of faecal sludge compost were willing to use it to fertilize their farms on condition that they did not handle the fresh sludge. The remaining 68% were not willing to use faecal sludge no matter how it was presented. The high percentage of farmers unwillingness to use faecal sludge as compost could be a result of the general perception and attitude of most Ghanaians towards anything related to faecal sludge as a negative one (Nimo *et al.,* 2014). Another reason reported by the farmers was the unavailability and ease of access to faecal sludge compost ($P<0.0001$). The majority of farmers (80%) also believed that faecal sludge compost could be a cheaper alternative to the rising cost of inorganic fertilizers. According to many of the farmers, health risk is not the most discouraging factor but rather the social rejection associated with the handling of faecal sludge ($P<0.0001$). A cross tabulation of educational level of farmers was examined against farmers' knowledge on faecal sludge compost. The results showed that the proportion of farmers with some knowledge on faecal sludge was higher among those with formal education and this was significant at $P=0.004$ (Figure 4-4). This could be due to the appreciation of the current awareness created on faecal sludge reuse by extension officers who periodically visited these farmers. This meant that the usage of faecal sludge compost was likely to be driven by the level of knowledge a farmer has on the compost, which could probably be linked to the level of education acquired. Farmers below the age of 25 years appeared to be more informed of the fact that faecal sludge was a good source of fertilizer (P=0.001) (Figure 4-5). This could be attributed to the fact that most of the youth were exposed to current trends in farming. The results obtained generally confirmed the findings of Mariwah & Drangert (2011), that education seems to have an effect on the perception of people about reuse of faecal sludge.

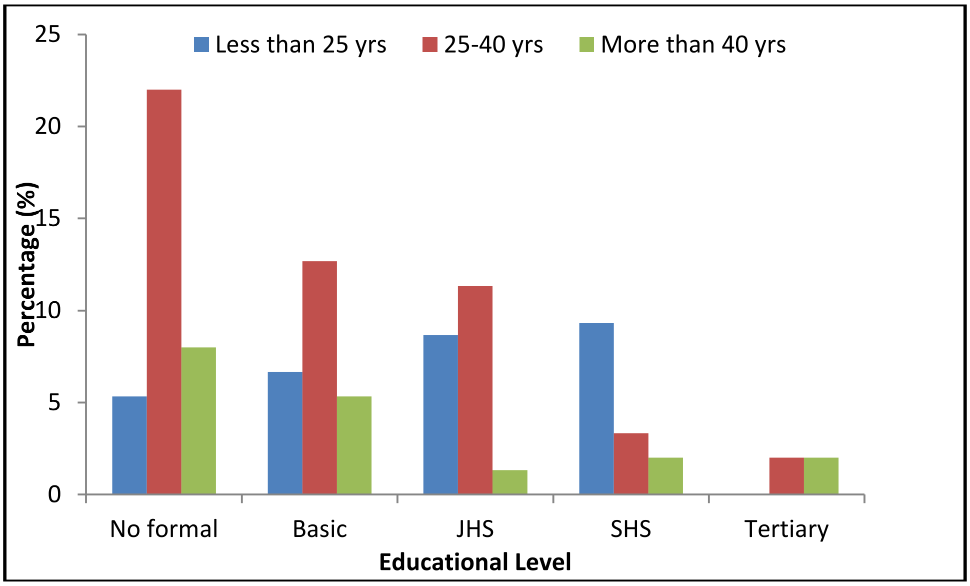

Figure 4-4: Farmers knowledge of FS as fertilizer against their educational level

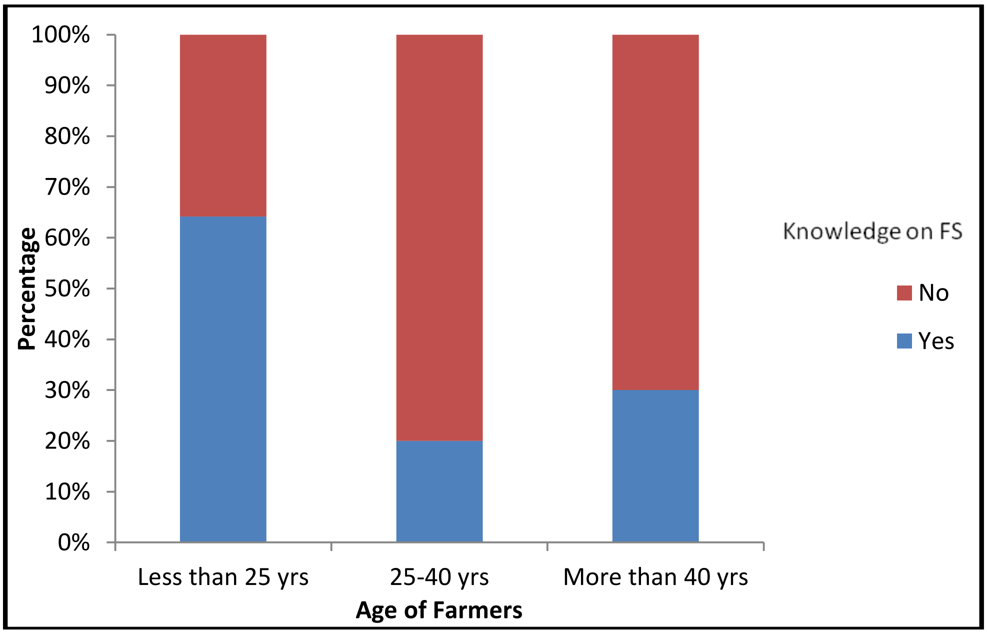

Figure 4-5: Farmers knowledge of FS against different age groups

4.2.4 Socio-cultural and health issues associated with faecal sludge compost

The socio-cultural and health issues associated with faecal sludge compost of the farmers toward its reuse were assessed. The results of the study showed no particular cultural beliefs against the use of faecal sludge. This was not consistent with a study by Mariwah & Drangert (2011), where 50% of peri-urban residents would not use faecal sludge compost based on some taboos. The acceptance of the various taboos might have informed many of the farmers not using faecal sludge compost (Mariwah & Drangert, 2011). This outcome was consistent with Ajzen's theory of planned behaviour, which explained how beliefs influence the way people behave (behavioural beliefs) (Ajzen's, 2002). Meanwhile, some social sayings such as "a chamber pot is still a chamber even if it is new" and "only vultures eat faeces" have come to stay due to the social perception that have developed over centuries. Farmers (30%) showed some concern about the fear of contracting diseases from the use of faecal sludge compost on their farms. However, health risk was not the main reason why most of the farmers do not use faecal sludge compost, rather the negative perception of the society that faecal sludge was total waste and therefore must not be used (Figure 4-6). This result did not concur with the findings by Cofie *et al.* (2010), who indicated that, although farmers considered faecal sludge as a resource in agriculture, the most important factor that prevented them from using faecal sludge as fertilizer was the perception on the health risks associated with its reuse. The most prominent factor responsible for the negative attitude of farmers (70%) towards the use of faecal sludge compost to fertilize their farms was the perception that faecal sludge must not be used in any form whatsoever. This was not consistent with Tsiagbey *et al.* (2005), who noted that a majority of households in peri-urban and urban communities in Ghana perceived excreta reuse as positive towards achieving household food security. About 30% of the farmers thought that the use of faecal sludge compost could cause significant health problems to both the farmer and the consumer. The majority of these farmers (69%) did not observe any health safety measures whereas the remaining, 31%, observed health and safety measures by wearing protective clothing. Gloves, Wellington boots, nose masks, and long-sleeved shirts and trousers were the main protective clothing used by farmers during fertilizer application. This might be attributed to the disregard for safety measures (Owusu-Boateng & Amuzu, 2013) during fertilizer application. However, all of the farmers who had used faecal sludge compost reported no known health risks caused by faecal sludge compost. Perhaps this could have informed the large patronage of faecal sludge fertilized foods in many countries, including Japan, China, and Sweden (Esrey *et al.,* 1998). This confirmed several studies conducted by researchers that a well composted faecal sludge is free of pathogens and could be used without any health implications (Kone *et al.,* 2010).

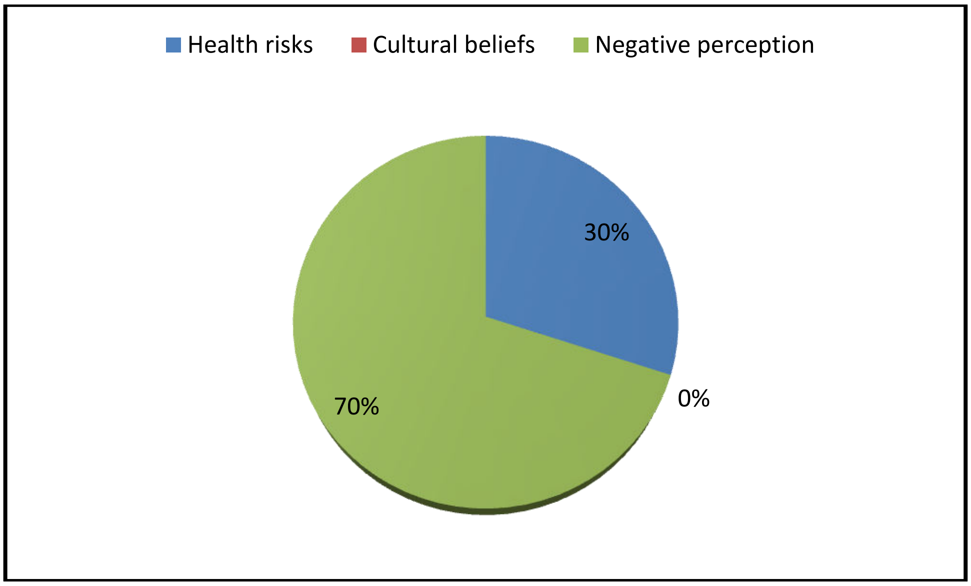

Figure 4-6: Factors affecting faecal sludge use as fertilizer.

4.3 Characteristics of Faecal Sludge from Public Latrines

A summary of analysis of results of characteristics of faecal sludge in terms of physico-chemical, heavy metals and microbial constituents from peri-urban and rural areas is presented in Table 4-6.

Table 4-6: Summary analyses of faecal sludge Characteristics (Number of samples= peri-urban 6,; rural areas 6)

		Peri-urban				Rural				
Parameter	**Unit**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	***p Value***
pH		6.7	0.18	6.4	6.9	7.3	0.57	6.6	8.1	*0.1073*
EC	µS/cm	26,952	5,643	20,101	35,342	26,564	3457.17	23,562	31,561	*0.9008*
TS	mg/l	66,370	10,422	53,720	82,045	65,152	12490	49,850	84,550	*0.7885*
TVS	% of TS	77	1.66	75	79	80	2.23	77	83	*0.1230*
BOD_5	mg/l	11,835	4,034	8,415	19,621	41,363	11,314	26,210	58,351	*0.0011*
COD	mg/l	85,998	12,305	71,206	99,621	105,679	17,930	80,004	125,531	*0.0141*
NH_3-N	mg/l	2,568	337	2,175	3,148	2,431	730	1,890	3,875	*0.6714*
NO_3-N	mg/l	822	198	501	1,089	710	193	480	998	*0.3215*
TKN	mg/l	4,083	508	3,490	4,845	4,218	817	3,524	5,565	*0.6858*
K	mg/l	950	316	623	1,524	963	299	528	1,384	*0.9583*
P	mg/l	2,088	1,000	993	3,831	1,626	714	879	2,832	*0.3270*

±= Standard Deviation (SD), p: p-value $p<0.05$ is significant, $p>0.05$ is not significant.

4.3.1 pH

The pH value of sludge is very important especially when the sludge is to be used for beneficial purposes such as compost. The measured pH values ranged from 6.4-7.3 and 6.6-8.1 for peri-urban and rural sludge respectively (Table 4-6). The mean values and the standard deviation were 6.7±0.18 and 7.3±0.58 for peri-urban and rural communities respectively. This indicated that faecal sludge from peri-urban was slightly acidic and that of rural, alkaline. The lower pH from peri-urban areas could be due to the formation of acidic biodegradation products. Lower moisture content as well as regular cleaning of toilet with acid containing detergents could have contributed to lower pH of faecal sludge from peri-urban areas compared to that of rural areas. A study to characterize faecal sludge in Kumasi by Doku (2002) and Kuffour *et al.* (2013) respectively, gave a mean pH of 8.3 and 7.77 which were slightly higher than what was measured during this study (Appendix C). However, the mean pH values of sludge from both peri-urban and rural communities fell within a pH range of 6.5 to 9.0 recommended for biological degradation of organic matter by microorganisms WHO/UNICEF (2012). This meant that most pathogenic microorganisms could show maximum growth and activity (NRAES, 1992). This indicated that when sludge is discharged into the environment, the soils pH might not be adversely affected thus activities of microorganisms in the soil will not be affected. Comparing the changes in hydrogen ion concentration, there existed no significant difference between faecal sludge from peri-urban and rural areas ($p=0.1073$) (Table 4-6).

4.3.2 Electrical conductivity (EC)

The EC values reflect the degree of salinity in sludge indicating its possible phyto-toxic effects on the growth of plants if applied to the soil (Zhang *et al.,* 2005). The results showed that the EC values for peri-urban areas ranged from 20,101-35,342 uS/cm and 23,562-31,561 uS/cm for rural areas (Table 4-6). The mean EC values measured in the peri-urban areas were 26,952±5643 uS/cm and 26,564±3457 uS/cm for rural areas (Table 4-6). The EC values measured were similar to previous studies by Kuffour *et al.*(2013) (Appendix C). Although the measured EC values were high, there was no significant difference between faecal sludge from peri-urban and rural areas. The higher EC values could be as a result of higher concentration of dissolved salts in the sludge (Kiely, 1998). This might cause osmotic stress in plants when applied directly into the environment without any prior treatment.

4.3.3 Total solids (TS)

Faecal sludges typically have very high total solid contents which normally comprise of suspended and dissolved solids. Mean TS were about the same for both peri-urban and rural areas. The measured TS values for the 6 samples ranged from 53,720-82045 mg/l and 49,850-84,550 mg/l for peri-urban and rural areas respectively (Table 4-6). These values were generally high compared to that obtained by Doku (2002) and Kuffour *et al.*(2013) (Appendix C). This could be an indication that sludge from peri-urban and rural areas have high contaminant load and sludge might have been stored for a few days or weeks only (Strauss *et al.,* 1997). This meant that faecal sludge might be harmful and therefore required further treatment before sludge could be discharged directly into the environment such as into water bodies to protect aquatic life. There was no significant difference between TS from peri-urban and rural areas (p=0.7885).

4.3.4 Total volatile solids (TVS)

Total volatile solids is that portion of the total solids which are volatilized at 550 ^{o}C. From the study conducted the total volatile solids content was measured to determine the organic fraction of total solids. TVS was calculated as a percentage of TS. Faecal sludge from the peri-urban areas contained 75-79% TVS whereas that of the rural areas ranged from 77-83%. The mean TVS were 77±1.664 % and 80±2.23 % for peri-urban and rural areas respectively (Table 4-6). The results showed generally high levels of TVS compared to values obtained by WRRI and SANDEC (1994) (Appendix C). TVS of faecal sludge from rural areas was higher compared to that of peri-urban areas and this could be as result of high organic matter content. This meant that there would be enough food for microorganisms thereby improving the performance of the stabilization process in the rural sludge than the peri-urban sludge. Calculated values of TVS from peri-urban areas was not significantly different from FS from rural areas (Table 4-6).

4.3.5 Biochemical and chemical oxygen demand

Biochemical Oxygen Demand (BOD) refers to the amount of oxygen that would be consumed if all the organics in one litre of water were oxidized by bacteria and protozoa. The biochemical and chemical oxygen demand for sludge samples were measured. Mean BOD_5 values measured were 11,835±4,034 mg/l and 41,363±11,314 mg/l for peri-urban and rural areas respectively (Table 4-6). The high level of BOD_5 from rural areas could be as result of the oxidation of the organic waste in the faecal sludge by natural microorganisms (Beruch, 1993). The high BOD_5 levels was an indication of decline of dissolved oxygen levels. This meant that the demand for oxygen by microorganisms will be high which might affect the number of microorganisms present to decompose faecal sludge. The mean BOD_5 value for peri-urban areas was in line with the study by WRRI & SANDEC (1994). Also mean BOD_5 of rural sludge was consistent with the range of values obtained by Doku (2002) and Strauss *et al.* (1997). Although there were variations in measured BOD_5 values across the study areas which were high, values fell within the range of measured values from Kumasi, that is up to 52,000 mg/l (Appendix C). However, there was a high significant difference, $p=0.0011$, for BOD_5 values peri-urban and rural areas.

When faecal sludge samples were analysed, the mean COD values measured were 85,998±12,305 mg/l and 105,679±17,930 mg/l for peri-urban and rural areas respectively (Table 4-6). There was a significant difference between mean COD values measured from peri-urban and rural areas. The higher values of COD could be influenced by higher concentrations of non biodegradable organic matter in the sludge which indicates the presence of biologically resistant organic substances (Sawyer & McCarty, 1978). The high values of COD meant that large amounts of oxygen would be required by micro-organisms to decompose the organic matter content of the sludge. The COD values were in line with the study of WRRI & SANDEC (1994) and Doku (2002), who reported a range of values of 10,400-97,000 mg/l and 36,600-175,000 respectively (Appendix C).

The COD/BOD_5, were determined as ratios 7/1 and 3/1 for peri-urban and rural areas respectively. This results indicated the presence of poorly degradable substances in the sludge as it is largely composed of slowly biodegradable organic contaminants (Quano, 1978). This could be due to the practice of disposing plastics, glass and other unapproved materials into the toilet thereby inhibiting biological oxidation. BOD_5 and COD values were observed to be too high for direct discharge into the environment. The concentrations of COD were several (10-100) times the strength of sewage (Strauss *et al.,* 1997). The COD/BOD_5 ratio were consistent with values measured by Doku (2002), during the characterisation of night soil/faecal sludge in Kumasi.

4.3.6 Nutrients

The range of values obtained from the analysis of Ammonia-Nitrogen (NH_3-N) were 2,175-3,148 mg/l for peri-urban and 1,890-3,875 mg/l for rural sludges (Table 4-6). The mean NH_3-N values were 2,568±337 mg/l and 2,431±730 mg/l for peri-urban and rural respectively (Table 4-6). The Nitrate-Nitrogen (NO_3-N) values of faecal sludge were observed to be in the range of 501-1,089 mg/l with a mean of 822±198 mg/l for peri-urban sludge. Measured values of NO_3-N for rural areas ranged from 480-998 mg/l with a mean of 710±193 mg/l (Table 4-6). There was no significant difference between values measured for peri-urban and rural areas.

Analysis of TKN showed that values ranged from 3,490-4,845 mg/l with a mean value of 4,083±508 for peri-urban areas (Table 4-6). Similarly TKN values ranged from 3,524-5,565 mg/l with a mean of 4,218±817 mg/l for rural areas (Table 4-6). The high values of NH_3-N, NO_3-N and TKN might have been as a result of the ammonification and mineralization of organic nitrogen in faecal sludge (Epstein, 2003). The higher values of NO_3-N could partly be due to greater rate of oxidation, while lower values were obtained due to lowering in oxygen, which reduced the rate of the oxidation (Tikariha & Sahu, 2014). The high nitrogen in faecal sludge could serve as good basis for its application in the soil for crop production or as a good compost material (Kuffour *et al.,* 2013).

Potassium (K) and Phosphorous (P) are essential nutrients for plant growth. K obtained from analysis of faecal sludge samples ranged from 623-1,524 mg/l and 528-1,384 mg/l for peri-urban and rural areas respectively (Table 4-6). Although there was no significant variations of measured K from peri-urban and rural areas, values were generally high. P values measured fell within the range of 993-3,831 mg/l for peri-urban and 879-2,832 mg/l for rural areas. Mean P values measured from peri-urban areas were much higher than that from rural areas (Table 4-6). The high P could be due to the use of detergents for cleansing of toilet (Awuah *et al.,* 2002). This high P content would tend to immobilize other chemical elements such as zinc and copper which are also essential for plant growth (Chang *et al.,* 1983).

4.3.7 Heavy metals

Although copper (Cu) as a heavy metal is essential for human health, too much of it can cause significant health problems. The measured concentrations of Cu in peri-urban areas were generally variable where as those of rural areas were fairly constant (Figure 4-7). The mean concentrations (±standard deviation) of Cu were 3.978±0.439 mg/l and 0.339±0.039 mg/l for peri-urban and rural areas, respectively ($p<0.0001$) (Table 4-7). The measured concentrations of Cu were higher in the peri-urban sludge compared with that of the rural. This could be attributed to the leachates from the solid waste dump sites mostly located near the public toilets in peri-urban areas. The Cu metal might have come from disposal of waste from petrochemicals and agro-based industries, which contain pesticides and fertilizer residues (Pierce *et al.*, 1998). The levels of Cu could also be as a result of natural (wind-blown dust, decaying vegetation, forest fires) or human-induced (mining, industrial works, agrochemicals) activities.

On the basis of iron (Fe) concentrations, recorded mean values ranged from a minimum of 2.166 mg/l to a maximum of 2.723 mg/l for peri-urban areas and a minimum of 0.872 mg/l to a maximum of 0.968 mg/l for rural areas (Table 4-7). The presence of iron could be as a result of infiltration as rainfall seeps through the soil and dissolves iron in the earth's surface and carries it into the toilet pits (Dima *et al.,* 2006). The mean levels of lead (Pb) measured were higher in the peri-urban sludge compared to that in the rural areas (Table 4-7). The presence of Pb in the sludge could be as a result of the disposal of unapproved materials such as lead-acid batteries, rubber and plastics which are disposed of into toilet pits. The results on faecal sludge management in low income areas revealed that users of public toilets dispose of materials such as plastics, bottles and stones into the pit. The levels of Pb might also be due to leachate from the dump sites usually located close to public toilets, where used motor oils and discarded electronic gadgets, including televisions, calculators and stereos (Woodbury, 1992) are disposed of. There were variations in levels of Pb across the different sampling periods (Figure 4-7).

The results indicated higher levels of cadmium (Cd) in peri-urban areas compared to the rural areas ($p<0.0002$) (Table 4-7). In the environment, cadmium is reported to be toxic to especially animals and microorganisms. The observed levels of Cd in the faecal sludge might be from diffuse sources such as food products, paint products, detergents and body care products, and storm water (Ulmgren 2000a, 2000b). Leachate from dump sites which may contain disposed nickel-cadmium batteries and plastics stabilized with cadmium could also contribute to the levels of Cd. The mean concentrations of 2.235±0.102 mg/l and 1.291±0.096 mg/l were measured for peri-urban and rural areas, respectively, for zinc (Zn) (Figure 4-8). The presence of Zn in the sludge might be due to deodorants and cosmetics disposed off at the dump site usually located close to the public toilet. More Zn was observed in the peri-urban sludge compared to that of the rural. This could be true as more blacksmiths were identified in the peri-urban areas compared to the rural areas.

Analyses of faecal sludge samples showed the levels of manganese and arsenic in the peri-urban areas to be 4.571±0.320 mg/l and 0.152±0.027 mg/l, respectively (Figure 4-8). However, the concentrations of manganese (Mn) and arsenic (As) were respectively 0.992±0.160 mg/l and 0.025±0.005 mg/l for rural areas (Table 4-7). The presence of Mn in sludge could be as a result of atmospheric deposition and wash off from plants and other surfaces. Arsenic concentration in faecal sludge is of importance due to its potential effects on humans and other living organisms. The levels of As might be due to the use of washing products for the cleaning of the toilets and medicines which may be disposed of into toilet pits. Soil particles could also contribute to the concentration of As as it contains relatively high contents of As (Guillemet *et al.,* 2009).

The concentrations of heavy metals in mg/l of faecal sludge from rural areas were significantly less compared to those obtained for peri-urban areas and were all much lower than the maximum soil metal concentrations for land application of biosolids (Webber & Sidhwa, 2007). The concentrations of the heavy metals were observed in the order of Mn>>Cu>>Fe>>Zn>>Pb>>As>>Cd and Zn>>Mn>>Fe>>Cu>>Pb>>As>>Cd for peri-urban and rural areas, respectively. These present results of heavy metals' concentrations in the sludge agree with other studies reporting similar contaminations levels (Kuffour *et al.,* 2013).

Table 4-7: Summary of analyses of heavy metals concentration in faecal sludge

Parameter	Peri-urban				Rural				
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	***p value***
Cu	3.978	0.439	3.415	4.681	0.339	0.035	0.279	0.370	<0.0001
Fe	2.492	0.256	2.166	2.723	0.930	0.040	0.872	0.968	<0.0001
Pb	0.160	0.053	0.109	0.241	0.050	0.005	0.042	0.056	0.003
Cd	0.045	0.005	0.039	0.051	0.013	0.004	0.010	0.021	0.0002
Zn	2.235	0.102	2.042	2.325	1.291	0.096	1.247	1.488	<0.0001
Mn	4.571	0.320	4.387	5.216	0.992	0.160	0.851	1.290	<0.0001
As	0.152	0.027	0.113	0.194	0.025	0.005	0.020	0.031	<0.0001

Parameters measured in mg/l, ±SD (standard deviation), Min = minimum, Max = maximum, *p*-value: $p < 0.05$ is significant, $p > 0.05$ is not significant.

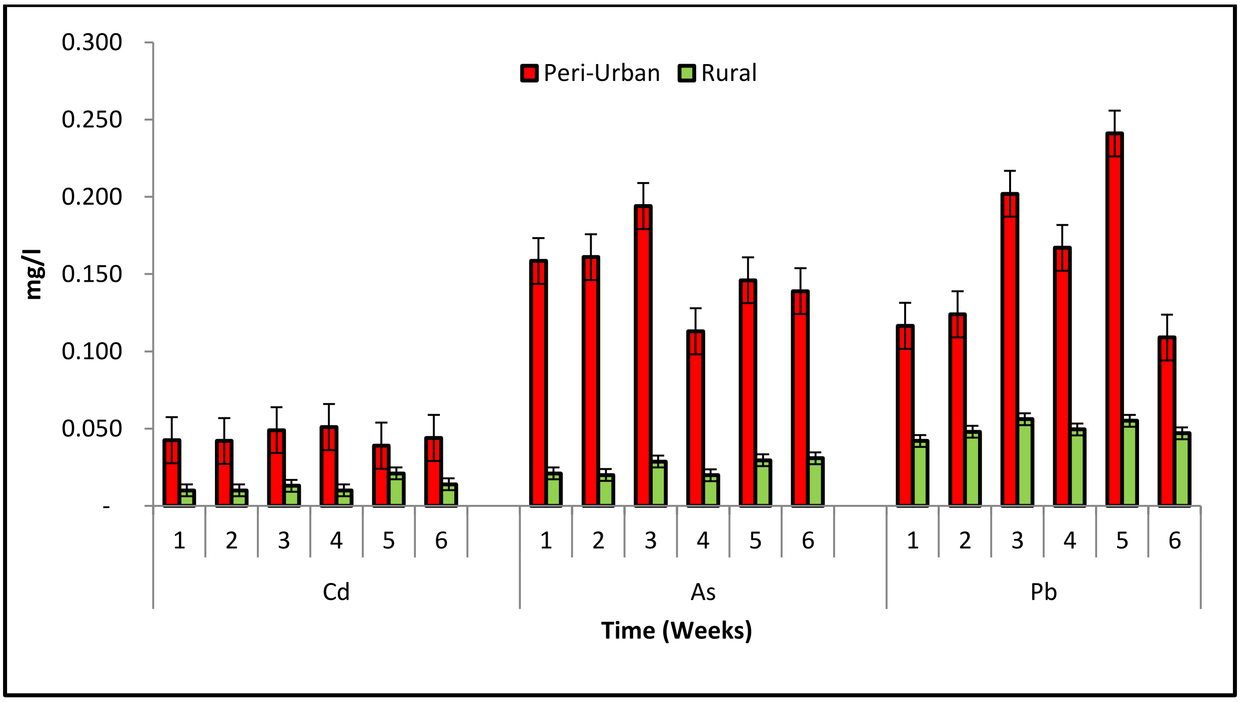

Figure 4-7: Mean concentrations (mg/l) of heavy metals (Cd,As, Pb) in peri-urban and rural faecal sludge. Vertical bars show the standard errors of means (n = 3)

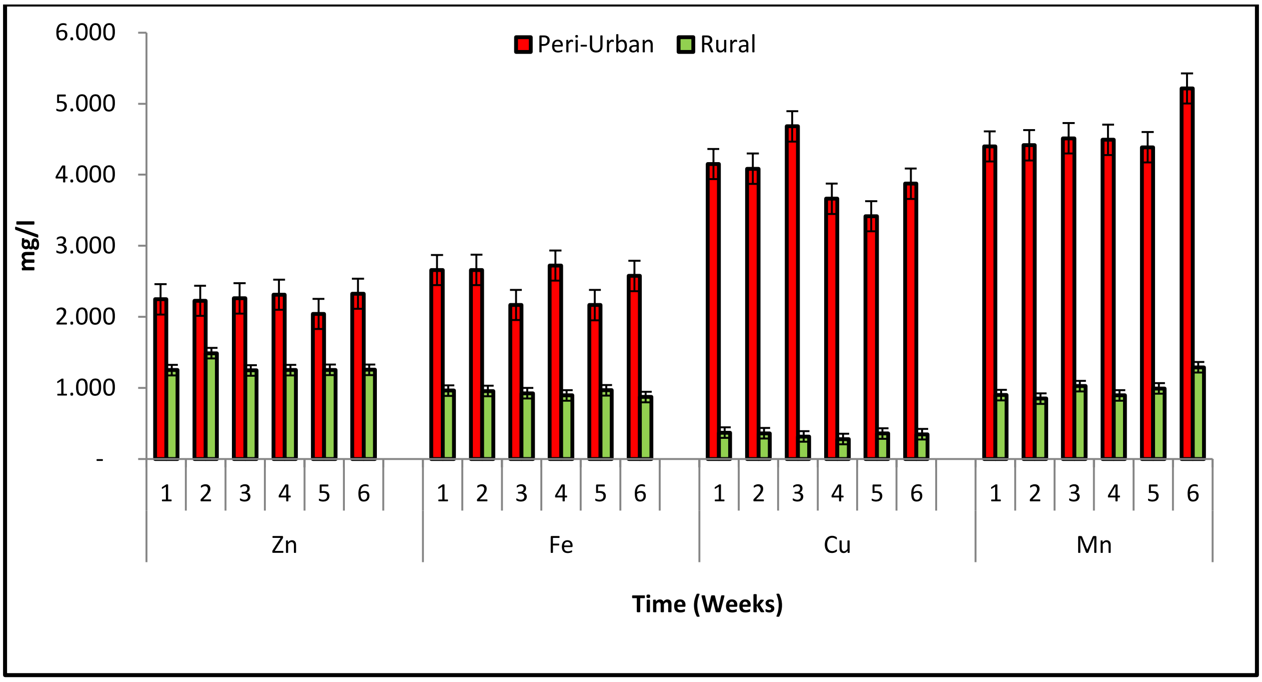

Figure 4-8: Mean concentrations (mg/l) of heavy metals (Zn, Fe, Cu, Mn) in peri-urban and rural faecal sludge. Vertical bars show the standard errors of means (n = 3).

Using linear regression analysis, the study found strong positive and negative correlations between Arsenic and Copper (R^2=0.680) and Lead and Iron (R^2=0.675) respectively in faecal sludge from peri-urban areas. No other significant correlations were observed (Table 4-8; Figure 4-9 and Figure 4-10). In the case of rural faecal sludge, the strongest correlation was found between Arsenic and Manganese (R^2=0.679). No other significant correlations were observed (Table 4-9; Figure 4-11).

Studies by Prasad (2003) and Reinhofer *et al.* (2002), found similar correlations between these heavy metals. This further supports the findings and presents more evidence that some heavy metals do occur together. This findings may allow laboratories to limit heavy metals testing and therefore carryout single tests for pairs of strongly correlated heavy metals. The accuracy of the findings of this study was limited due to the fact that only a small number of faecal sludge samples were available for laboratory analysis.

Table 4-8: Pearson's Correlations Between Heavy Metals in Peri-urban Faecal Sludge

	Copper (Cu)	***Iron (Fe)***	***Lead (Pb)***	***Cadmium (Cd)***	***Zinc (Zn)***	***Manganese (Mn)***	***Arsenic (As)***
Copper (Cu)	1						
Iron (Fe)	-0.14	1					
Lead (Pb)	-0.21	**-0.82**	1				
Cadmium (Cd)	0.37	0.18	-0.01	1			
Zinc (Zn)	0.42	0.61	-0.69	0.70	1		
Manganese (Mn)	-0.04	0.15	-0.44	0.09	0.52	1	
Arsenic (As)	**0.82**	-0.56	0.15	-0.10	-0.14	-0.21	1.00

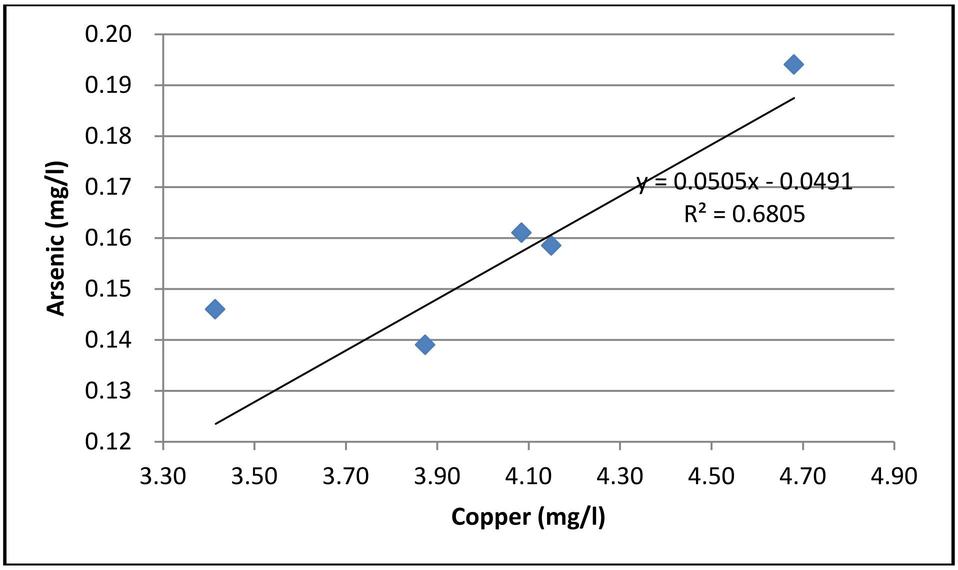

Figure 4-9: Correlation between Arsenic and Copper in Peri-urban faecal sludge

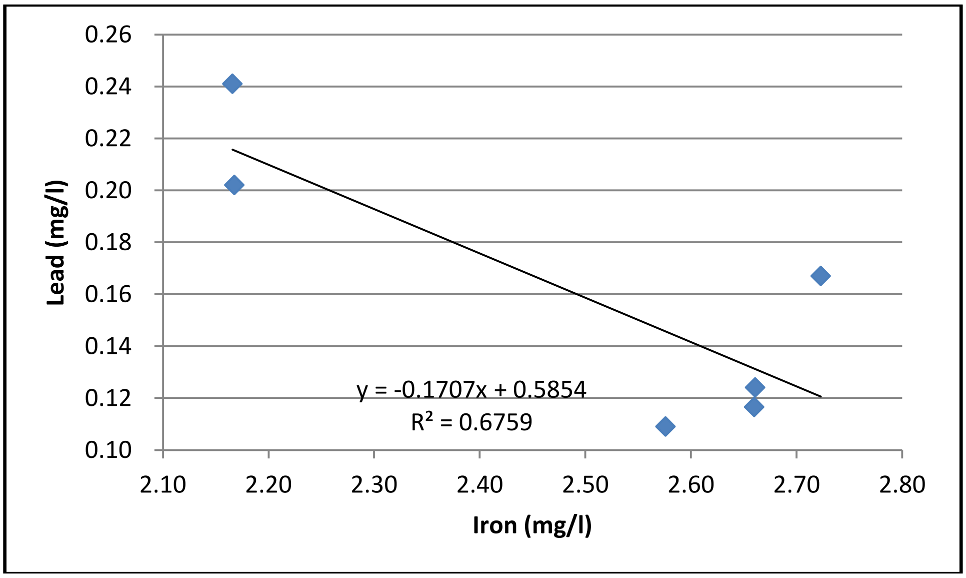

Figure 4-10: Correlation between Lead and Iron in Peri-urban faecal sludge

Table 4-9: Pearson's Correlations Between Heavy Metals in Rural Faecal Sludge

	Copper (Cu)	***Iron (Fe)***	***Lead (Pb)***	***Cadmium (Cd)***	***Zinc (Zn)***	***Manganese (Mn)***	***Arsenic (As)***
Copper (Cu)	1						
Iron (Fe)	0.59	1					
Lead (Pb)	-0.36	0.04	1				
Cadmium (Cd)	0.24	0.20	0.61	1			
Zinc (Zn)	0.34	0.32	-0.16	-0.33	1		
Manganese (Mn)	0.05	-0.66	0.09	0.38	-0.41	1	
Arsenic (As)	0.13	-0.27	0.53	0.76	-0.46	**0.82**	1

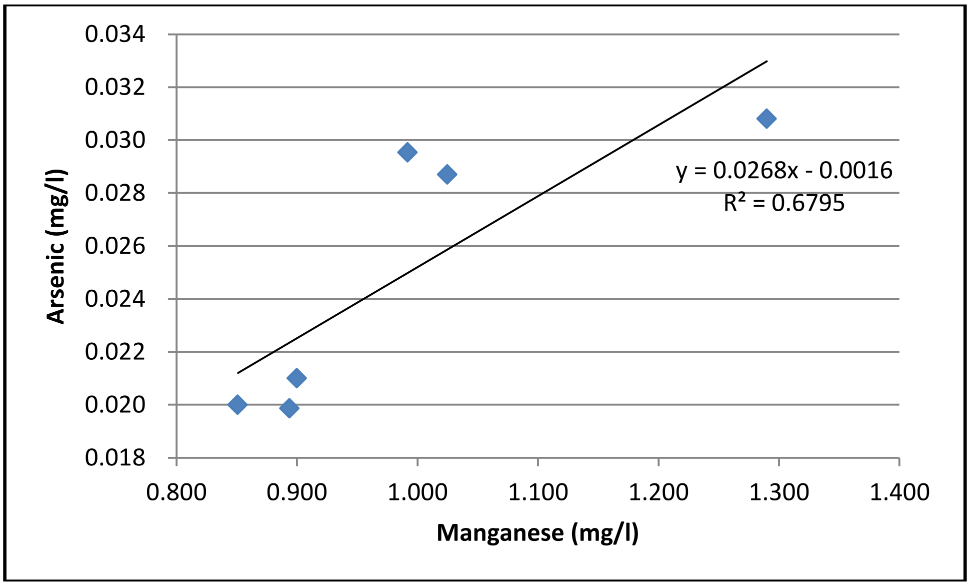

Figure 4-11: Correlation between Arsenic and Manganese in rural faecal sludge

4.3.8 Microbial parameters

Faecal sludges contain pathogenic organisms and are liable to undergo biological action and thus should be handled with care (Environment Agency, 2004). The high concentration of microorganisms may create a severe health risk when faecal sludge is discharged to receiving waters. There were slight variations in the total coliform population measured across the study duration. However, significantly high values were recorded for the third sampling (Figure 4-12). The total coliform population in faecal sludge from peri-urban areas ranged from $1.7\text{x}10^7$CFU/100 ml to $3.6\text{x}10^7$CFU/100 ml with a mean of $2.5\text{x}10^7$CFU/100 ml ±0.71 (Table 4-10). There was no significant variation between the coliform counts in peri-urban and rural areas (p>0.065). Faecal coliform bacteria are indicators of faecal contamination and of the potential presence of pathogens associated with wastewater or sewage sludge (Environmental Factsheet, 2003) and, for that matter, faecal sludge. The measured concentrations of faecal coliform for peri-urban areas ranged from $3.6x10^7$CFU/100 ml to $4.5x10^7$CFU/ 100 ml and $0.4x10^6$ CFU/100 ml to $4.5x10^6$CFU/100 ml for rural areas (p=0.0012) (Table 4-10). Significantly higher levels of faecal coliform populations were observed in faecal sludge sampled from peri-urban areas compared to the rural areas (Figure 4-12). In the peri-urban areas the mean concentrations of *E. Coli* population determined were $3.4x10^6$±1.05 CFU/100 ml and $2.8x10^6$±1.50 CFU/100 ml for rural areas (p=0.0191) (Figure 4-13). The levels of *Salmonella spp*. ranged from $1.4x10^6$CFU/100 ml to $1.7x10^6$CFU/100 ml and $0.2x10^6$CFU/100 ml to $1.7x10^6$CFU/100 ml for peri-urban and rural areas, respectively (Table*4-10*). *Salmonella spp*. has been considered the causal agent of the largest number of enteric infections in the world (Bell & Kyriakides, 2002).

Figure 4-14, graphically illustrates the pattern of the measured levels of hookworm, *Ascaris, S. haematobium, S. mansoni* and *T. trichiura*. The mean hookworm ova were analyzed as 13.6 eggs/100 ml and 10.9 eggs/100 ml for peri-urban and rural areas, respectively (p=0.2096). Helminth eggs (*Ascaris, S.haematobium, S. mansoni* and *T. trichiura*) are one of the most resistant pathogenic structures that might be found in faecal sludge. The mean number of *Ascaris* eggs were measured as 10.1 eggs/100 ml and 8.2 eggs/100 ml for peri-urban and rural areas, respectively. The measured range of values of *S. haematobium* was 2.0 to 5 eggs/100 ml for peri-urban and 1.1 to 5.0 eggs/100 ml for rural areas. Analysis of *S. mansoni* in 100 ml of faecal sludge samples showed a mean of 8.8±2.34 eggs and 7.3±4.11 eggs for peri-urban and rural areas, respectively (p=0.0302) (Table 4-10). Observation on the periods of analysis for *T. trichiura* appears to show slight variations for both peri-urban and rural areas (Figure 4-14); however, it was not statistically significant (Table 4-10). The eggs contained in the faecal sludge are not always infectious but are infectious when they are viable and the larvae develops. Similarly, the prevalence of the eggs could be attributed to human origin. Faecal sludge from peri-urban areas generally exhibited more numbers of eggs compared to that of rural areas (Figure 4-14). This could be as a result of ingestion of polluted crops or contact with faeces by majority of peri-urban inhabitants compared to that of rural.

Table 4-10: Summary of analyses of microbial parameters in faecal sludge

Parameter	**Peri-urban**				**Rural**				***p value***
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	
Total coliform*	2.5	0.71	1.7	3.6	2.1	1.22	0.7	3.6	0.0652
Faecal coliform*	4.0	0.40	3.6	4.5	3.1	1.84	0.4	4.5	0.0012
*E. coli***	3.4	1.05	2.1	4.5	2.8	1.50	1.1	4.5	0.0191
Salmonella spp.**	1.5	0.16	1.4	1.7	1.2	0.70	0.2	1.7	0.9566
Hookworm***	13.6	3.12	9.0	18.0	10.9	6.37	3.1	18.0	0.2096
*Ascaris****	10.1	2.82	6.5	13.5	8.2	4.60	2.8	13.5	0.6884
*S. haematobium****	4.2	1.13	2.0	5.0	3.1	1.81	1.1	5.0	0.4930
*S. mansoni****	8.8	2.34	6.0	12.0	7.3	4.11	2.3	12.0	0.0302
*T. trichiura****	4.7	1.03	4.0	6.0	3.9	2.10	1.0	6.0	0.2989

Parameters measured in $\times 10^7$ CFU/100 ml, $\times 10^6$ CFU/100 ml** and eggs/100 ml****

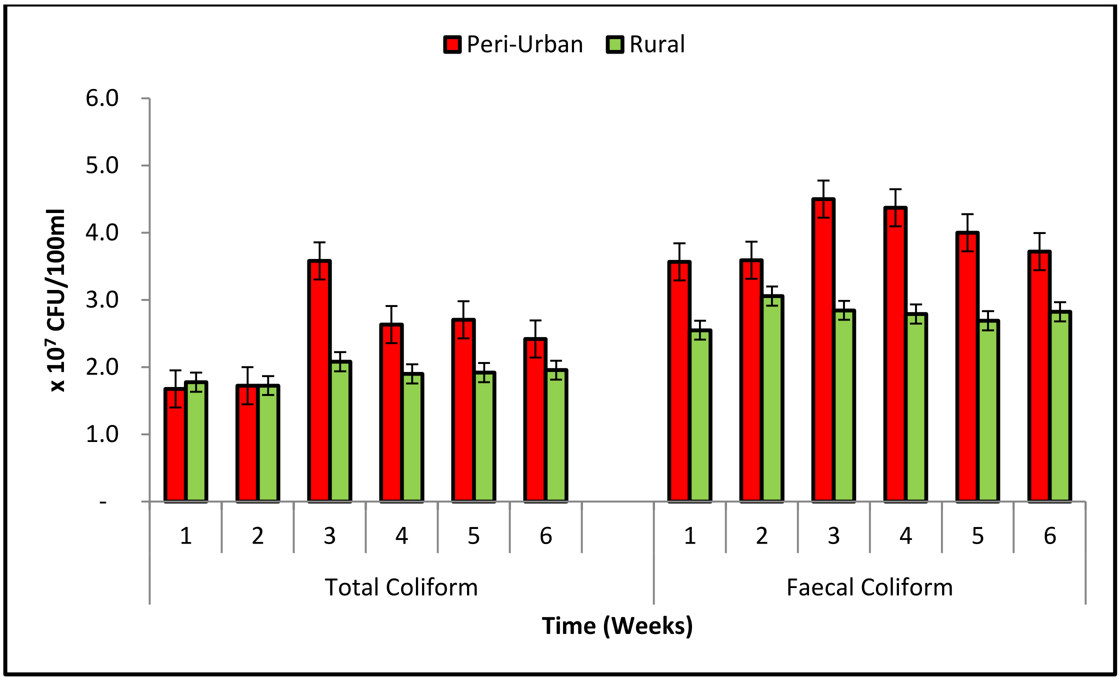

Figure 4-12: Mean levels of total and faecal coliform in peri-urban and rural faecal sludge. Vertical bars show the standard errors of means (n = 3).

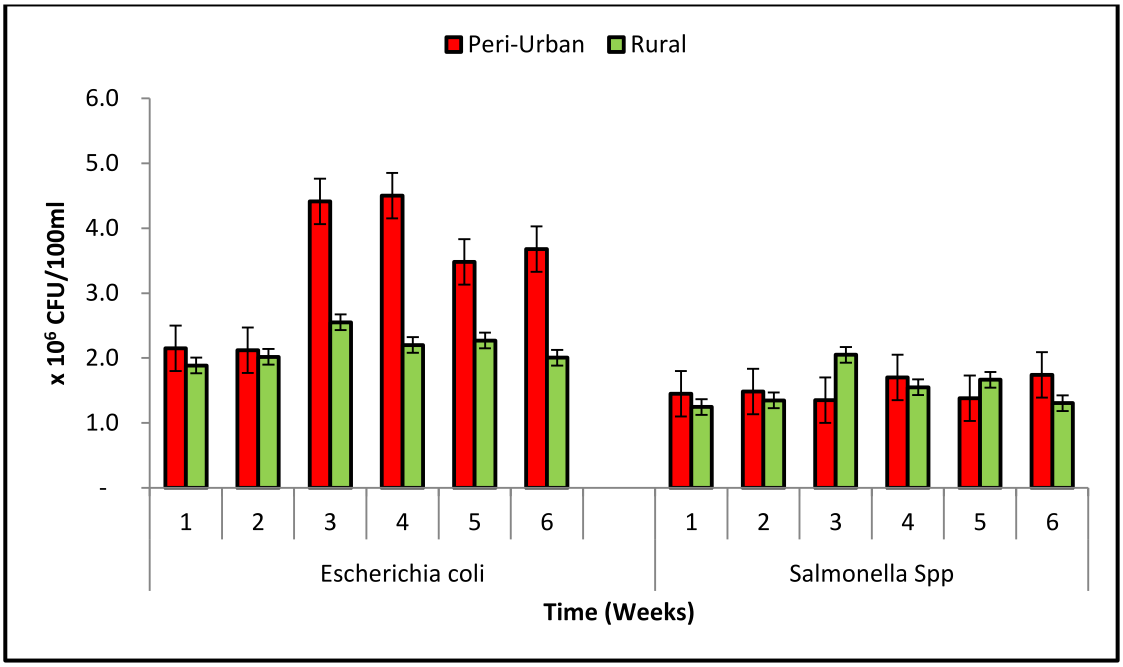

Figure 4-13: Mean levels of Escherichia coli and Salmonella spp. in peri-urban and rural faecal sludge. Vertical bars show the standard errors of means (n = 3).

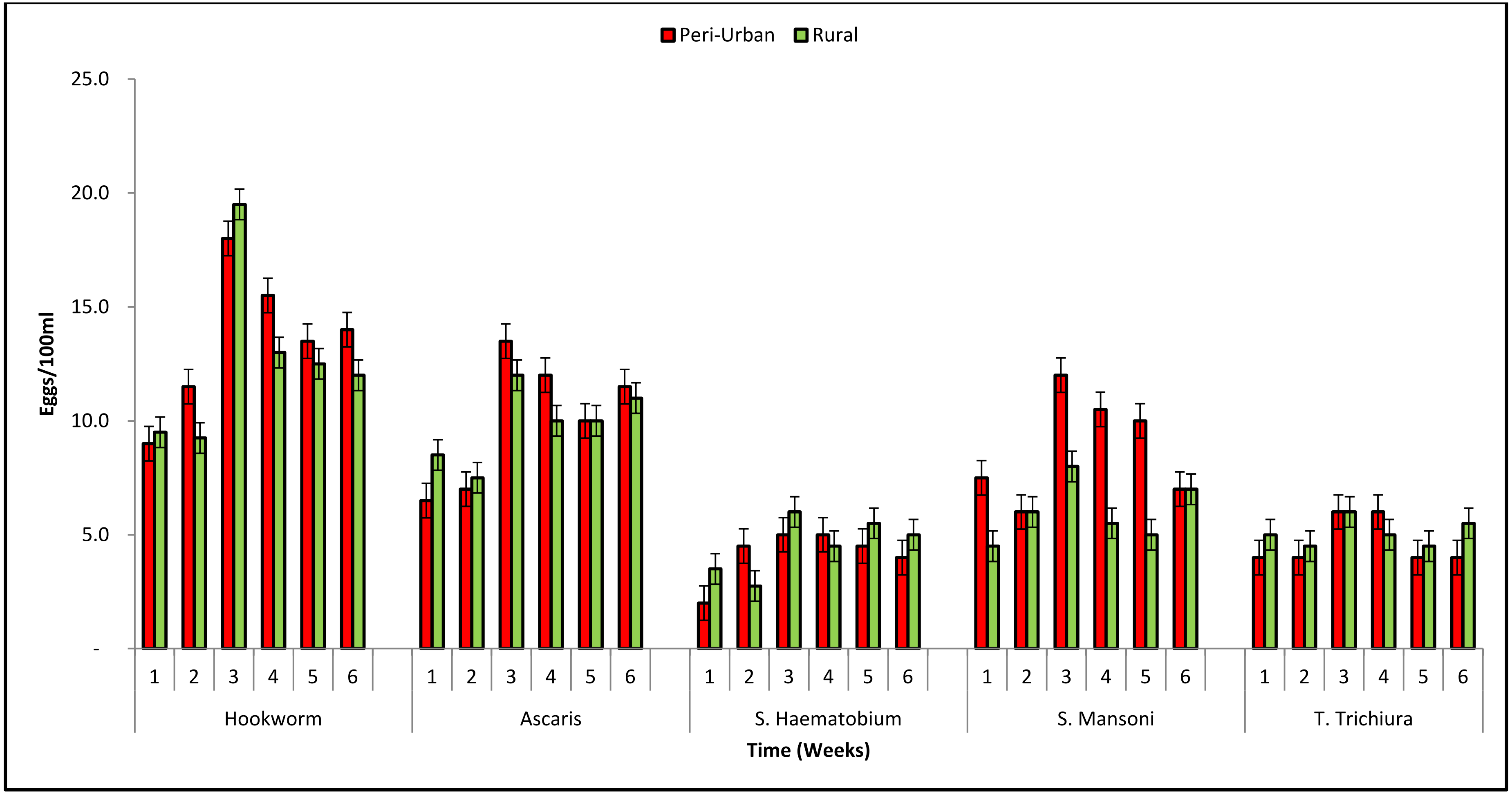

Figure 4-14: Mean levels of helminths in peri-urban and rural faecal sludge. Vertical bars show the standard errors of means (n = 3).

4.4 Effect of bulking materials and mixing ratios on the properties of peri-urban faecal sludge compost

4.4.1 Suitability of compost materials

The materials used in the composting process comprised raw FS, wood chips and maize cobs (chopped). The wood chips were by products of wood processing whereas maize cobs were obtained after removal of the kernels. These materials provide the free air space, moisture control and maintain the C/N ratio during composting (Adhikari *et al.,* 2008). The general characteristics of the BM and raw FS were initially monitored before they were composted and the results are presented in the Table 4-11.

Carbon content was higher in Wood chips (53.6±0.30) compared to maize cobs (49±2.0). Nitrogen and Phosphorus levels in Maize cobs were however, greater than that present in the wood chips (Table 4-11). The measured C/N ratio for the raw FS (11) was very low and was not suitable for composting. Also, the BM used for the composting process showed an initial high C/N ratio of 199 and 114 for wood chips and maize cobs respectively. This is indicative of the fact that composting of raw FS requires addition of bulking materials that allow optimal moisture, C/N ratio and also provide structural support to obtain sufficient air-filled porosity to improve on the compost process. Also the mean values (n=3) of measured compost parameters at the initial and final stages of the compost process are shown in the Figure 4-15 to Figure 4-36.

Table 4-11: Characteristics of bulking material used in the study

Table 2: **Parameter**	**Unit**	**Wood Chips**	**Maize Cobs**
Carbon	%	53.6±0.30	49±2.0
Nitrogen	%	0.27±0.04	0.43±0.07
Phosphorus	%	0.74±0.45	0.93±0.33
Potassium	%	0.44±0.23	0.61±0.18
Particle Size	mm	2-10	2-10

Standard Deviation = ±, where n=3

4.4.2 Temperature

Temperature plays a major role in the composting process because its impact on the microbiological community is strong. Figure 4-15 and Figure 4-16 clearly show the temperature variations experienced during the composting process compared with ambient air for a period of sixty (60) days. However, the temperatures of all the experimental trials were consistently above the ambient air temperature due to the generation of metabolic heat as a result of microbial activities. Maximum temperature (42 ^{o}C) was observed in Maize Cobs (1:2) and this was attained on the 5th to 12th day (Figure 4-16). Most pathogenic microorganisms would be destroyed at these temperatures (>40 °C-50 °C) (Schönning & Stenström, 2004). However, all the remaining experimental trials experienced temperatures less than 40 ^{o}C. After the initial high temperature periods, compost temperatures begun to drop gradually for all the experiments. The lower temperatures observed could be as a result of the size of the compost reactor used for the process. The result is consistent with the study by Petiot & de Guardia (2004), where he noted that reactors of small size, typically less than 30 litres did not allow the self-heating of compost substrate or at least did not allow the temperature to stay in the thermophilic zone. Minimum temperatures for Wood (2:1)=24 ^{o}C, Wood (1:1)=25 ^{o}C, Wood (1:2)=25 ^{o}C, Maize cob (2:1)=25 ^{o}C, Maize cob (1:1)=26 ^{o}C and Maize cob (1:2)= 27 ^{o}C were observed at the end of the compost process (Figure 4-15 and Figure 4-16). Generally, compost temperature was raised with increasing bulking material ratio. This confirmed a study by Michel *et al.* (2004), where he reported that different types and quantity of bulking material have very different effects on compost temperatures. An ANOVA test was carried out to see if there was a significant difference between the means of the temperature for the different experiments (Wood (2:1), Wood (1:1), Wood (1:2), Maize cob (2:1), Maize cob (1:1) and Maize cob (1:2)). From the results presented in Table 4-12 it was found that there was significant difference between the means (p=0.000).

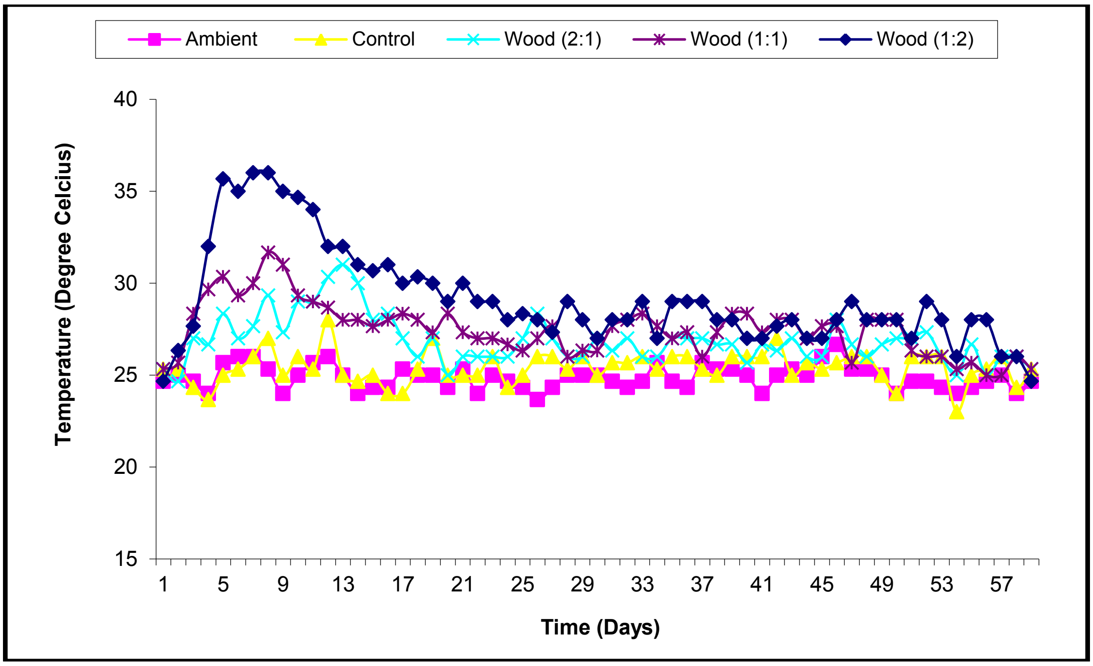

Figure 4-15: Variation of Temperature during composting withwood chips

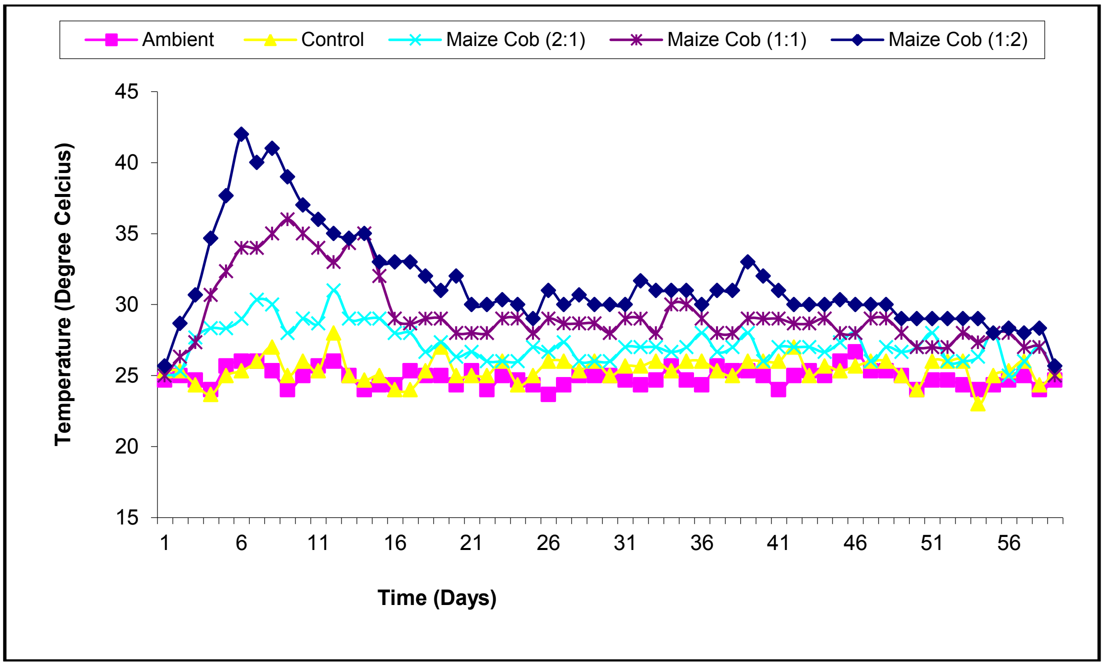

Figure 4-16: Variation of Temperature during composting with maize cobs

Table 4-12: ANOVA between means of temperature for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	1958.378	7	279.7683	69.66809	2E-68	2.02931

4.4.3 Potential hydrogen (pH)

The pH value of compost is looked as an indicator of process of decomposition and stabilization. The variations in pH values in all the experimental trials are shown in Figure 4-17 and Figure 4-18. During the composting process for experimental trials with wood, initial pH dropped from 7.6 to 7.4 (Ratio 2:1), 7.6 to 7.5 (Ratio 1:1) and 7.8 to 7.3 (Ratio 1:2) at the end of the compost (Appendix C). There was a similar drop in pH from the start to end of composting for experiments with maize cobs from 7.8 to 7.2 (Ratio 2:1), 7.4 to 7.3 (Ratio 1:1) and 7.7 to 7.0 (Ratio 1:2) (Appendix C). In the control experiment a similar drop in pH from 8.6 to 7.7 at the end of the compost process was observed. This drop in pH might be due to the ammonification and mineralization of organic matter by the activities of microorganisms as found by Wong *et al.* (2001).

At the end of the composting process, the pH values ranged from 7.0 to 7.5,for all the experimental trials and this was suitable for a final compost. An ANOVA test was carried out to see if there was a significant difference between the means of the pH for the different experiments. From the results presented in Table 4-13it was found that there was a highly significant difference between the means (p=0.000). However, measured pH values for all the experiments were within the optimum pH range for microbial activities. For the better biodegradation of composting materials, the pH value should not be very basic and very acidic but should be within the range of 6-8 (Alburquerque, 2006).

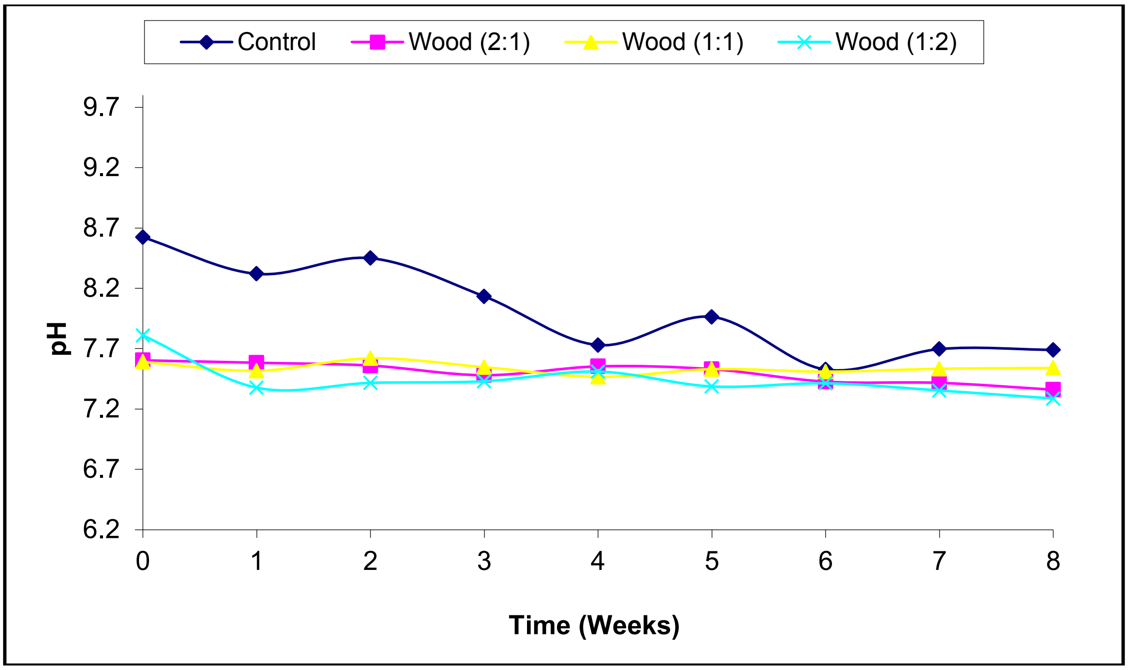

Figure 4-17: Variation of pH during composting with wood chips

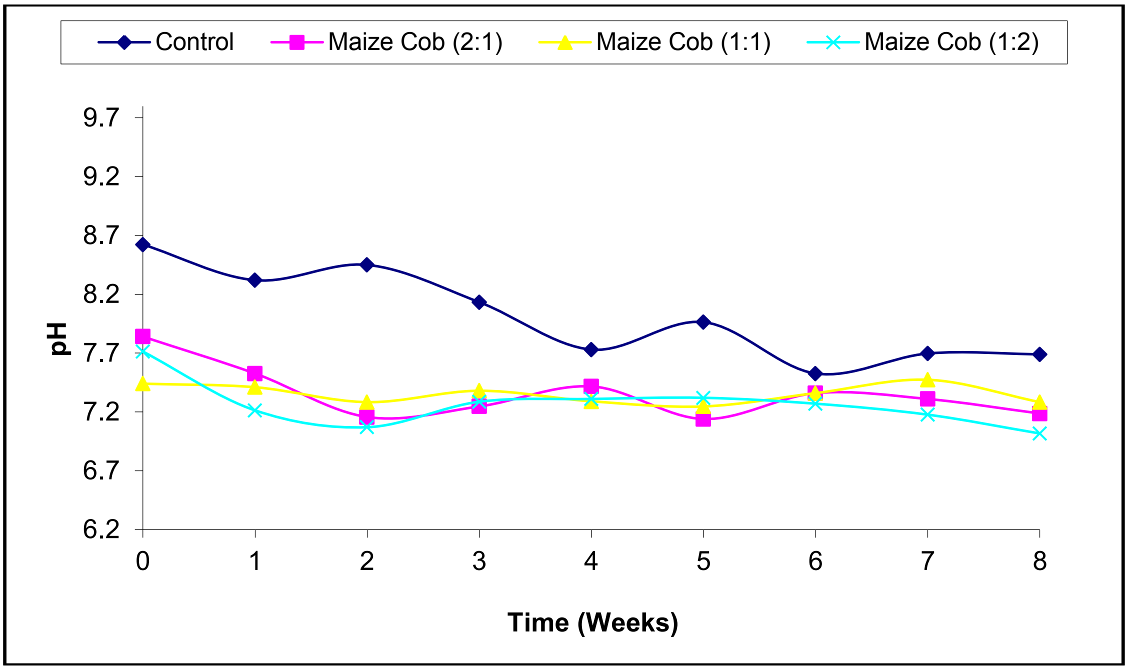

Figure 4-18: Variation of pH during composting with maize cobs

Table 4-13: ANOVA between means of potential hydrogen for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	3.318629	6	0.553105	13.99182	1.19E-09	2.265567

4.4.4 Moisture content

McCartney & Tingley (1998), reported that moisture content of compost blend is an important environmental variable as it serves as a medium for transport of dissolved nutrient needed for the metabolic and physiological activities of microorganisms. Regarding moisture content, the results showed that the initial 65% to 67% values for all the experimental trials were within an acceptable range for microbial activities (Appendix C). The results satisfied previous works conducted with other biosolid mixtures (Tiqua *et al.,* 1998; Liang *et al.,* 2003) which indicated an 50% initial moisture content to be the lower limit for a rapid increase of microbial activities. To prevent anaerobic conditions and lixiviate formation in compost it is better to have optimum moisture content of 60-70% (Roca-Pérez *et al.,* 2004). The moisture content of the final (matured) compost ranged from 20.7% to 40.7% with the maize cobs (1:2) and control experiment having the minimum and maximum values respectively. There was a gradual reduction in the moisture content for all the experiments throughout the composting period as shown in Figure 4-19 and Figure 4-20. There was no significant difference between the measured moisture content values of all the experimental trials when ANOVA test was conducted (p=0.582) (Table 4-14).

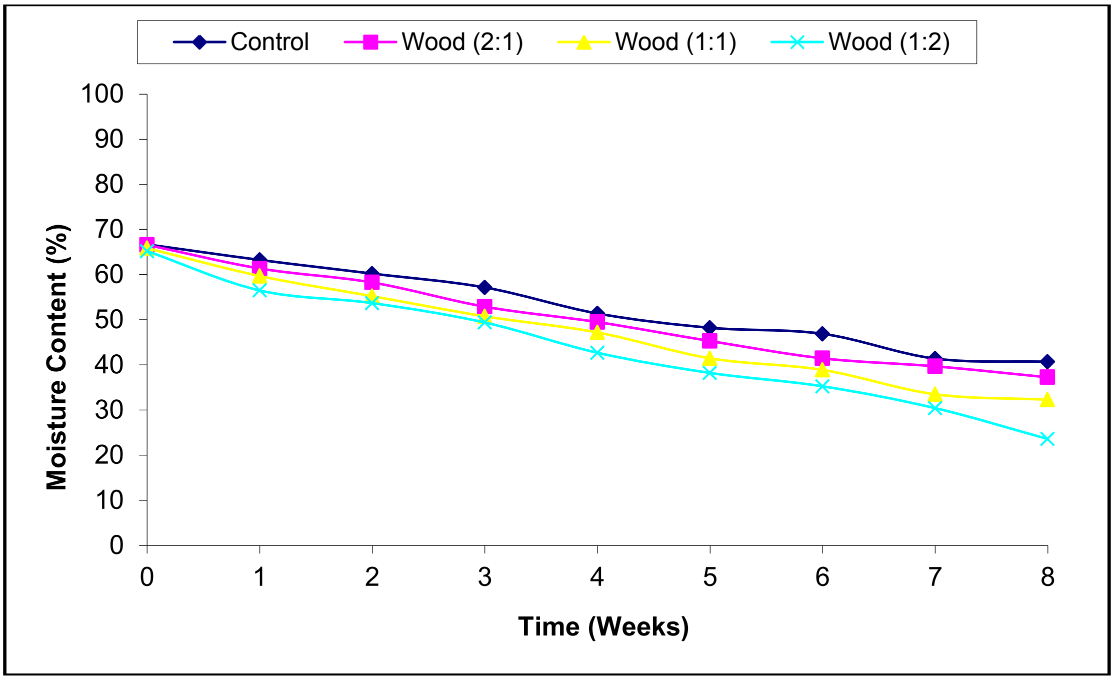

Figure 4-19: Variation of Moisture content during composting with wood chips

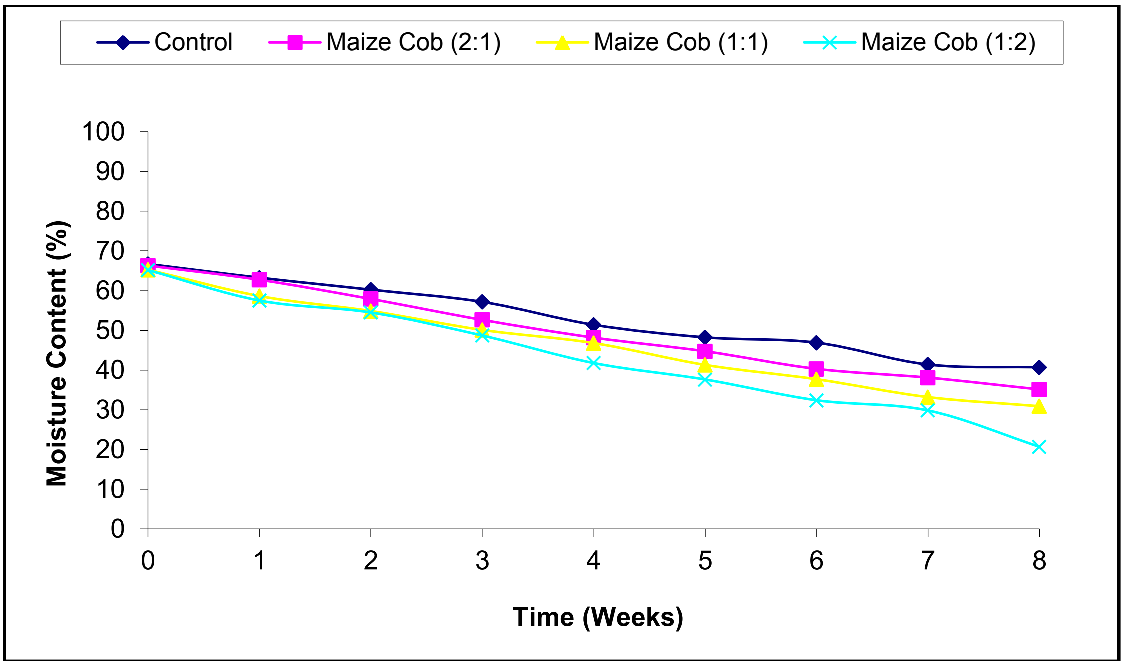

Figure 4-20: Variation of Moisture content during composting with maize cobs

Table 4-14: ANOVA between means of moisture content for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	664.8024	6	110.8004	0.789531	0.581917	2.265567

4.4.5 Total solids (TS)

Total solids (TS) is a measure of all the suspended, colloidal, and dissolved solids in a sample. Low or high TS can impact on the health of microorganisms for biodegradation. The variations in TS over the period for the various experiments are shown in Figure 4-21 and Figure 4-22. There was a gradual increase in TS content from the start to the end of the experiment. Low TS values were recorded at the beginning (33.27%-34.90%) whereas high values were recorded at the end of the composting (Appendix C). The rate of increase of TS contents varied according to the quantities of bulking material with larger ratios having greater TS contents. An ANOVA test was carried out to see if there was a significant difference between the means of the total solids for the different experiments. From the results presented in Table 4-15 it was found that there was a no significant difference between the means (p=0.576).

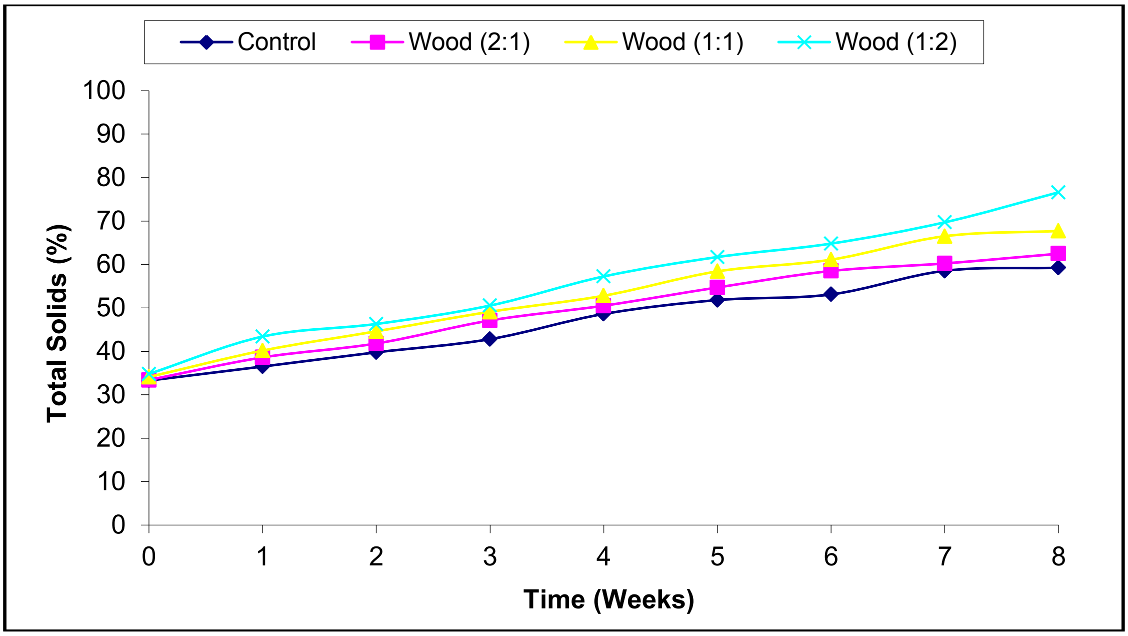

Figure 4-21: Variation of Total solids during composting with wood chips

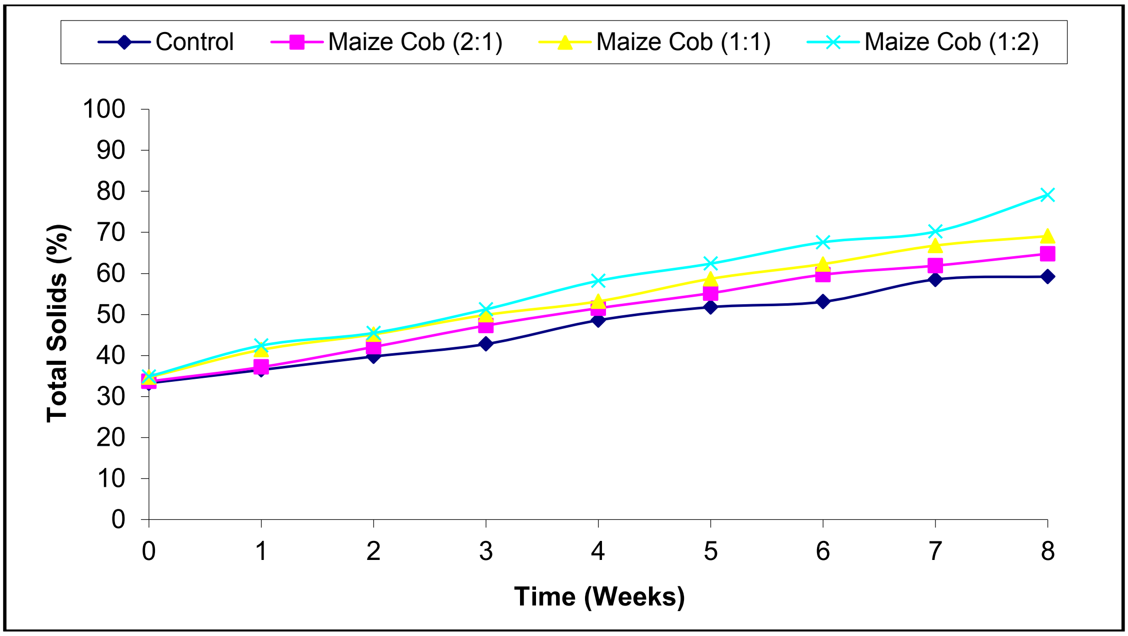

Figure 4-22: Variation of Total solids during composting with maize cobs

Table 4-15: ANOVA between means of total solids for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	672.0855	6	112.0143	0.797233	0.576127	2.265567

4.4.6 Organic matter content

Organic matter content, measured on a dry matter basis, decreased from maximum values of86% and 89% at the beginning of composting to a minimum of 59% to 61% measured in experimental trials of Wood and Maize cobs respectively, 60 days after composting was initiated (Figure 4-23 and Figure 4-24). The means of Maize cob (1:2) and Maize cob (1:1) did not differ from one another (p>0.05) but differed from that of the other experimental trials (p=0.0004) when ANOVA test was conducted (Table 4-16). The decrease in OM content was indicative of the rapid decomposition of the readily biodegradable substrates and a high rate of microbial activity. This meant that experimental trial, Maize cob (1:2) had better decomposition compared to the other experimental trials as the rate of decrease of its initial OM to the final OM was larger than the others. The result is similar to a study by Banegas *et al.* (2007), where he observed that the organic matter (OM) content of his experiments, anaerobic and aerobic sewage sludges using two proportions of sawdust, gradually decreased over time during the composting process due to mineralization processes.

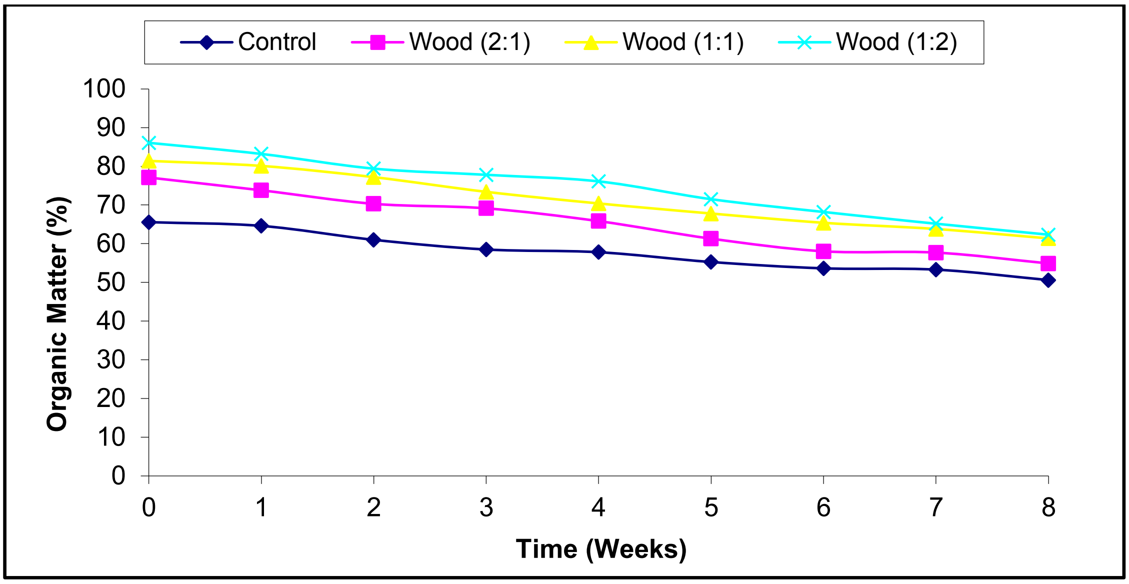

Figure 4-23: Variation of Organic matter content during composting with wood chips

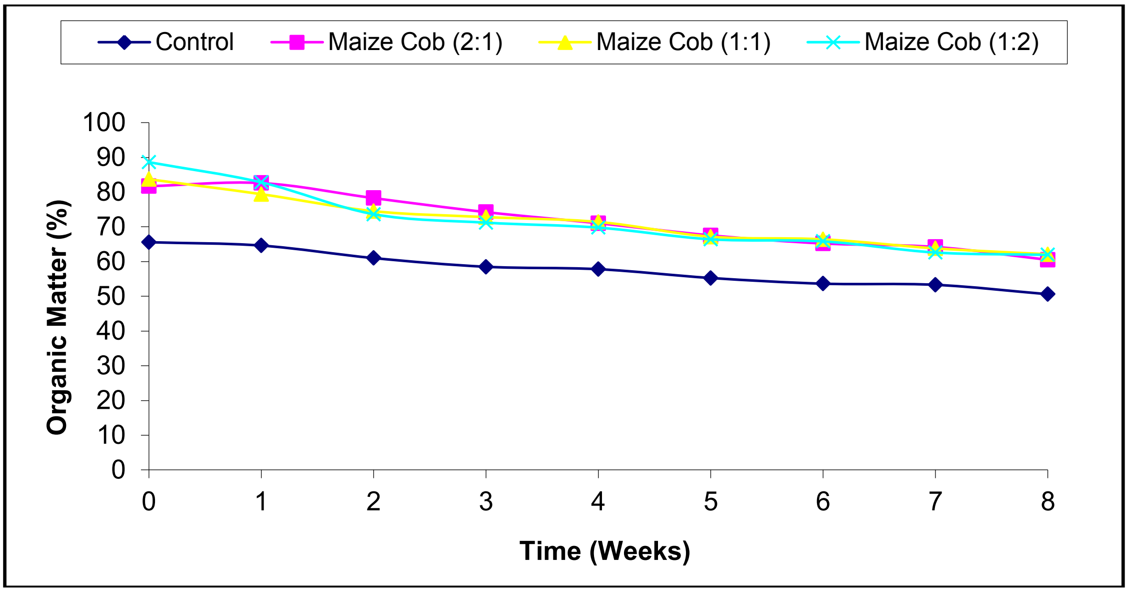

Figure 4-24: Variation of Organic matter content during composting with maize cobs

Table 4-16: ANOVA between means of organic matter content for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	1719.356	6	286.5593	4.96473	0.000388	2.265567

4.4.7 Ash content

The content of ash at the end of the compost process for Wood (2:1), Wood (1:1) and Wood (1:2) were 39%, 39% and 38% respectively (Appendix C). The values aforementioned compared with their corresponding, Maize cob (2:1), Maize cob (1:1), and Maize cob (1:2), showed slightly higher percentage ash content (Appendix C). There was a general increase from the initial days of composting over the remaining periods of the composting for all the experimental trials (Figure 4-25 and Figure 4-26).There was no statistical significance (p=0.712) when ANOVA test was carried out to see if there was a significant difference between the means of the all the experiments (Table 4-17).

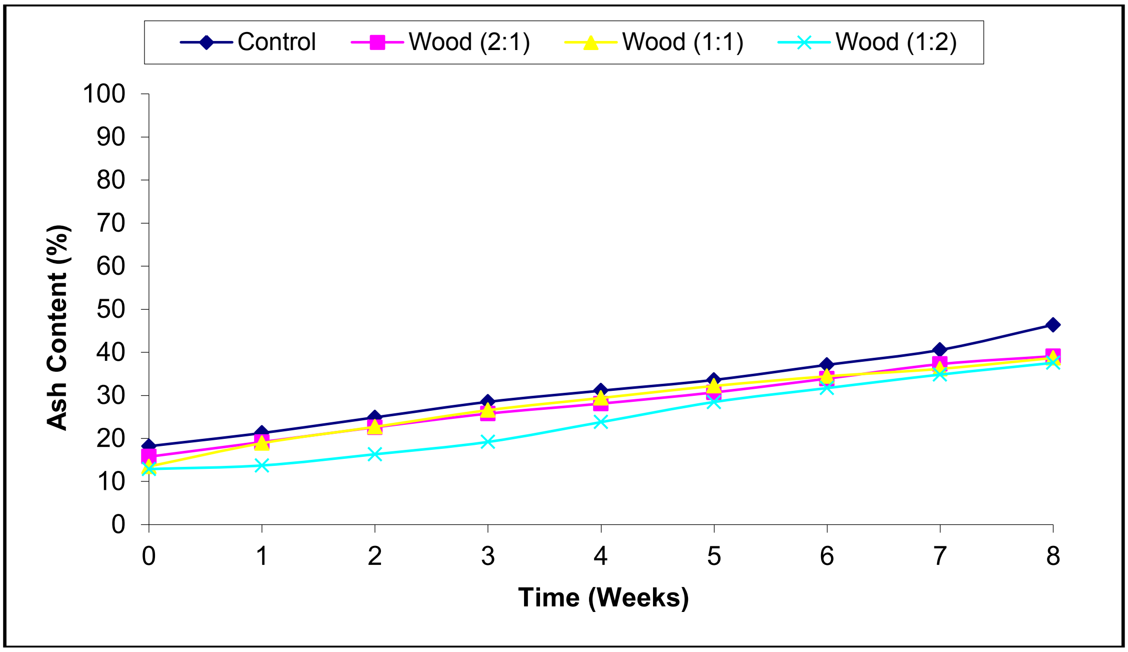

Figure 4-25: Variation of Ash content during composting with wood chips

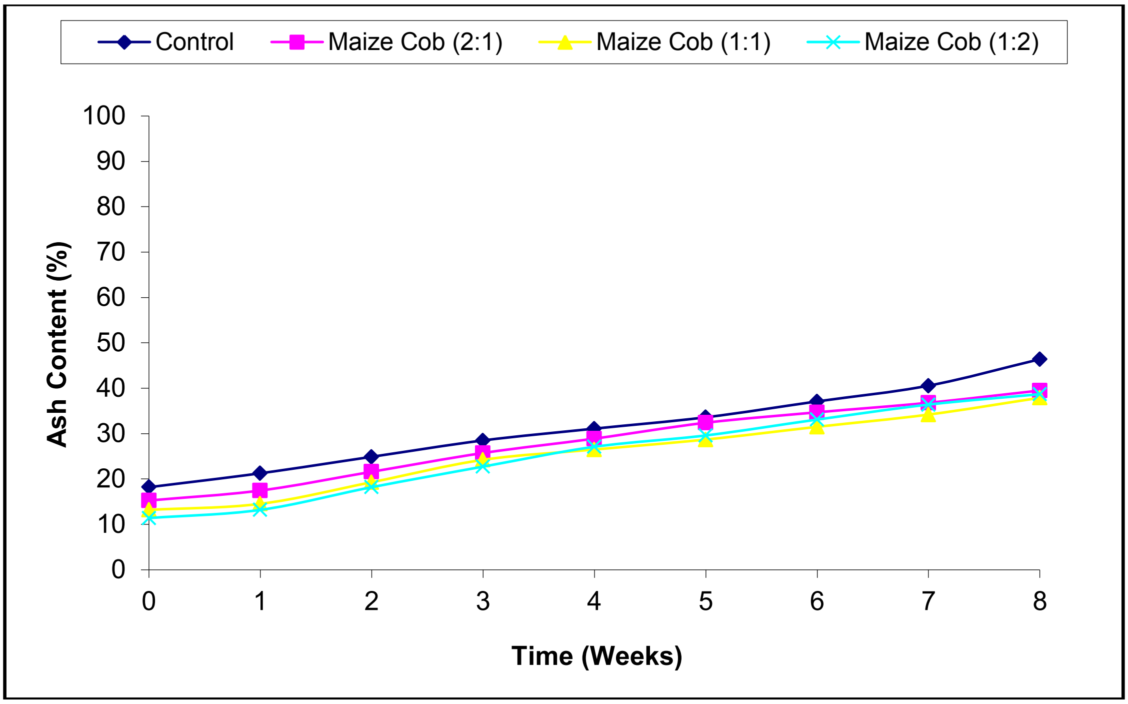

Figure 4-26: Variation of Ash content during composting with maize cobs

Table 4-17: ANOVA between means of ash content for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	293.5789	6	48.92982	0.621896	0.711926	2.265567

4.4.8 Total carbon and Total nitrogen

As shown in Figure 4-27 and Figure 4-28, initial total carbon (TC) contents of experimental trials Wood (2:1), Wood (1:1), Wood (1:2), maize cob (2:1), maize cob (1:1) and maize cob (1:2) were 36.32%, 42.63%, 46.41, 35.34%, 38.41% and 44.82% respectively with a control of 17.52%. There was general fluctuation of the levels of TC from the initial stage to the final stage (Figure 4-27 and Figure 4-28). The measured TC at the final stage of composting did not show any significant difference between all the experiments. The TC contents of all the experiments decreased at the end of the composting process. The decrease in TC occurred as a result of the transformation of the carbon into carbon dioxide due to microbial activities during composting.

Total Nitrogen contents were lower in the end products than the initial compost materials of all the experimental trials (Figure 4-29 and Figure 4-30). That notwithstanding, means of final total nitrogen were not significantly different when compared among all the experiments ($p>0.05$). The nitrogen in experimental trials for wood were slightly lower than that of Maize cob. Low nitrogen levels may have an impact on the fertilising value of the compost, thus influencing crop yield. The variations in the nitrogen levels might have been as a result of bioxidation of the organic matter during composting process as this affected the available forms of nitrogen (Mena *et al.,* 2003). A decrease in nitrogen levels were expected due to mineralization of nitrogen and transformation to ammonia and later to nitrate. The losses were also due to the handling of the compost including the storage and mixing. At the end of the compost process, carbon and nitrogen concentrations were observed to be high in Maize Cob(1:2) compared with the other experimental trials (Appendix C). An ANOVA test was carried out to see if there were significant differences between the means of the Total Carbon and Nitrogen for the experiment trials. From the results presented in Table 4-18 and Table 4-19, it was found that there were high significant differences between the means of Total Carbon and Nitrogen ($p=0.000$).

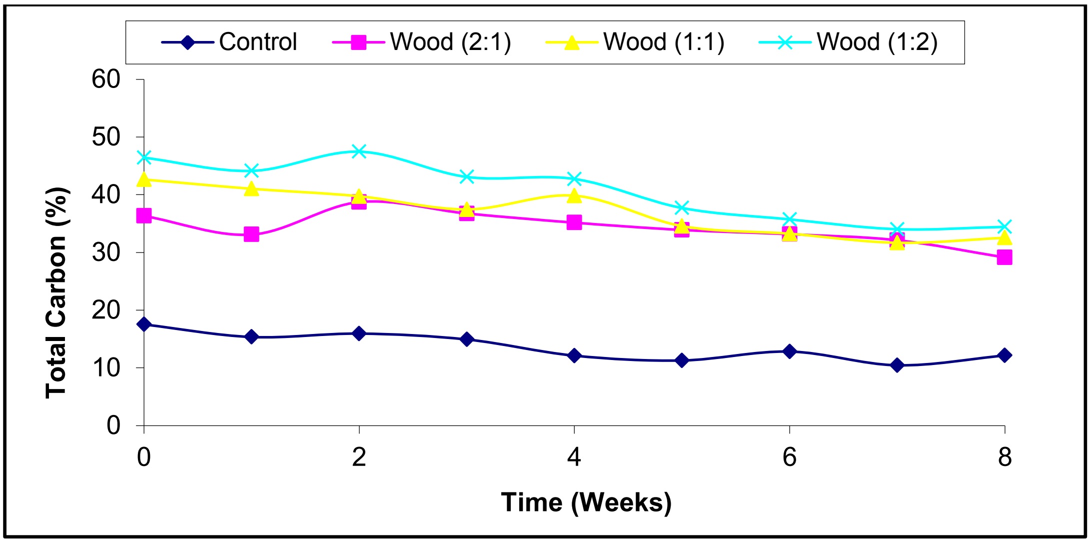

Figure 4-27: Variation of Total Carbon during composting with wood chips

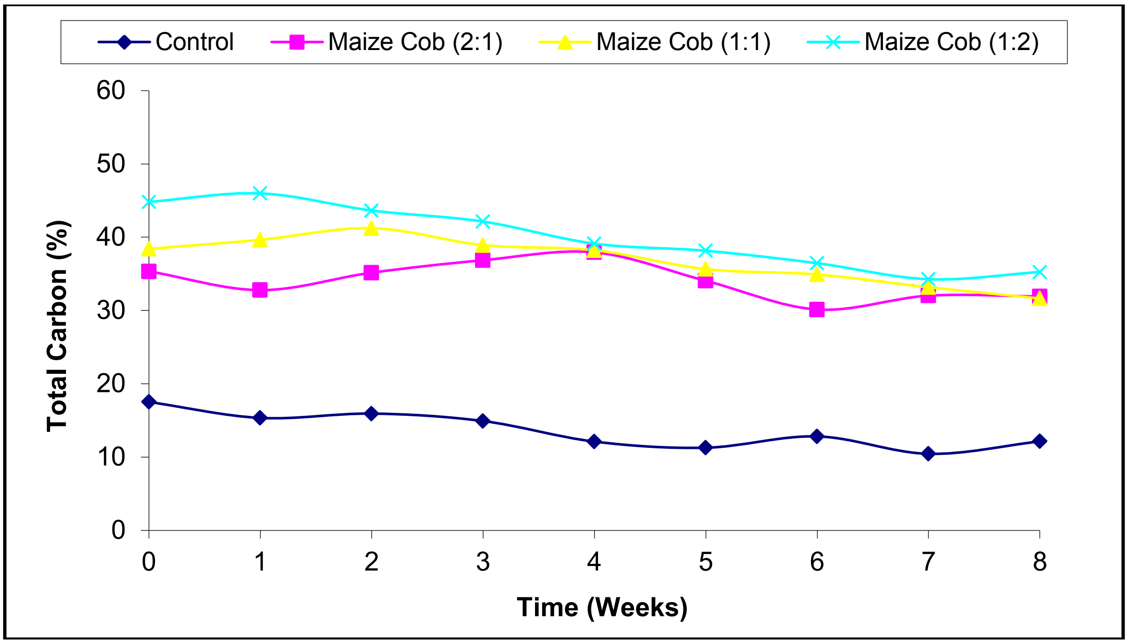

Figure 4-28: Variation of Total Carbon during composting with maize cobs

Table 4-18: ANOVA between means of total carbon for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	4607.854	6	767.9757	57.97119	3.09E-22	2.265567

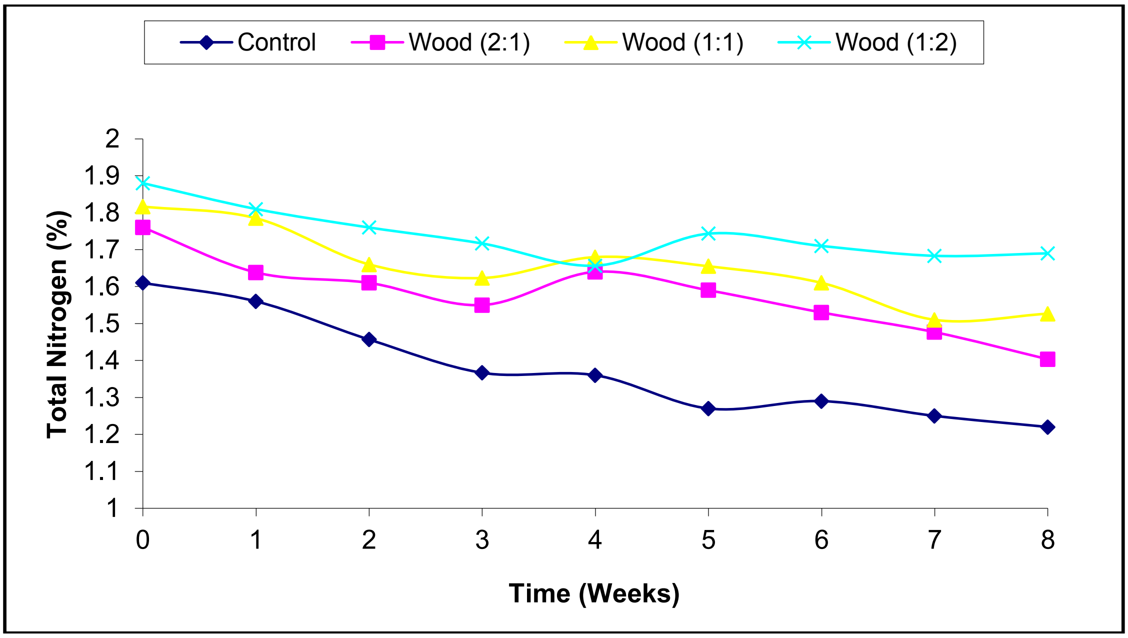

Figure 4-29: Variation of Total Nitrogen during composting with wood chips

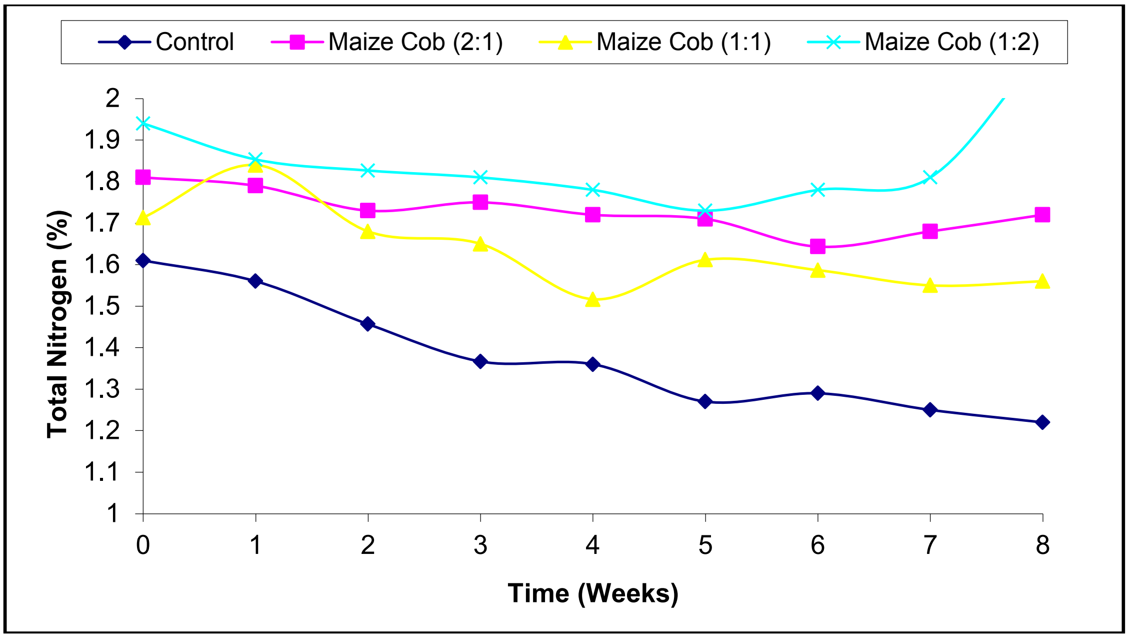

Figure 4-30: Variation of Total Nitrogen during composting with maize cobs

Table 4-19: ANOVA between means of nitrogen for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	1.211514	6	0.201919	19.72897	3.19E-12	2.265567

4.4.9 Carbon-Nitrogen (C/N) ratio

C/N ratio of compost substrates has an important effect on the composting process as well as on potential odour emissions (Xiujin *et al.,* 2008). It is the amount of carbon relative to the amount of nitrogen which is an indicator of nitrogen availability for plant growth. C/N ratio decreased from an initial value of 23 to 21, and from 25 to 20 at the end of the composting process for experimental trials Wood (1:1) and Wood (1:2) respectively (Appendix C). Similarly, experimental trials for Maize Cob (2:1), Maize Cob (1:1) and Maize Cob (1:2) experienced a decrease in C/N values from an initial value of about 20 to 18, from 22 to 20 and 23 to 17 respectively at the end of the composting process. The control experiment observed a marginal decrease in C/N values from an initial of 11 to 10 at the final stage of composting. The decrease in C/N ratio was due to mineralization of the substrates present in the feedstock initially put in the composting reactors (Solano *et al.,* 2001) (Figure 4-31 and

Figure 4-32). This led to the supply of excess nitrogen causing its loss as ammonia gas resulting in undesirable odours. In contrast, the C/N ratio slightly increased from 20 to 21 in experimental trial Wood (2:1). There was high significant difference between the means of the experiments after conducting an ANOVA test (p=0.000) (Table 4-20).

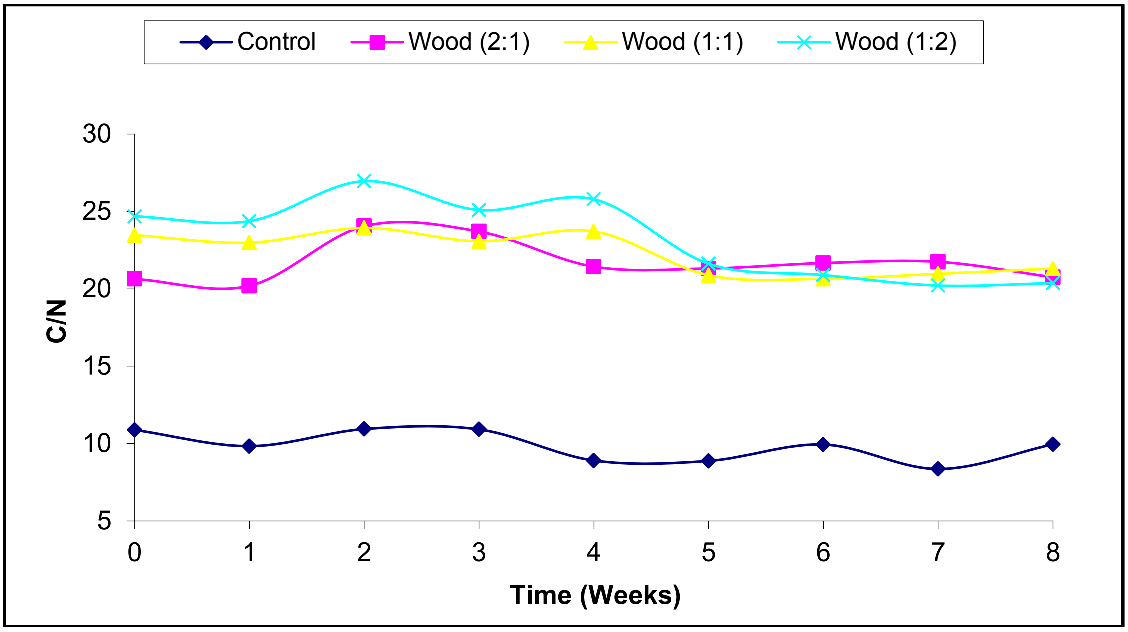

Figure 4-31: Variation of Carbon-Nitrogen ratio during composting with wood chips

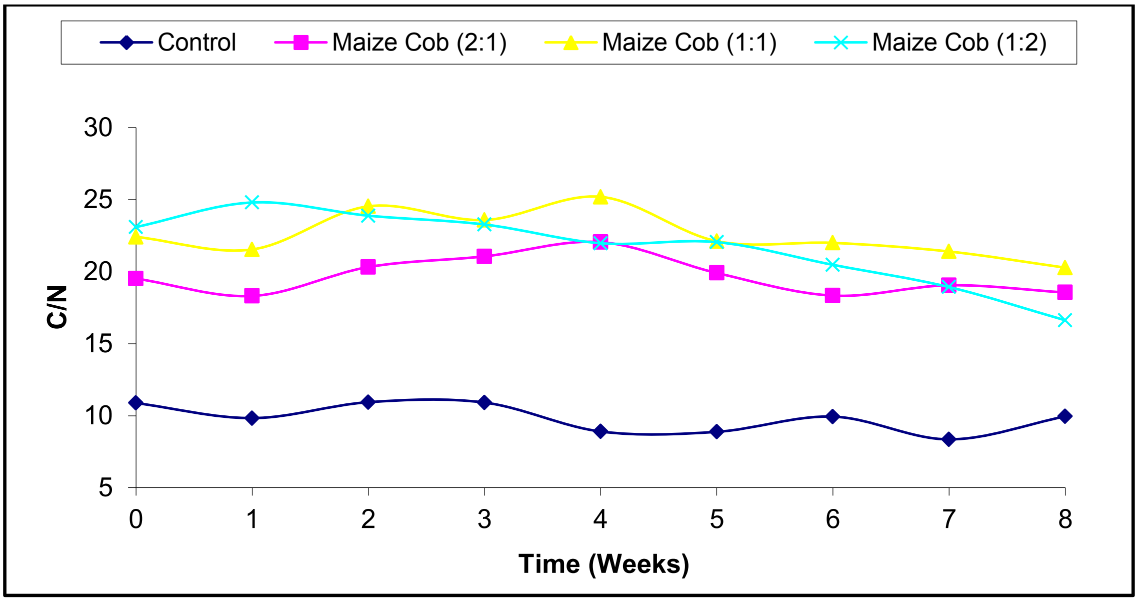

Figure 4-32: Variation of Carbon-Nitrogen ratio during composting with maize cobs

Table 4-20: ANOVA between means of C/N for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	1187.674	6	197.9457	62.95764	4.26E-23	2.265567

4.4.10 Phosphorus and Potassium

Phosphorus and potassium are essential elements for plant growth. Lindsey *et al.*(1989) reports that, phosphorus deficiency is the second most important soil fertility problem throughout the world. Notwithstanding, excessive amounts of phosphorus in the soil tend to immobilize other chemical elements such as zinc (Zn) and copper (Cu) that are also essential for plant growth (Chang *et al.,* 1983). Potassium is also important in amino acids and protein synthesis and helps regulate the flow of water through the plant. Composted materials at the end of the experiment showed lower concentrations of available phosphorus and potassium in all the experiments than the initial substrate materials (Figure 4-33, Figure 4-34, Figure 4-36 and Figure 4-36). Phosphorus and potassium concentrations were observed to be low and decreased gradually throughout the composting period. The loss of phosphorus during the composting period was probably due to the mineralization of organic phosphorus and the consumption by microbes (Huang *et al.,* 2004). These findings were explained by (Stryer, 1975) that for effective composting, phosphorus is utilized in the energy transfer process of cells and potassium helping to regulate the osmotic pressure of cells. Comparing all the experimental trials, Maize cob (1:2) maintained high concentration of plant nutrients (phosphorus and potassium) at the end of the compost process (Appendix C). The means of phosphorus and potassium content measured at the end of the experiment using ANOVA test highly differed from the means of the other experiments (p=0.000) (Table 4-21 and Table 4-22).

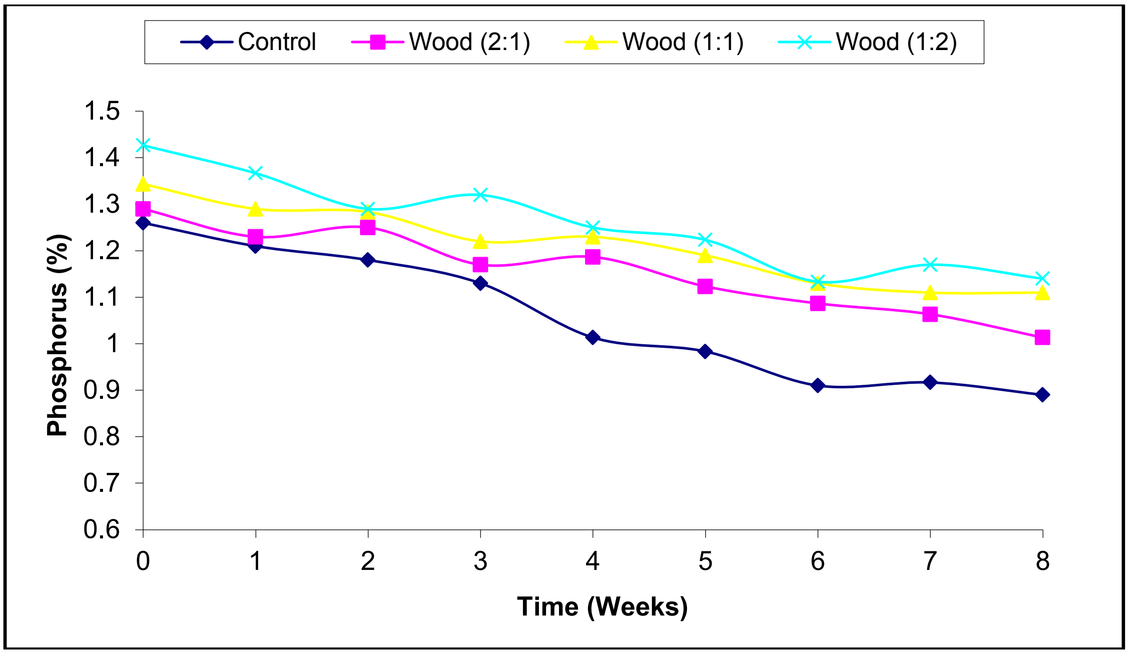

Figure 4-33: Variation of Phosphorus during composting with wood chips

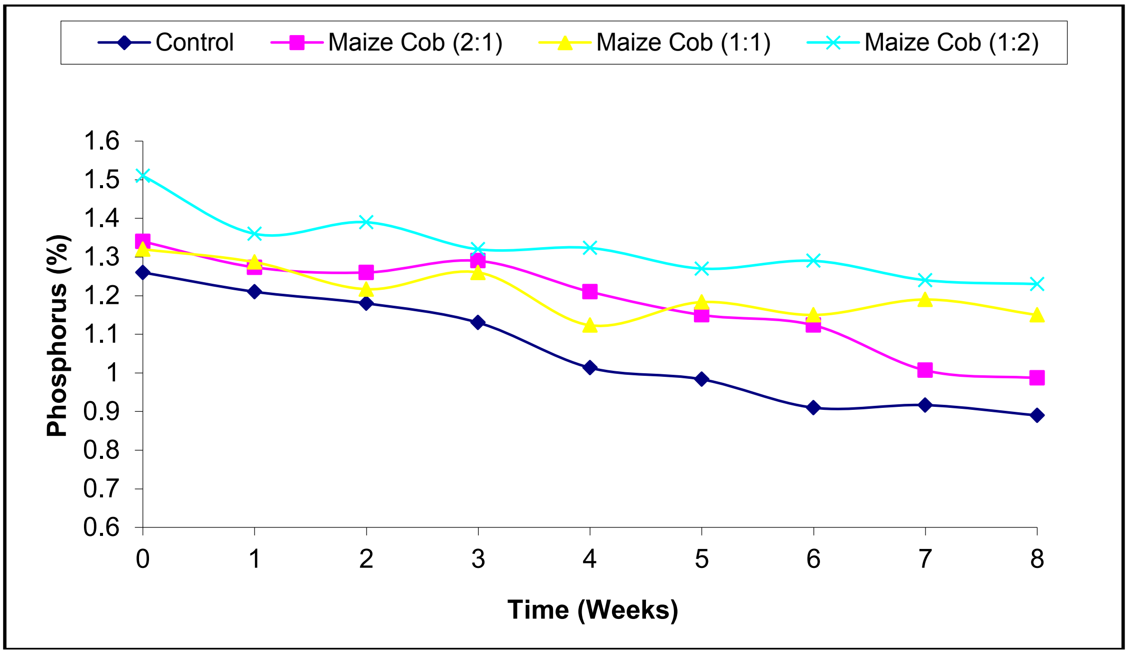

Figure 4-34: Variation of Phosphorus during composting with maize cobs

Table 4-21: ANOVA between means of phosphorus for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	0.383898	6	0.063983	6.05326	6.24E-05	2.265567

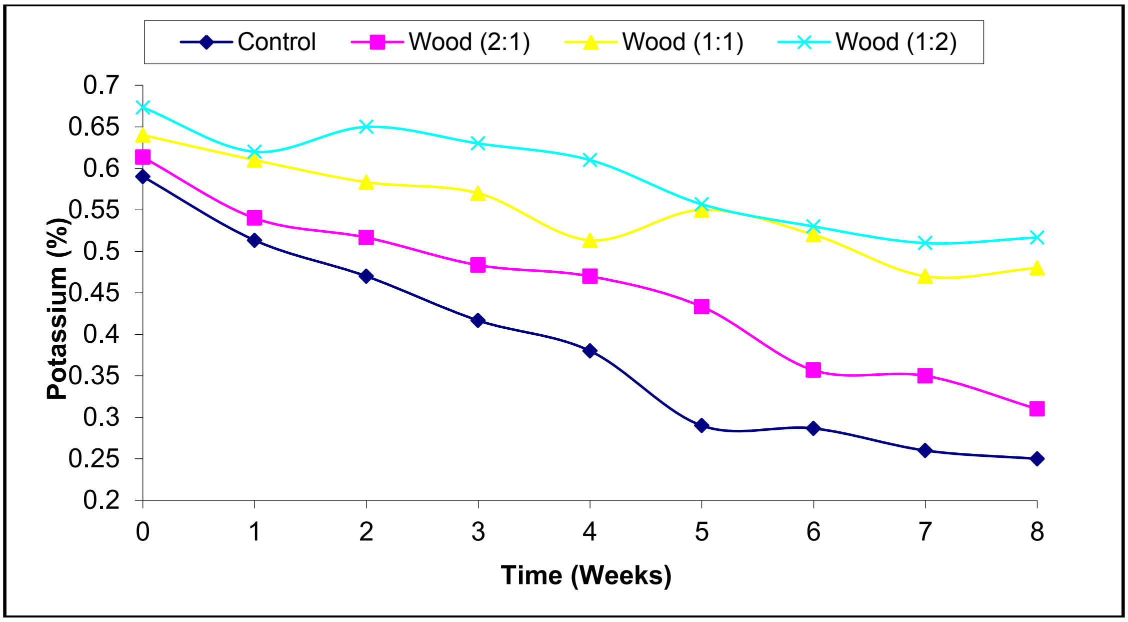

Figure 4-35: Variation of Potassium during composting with wood chips

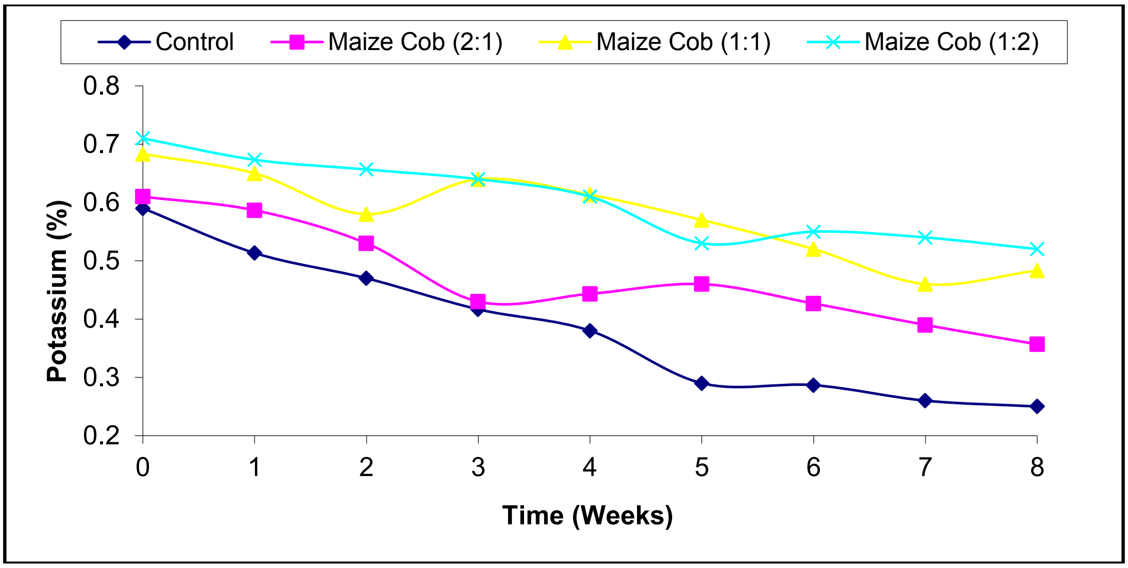

Figure 4-36: Variation of Potassium during composting with maize cobs

Table 4-22: ANOVA between means of potassium for the different experiments.

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between means	0.37118	6	0.061863	8.598174	1.24E-06	2.265567

4.5 Performance of the Rotary Drum Composter on the Die off of Helminth Eggs

4.5.1 Characteristics of compost feedstock

The general characteristics of the compost feedstock are presented in Table 4-23. The pH ranged from 6.7 to 7.9 for Cycle 1 and 6.9 to 8.1 for Cycle 2. The moisture content (MC) of all the different experimental set ups for the two trials were monitored before starting the compost process. The values of MC ranged from 52.1% to 52.9% and 50.3% to 54.6% for Cycle 1 and Cycle 2 respectively. These values were seen as desirable for efficient composting since the optimum MC content of 40% to 60% has been identified for optimum biological activity (Bernal *et al.,*1998; Zhu *et al.,* 2004; Goyal *et al.,* 2005). The C/N ratio is considered as an important factor that affect the quality of compost (Michel *et al*., 1996). The C/N ratio of the feedstock did not vary considerably as was expected (Table 4-23). This was so because the starting compost material and ratios were consistent for each of the experimental set ups and were within recommended range of 15 to 30 suggested by Haug (1993).

The total solids (TS) content of the starting material ranged from 45.4% to 49.7% for both the first and second cycles. *Ascaris* were observed to be prevalent in the studied communities compared to *Trichuris*. This is not surprising, because female *A. lumbricoides* worms produce 200'000 eggs per day compared to the 2'000-10'000 produced by *T. trichiura* (Feachem *et al.,* 1983). This is consistent with earlier studies conducted by Gazilli during a field study to reduce helminth eggs during co-composting of faecal sludge (Gazilli, 2003). Also, in Ghana the estimated *Trichuris* prevalence is much lower than the infection rate for *Ascaris:* 6.4% and 15.9% respectively (Hotez, 2006). The viability of helminths (*Ascaris* and *Trichuris*) population in the compost feedstock did not have wide variation.

Table 4-23: Summary of characteristics of compost feedstock

CYCLE	Compost Design	Parameters					
		pH	MC (%)	C/N (%)	TS (%)	% Viable *Ascaris*	% Viable *Trichuris*
Cycle 1	Metal Paddle(MP)	7.3	52.9%	27.9	47.1%	68%	91%
	Metal Baffle (MB)	7.9	53.1%	28.4	46.9%	84%	73%
	Plastic Paddle (PP)	7.1	52.2%	27.2	47.8%	79%	84%
	Plastic Baffle (PB)	6.7	52.1%	26.8	47.9%	71%	87%
Cycle 2	Metal Paddle (MP)	6.9	50.3%	28.5	49.7%	81%	83%
	Metal Baffle (MB)	7.4	54.9%	25.9	45.1%	75%	69%
	Plastic Paddle (PP)	8.1	53.8%	26.3	46.2%	89%	82%
	Plastic Baffle (PB)	7.8	54.6%	27.3	45.4%	76%	79%

4.5.2 Temperature development in compost

Composting is essentially a microbiological phenomenon that depends highly on temperature within the compost. The temperature within a composting material determines the rate at which many of the biological processes take place and it plays a selective role on the development and the succession of the microbiological communities (Hassen *et al.,* 2001). Three significant changes characterised temperature development during the composting process for all the experimental set ups in both Cycles 1 and 2. These were (i) the low activity stage with relatively low temperatures (mesophilic stage), (ii) the active stage during which there were high temperatures (thermophilic stage) probably resulting from high microbial activity, and (iii) the maturation stage where the compost temperatures stabilised at <10 °C above the ambient temperature. As it was indicated by Miller (1996), there is no general definition of the mesophilic and thermophilic range in temperature interval and it is difficult to determine an immutable border among them. Temperatures between 20 °C and 45 °C were considered to be within the mesophilic range; whereas 45 °C was considered the lower threshold temperature of the thermophilic phase (Ugwuanyi *et al.,*1999).

At the initial stage of composting, a fast increase in temperature was observed in both Cycles 1 and 2, which indicated signs of microbial activity. Typical temperature profiles for Cycle 1 and Cycle 2 are, shown in Figure 4-37 and Figure 4-38.The ambient temperature ranged from 25 ^{o}C to 33 ^{o}C for Cycle 1 whiles that of Cycle 2 ranged from 25 ^{o}C to 35 ^{o}C. During Cycle 1, thermophilic temperatures were obtained few days after starting the compost. Experiment MP attained thermophilic temperatures (>/=45 ^{o}C) on the third day whereas it took 4 days for thermophilic temperature to be recorded for experiments MB, PP and PB. Experiment PP had the highest temperature of 62 ^{o}C recorded on the 8th day. Meanwhile experiments MP, MB and PB recorded highest temperatures of 56 ^{o}C, 55 ^{o}C and 58 ^{o}C on days 9, 8 and 8 respectively. Thermophilic temperatures lasted for 11 to 21 consecutive days for all the experiments with PB having the longest number of days (Figure 4-37). The Figure 4-37 shows the temperature increasing rapidly initially to maximum values and then the profile decreased gradually and flattened as time continued in all cases. In Cycle 2, temperature development were similar to those recorded in Cycle 1. A maximum temperature of 54 ^{o}C was reached after 3 days in experiment PP. Meanwhile maximum temperatures observed for experiments MP, MB and PB were 50 ^{o}C, 53 ^{o}C and 52 ^{o}C respectively. Thermophilic temperature lasted for 12-17 days. It was observed that thermophilic temperatures ended between day 16 and 22 after composting (Figure 4-38). Similar temperature profiles were recorded in Cycle 2 as compared to Cycle 1. The highest temperatures attained in both Cycle 1 and Cycle 2 were indication that the temperature theoretically required to ensure the die off of pathogens including *Ascaris* and *Trichuris* eggs were reached in all cases of the experimental set ups. The number of days for which composts could sustain high temperatures in the experimental set-ups might have been influenced by the composter material, the mode of turning, provision of coating and insulation (Figure 4-37 and Figure 4-38). The results from this experiment confirmed that sufficient insulation is required to maintain high thermophilic temperatures for a long time to ensure an efficient disinfection of faecal matter during composting Vinnerås (2002). Also it could be presumed that there was a higher population of microorganisms responsible for degradation and that might have speeded up the process resulting in higher temperatures of the compost of all the experimental trials although this parameter was not directly assessed. The mixing regime exposed different parts of the compost for microbial degradation of carbon and this could result in an increase in temperature. That notwithstanding frequent mixing of compost might not be necessary once the organic matter content of the compost has been reduced. The rotary composters with paddles were observed to enhance effective mixing as compared to their respective composter with baffles. Thus thermophilic temperature generated by the composters showed the following trend; PP>PB>MP>MB.

The general trend in temperature development across all the experiments showed a continuous decrease in temperature after about 3 weeks from initial start of the compost. The declining temperatures might be as a result of the reduction in the quantities of available degradable materials (organic matter) upon which microorganisms could feed. Though there were little difference in the highest temperatures recorded for each of the experiments, there existed a potential for heat to be lost in the metal fabricated rotary composters as metal looses temperature easily compared to the plastic fabricated rotary composters. Thus the metal rotary drums sustained temperatures for a relatively shorter time. Based on these experiments, the initial observation suggested certain design parameters and considerations were necessary to achieve thermophilic temperatures.

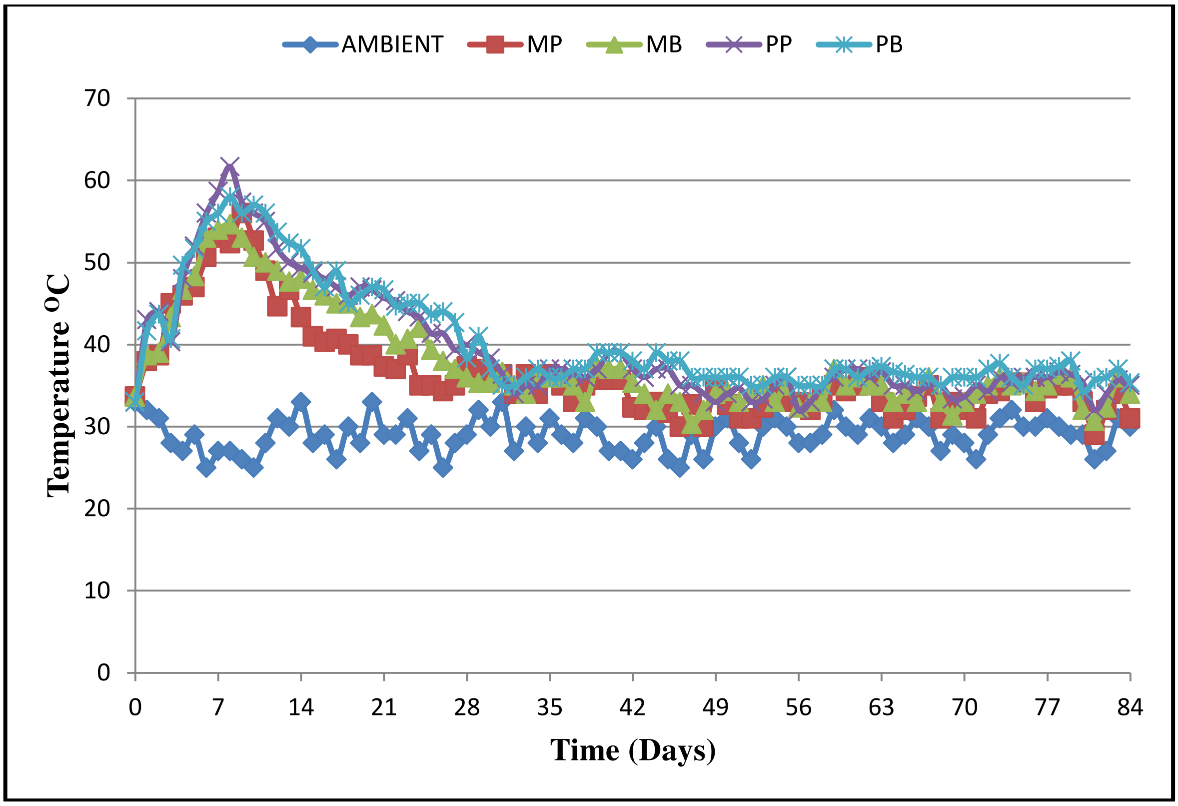

Figure 4-37: Temperature profile for cycle 1 during composting process

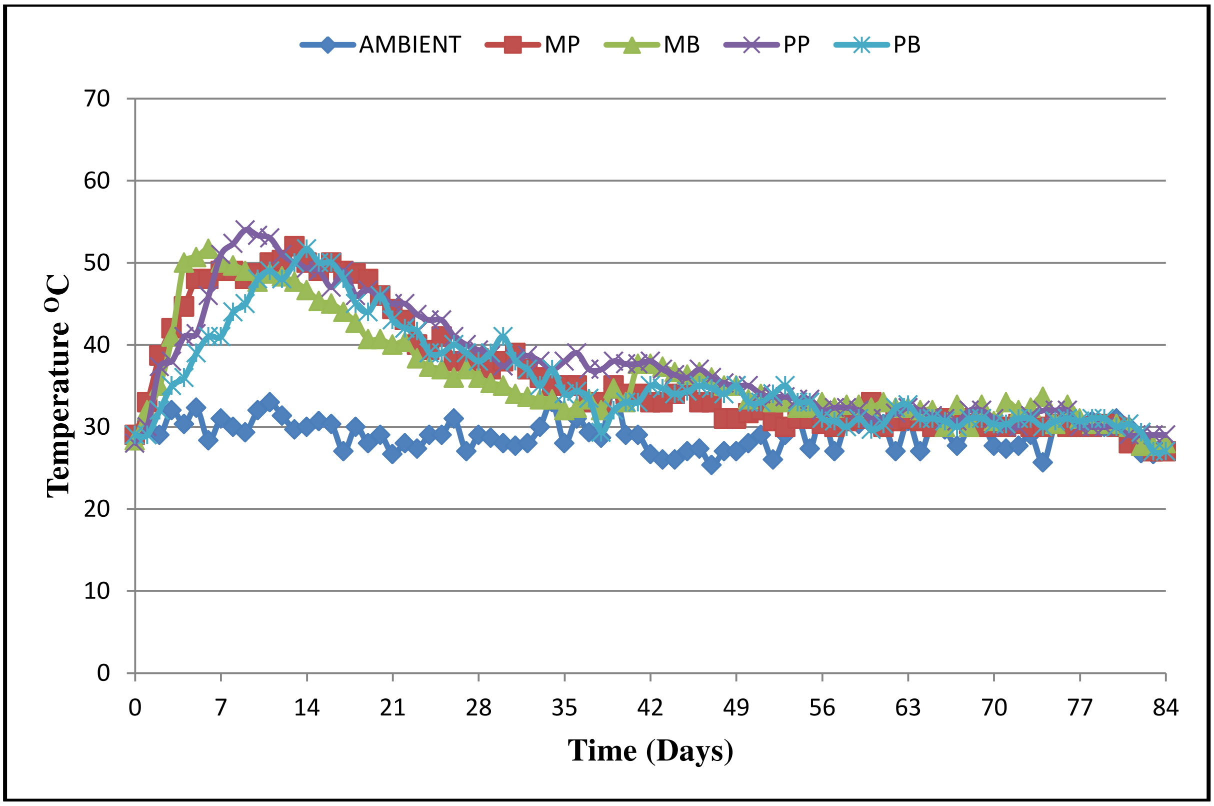

Figure 4-38: Temperature profile for cycle 2 during composting process

4.5.3 Concentration of Ascaris and Trichuris eggs in sample

The concentration of *Ascaris* and *Trichuris* eggs of Cycle 1 ranged from 65-77 eggs/gTS and 30-41 eggs/gTS respectively at the beginning of the experiment (Appendix C). In Cycle 2, *Ascaris* concentration at beginning of the experiment ranged from 77-110 eggs/gTS whereas *Trichuris* eggs ranged from 46-52 eggs/gTS (Appendix C). This results is an indication that all the samples analyzed were infected with helminth eggs. In each of the experiments, *Ascaris* eggs were observed to be prevalent as compared to *Trichuris*. However, the variations obtained in each of the experiment showed the degree of infection. This means that in all the experiments the helminth eggs (*Ascaris* and *Trichuris*) concentration was well above (more than 40-105 times) the recommended value for safe use in agriculture (WHO guideline of Eggs≤ 1/gTS).

Figure 4-39 and Figure 4-40, illustrates the gradual decrease of *Ascaris* and *Trichuris* eggs concentration over the 12 weeks of composting. In Cycle 1, *Ascaris* concentration dropped from initial values at the beginning to final values of 1-13 eggs/gTS for all the experiments (Figure 4-39). There was a sharp decrease in *Ascaris* concentration from day 0 to the 14th day. The decline in *Ascaris* concentration subsequently was fairly consistent for all the experiments except PP experiment. There was an unexpected marginal increase in *Ascaris* concentration for PP experiment on day 21 before it subsequently dropped till the end of the experiment. This might be attributable to favourable conditions (adequate moisture and aeration) present for their growth. The largest percentage die off (98%) of *Ascaris* was observed in experiment PP. Percentage die off observed in the other experiments were MP (88%), MB (90%) and PB (92%) (Appendix C). There was significant difference in the mean number of *Ascaris* eggs among the four experimental set-ups in Cycle 1 with the highest number of eggs recorded in the MB experiment (30.1 eggs/g) and the least by the PB experiment (16.2 eggs/g, p=0.0047, (Appendix C). The concentration of *Trichuris* decreased to 1-4 eggs/gTS at the end of composting (Figure 4-40). PP experiment had the lowest concentration (1 egg/gTS) compared to MP experiment with the highest concentration (4 eggs/gTS) in the compost at the end of the experiment. *Trichuris* eggs experienced a significant drop in concentration by the 7-28th day and afterwards decreased steadily till the end of the experiment (Figure 4-40). However, there was an increase in the concentration of *Trichuris* in MB experiment on the 77th day. This situation was not expected after the long exposure of compost to adequate sanitizing temperature. The reason could be as a result of sample location as *Trichuris* appears to survive longer in corner samples than centre samples. However, in all the experiments, *Trichuris* die off at the end of the experiment was statistically significant ($p<0.0001$) when compared with their initial concentrations (Appendix C).

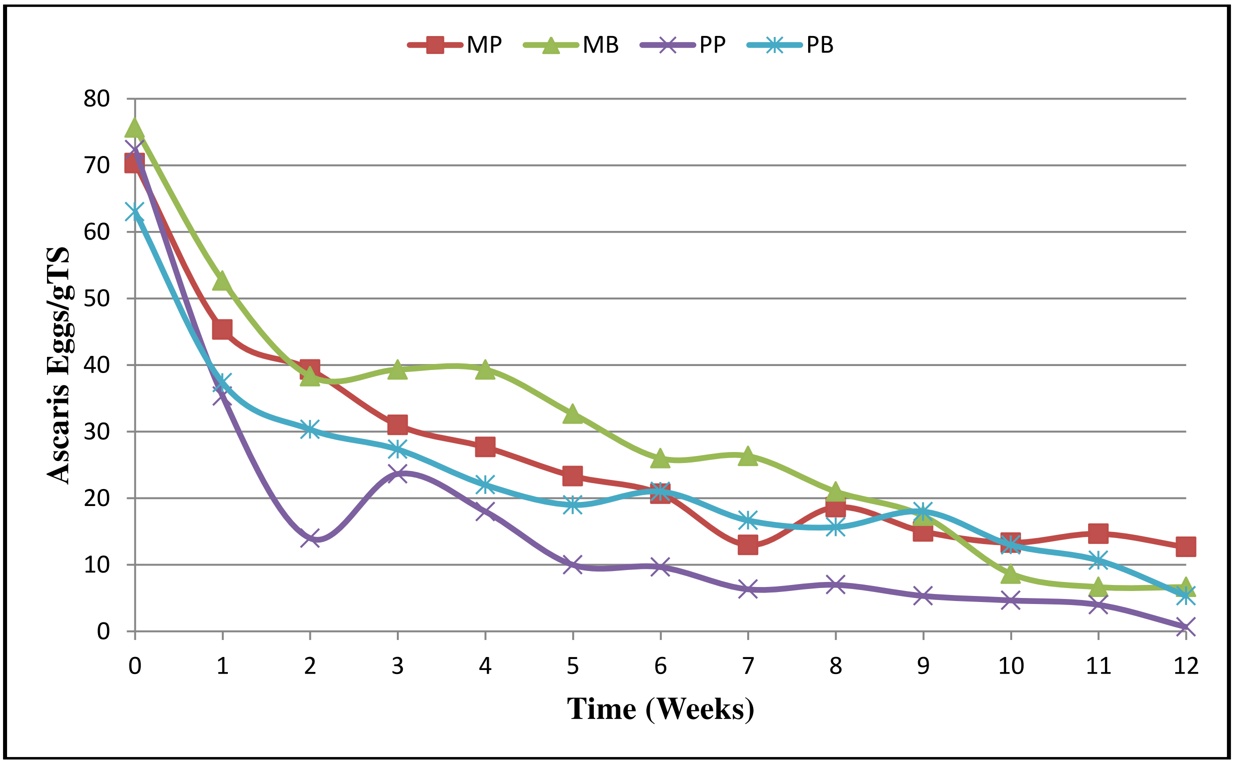

Figure 4-39: Profile of Ascaris concentration for cycle 1 during composting

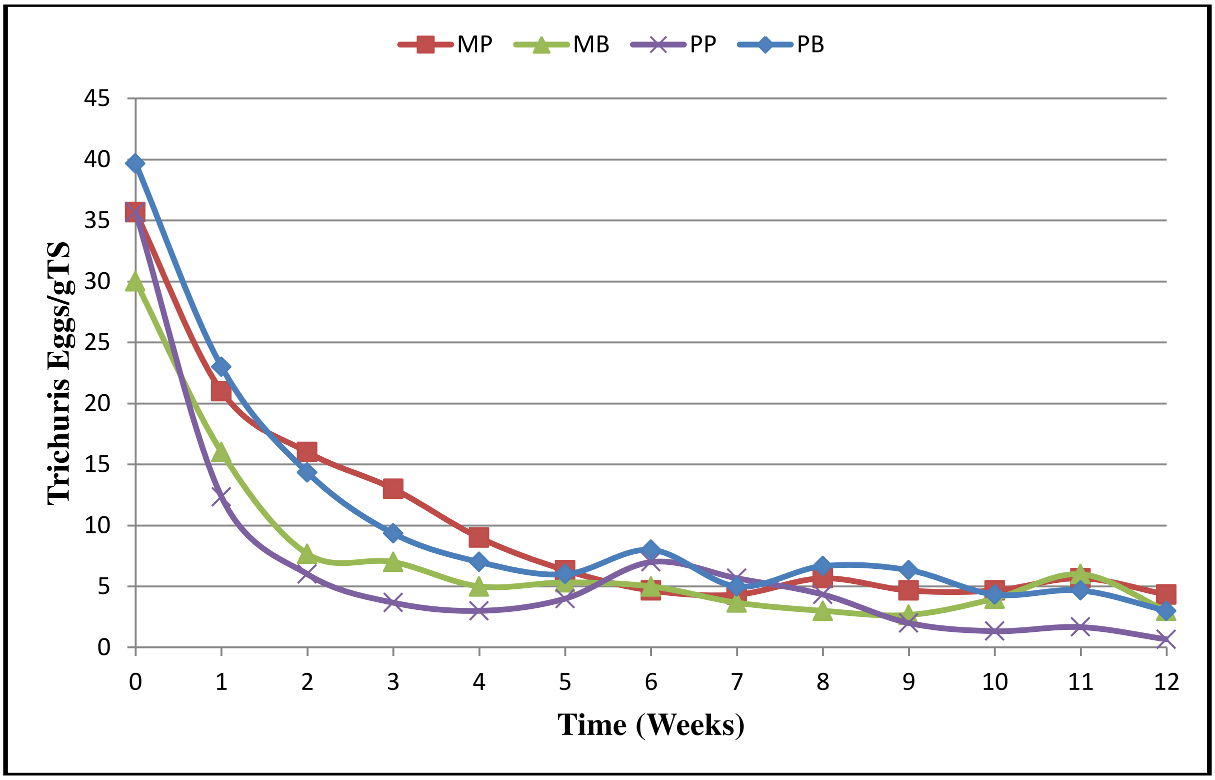

Figure 4-40: Profile of Trichuris concentration for cycle 1 during composting

The Figure 4-41and Figure 4-42 shows the results of *Ascaris* and *Trichuris* concentration in Cycle 2. At the start of the experiment, the concentration of *Ascaris* ranged from 95-105 eggs/gTS compared with *Trichuris* which ranged from 40-52 eggs/gTS. The initial concentration of *Ascaris* eggs in g/TS were as follows, MP=103, MB=95, PP=105 and PB=98 (Figure 4-41). The number of *Trichuris* eggs present in the initial sample was larger in MB experiment (52 eggs/gTS) compared with the least in MP experiment (40 eggs/gTS)(Appendix C). There was a general and consistent decline in *Ascaris* and *Trichuris* concentrations to a minimum at the end of the experiment (Figure 4-41 and Figure 4-42). MP, MB, PP and PB experiments declined to 5, 3, 0 and 2 eggs/gTS for *Ascaris* at the end of composting. Meanwhile the decline in *Trichuris* concentration was 1, 2, 0 and 2 eggs/gTS for MP, MB, PP and PB experiments respectively at the end of composting. Similar results in decline in *Ascaris* and *Trichuris* concentrations were reported during co-composting of faecal sludge and other organic waste materials (Gazilli, 2003). The reason for the consistent decrease is attributable to the fact that the thermophilic temperatures obtained were adequate to destroy both *Ascaris*. This thermophilic temperatures increase the rate of die off of *Ascaris* by increasing the desiccation rate of cells. Eventually the cell can no longer slow down the rate of desiccation and dies (Pecson *et al.,* 2007). It is worthy to note that no *Ascaris* and *Trichuris* eggs were observed in experiments PP. This might be due to the fact that the material for the composter was able to sustain relatively high temperatures whiles enabling effective mixing regime as a result of the mixing configuration in relation to the other experiments. However, in all the experiments, *Ascaris* and *Trichuris* die off at the end of the experiment were statistically significant ($p<0.0001$) when compared with their initial concentrations (Appendix C).

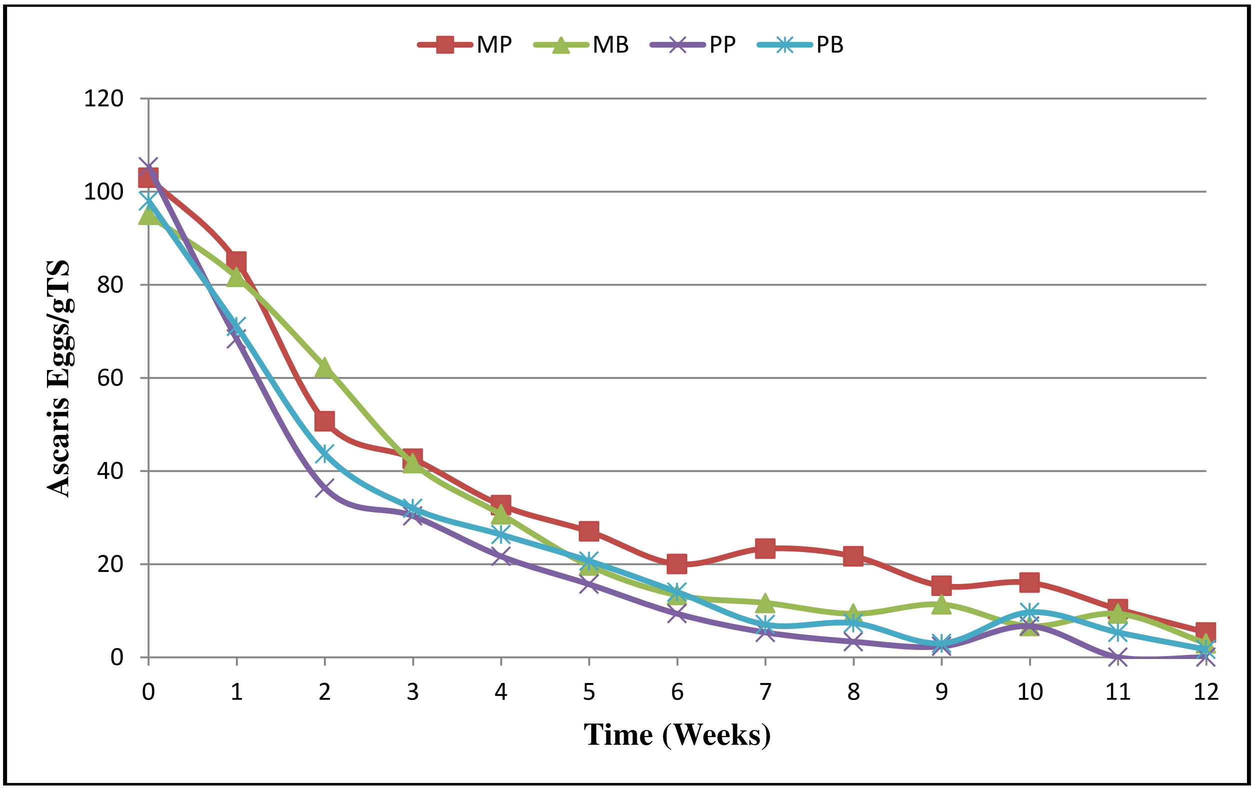

Figure 4-41: Profile of Ascaris concentration for cycle 2 during composting

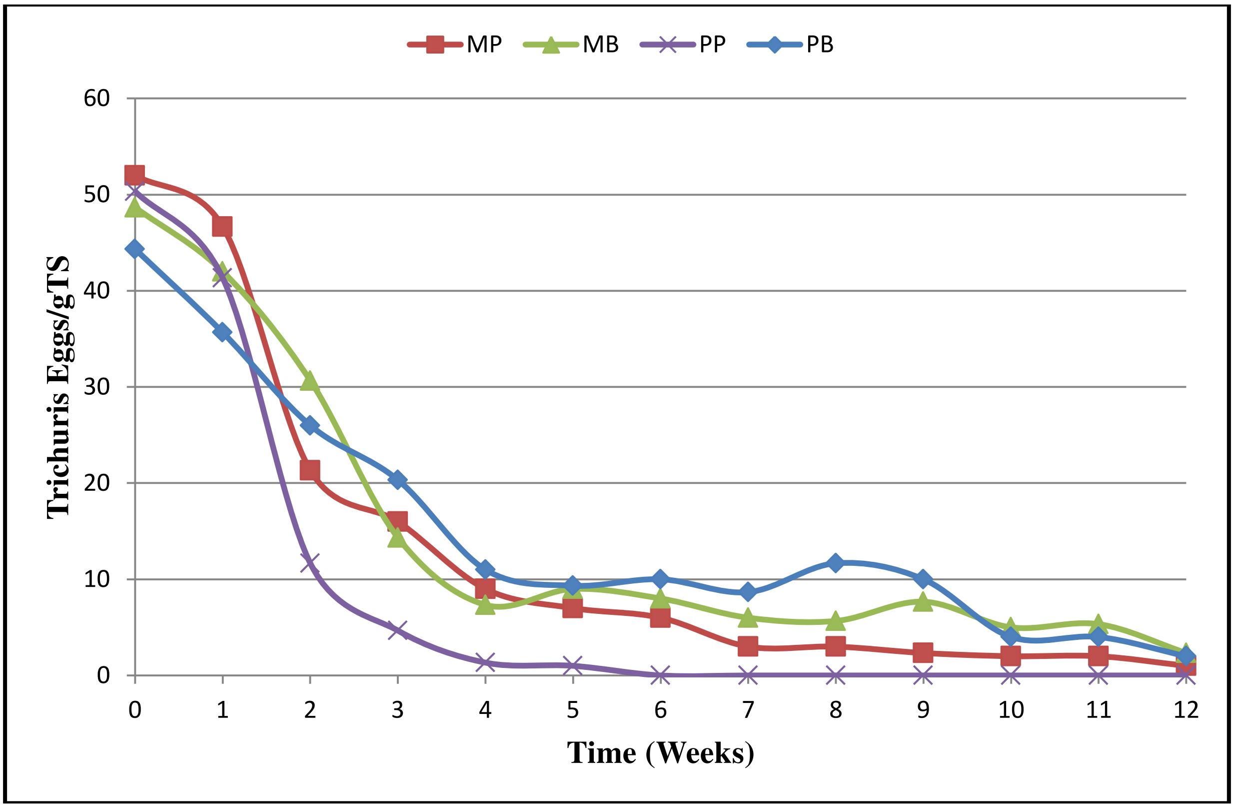

Figure 4-42: Profile of Trichuris concentration for cycle 2 during composting

4.5.4 Analyses of factors associated with Ascaris and Trichuris die off

Statistical analyses (univariable and multiple variable) was conducted to ascertain whether there was an obvious association between the experimental set up (the composter material and mixing configuration) and the concentration of *Ascaris* and *Trichuris* eggs (Table 4-24 and Table 4-25).

From Table 4-24, temperature, time of composting and the experimental set ups were all observed to be associated with *Ascaris* die off in the multiple variable analysis in both Cycles 1 and 2. The time of composting had the most significant impact on *Ascaris* die off, where every one week after composting was associated with a reduction of 4.6 and 8.3 eggs/gTS of *Ascaris* in cycles 1 and 2 respectively Table 4-24. For cycle 1, all experimental set-ups were associated with *Ascaris* die off and PP experiment was more likely to result in a highest reduction of 13 eggs/gTS of *Ascaris* compared to MB, MP and PB experiments. In Cycle 2, however, only PP experiment was significantly associated with *Ascaris* die off, and could result in a reduction of 6.8 eggs/gTS. The association between PB experiment and *Ascaris* die off rates was at borderline significance (p= 0.06, Table 4-24).

For *Trichuris* eggs, during Cycle 1 only temperature and time of composting were observed to be significantly associated with die off in the multiple variable analysis (Table 4-25). A comparison of the various experimental set ups showed that only PB experiment was associated with *Trichuris* die off and was likely to result in a reduction of 3 eggs/gTS compared to MP, MB and PP experiments. The case was different for Cycle 2 where all the experimental set ups were associated with *Trichuris* die off. PP experiment was observed to be more likely to result in a reduction of 6 eggs/gTS at a significant difference of p=0.040 (Table 4-25).

The findings are consistent with Hays (1976) and Sangiunetti *et al.* (2005), who found that the efficiency in the die off of helminth eggs depended on time and temperature. In addition type of experimental set up was observed to be another factor that could influence the rate of *Ascaris* and *Trichuris* die off during the composting process. PP experiment was efficient since it reached satisfactory die off of both viable *Ascaris* and *Trichuris* eggs.

Table 4-24:Univariable and multiple variable analyses of factors associated with Ascaris die off

	Univariable analysis				**Multivariable analysis**		
Parameter/variable	**N**	**coefficient**	**95% CI**	**p-value**	**Change in mean**	**95% CI**	**p-value**
Ascaris (Cycle 1)							
Temperature	156	0.726	0.319 – 1.132	0.001	-0.670	-0.915, -0.425	<0.001
Time (weekly)	156	-3.912	-4.349, -3.474	<0.001	-4.602	-5.035, -4.169	<0.001
Experimental set up	156	-4.497	-6.941, -2.054	0.0047	-4.008	-5.206, -2.811	<0.001
Metal baffle	39	Baseline					
Metal paddle	39	-3.513	-11.282, 4.256	0.373	-4.372	-8.109, -0.635	0.022
Plastic baffle	39	-7.026	-14.795, 0.743	0.076	-5.599	-9.359, -1.839	0.004
Plastic Paddle	39	-13.821	-21.589, -6.052	0.001	-12.875	-16.615, -9.135	<0.001
Ascaris (Cycle 2)							
Temperature	156	1.483	0.861 – 2.105	<0.001	-1.313	-1.694, -0.931	<0.001
Time (weekly)	156	-6.699	-7.342, -6.057	<0.001	-8.267	-8.977, -7.556	<0.001
Experimental set up	156	-2.926	-7.066, 1.215	0.165	-2.687	-4.535, -0.839	0.005
Metal baffle	39	Baseline					
Metal paddle	39	4.410	-8.710, 17.530	0.508	3.165	-2.621, 8.951	0.282
Plastic baffle	39	-4.308	-17.428, 8.812	0.518	-5.519	-11.305, 0.266	0.061
Plastic Paddle	39	-6.846	-19.966, 6.274	0.304	-6.072	-11.851, -0.293	0.040

Table 4-25: Univariable and multiple variable analyses of factors associated with Trichuris die off

	Univariable analysis				Multiple variable analysis		
Parameter/variable	**N**	**coefficient**	**95% CI**	**p-value**	**Change in mean**	**95% CI**	**p-value**
***Trichuris* (Cycle 1)**							
Temperature	156	0.262	0.054 – 0.469	0.014	-0.424	-0.593, -0.254	<0.001
Time (weekly)	156	-1.695	-1.964, -1.426	<0.001	-2.131	-2.431, -1.832	<0.001
Experimental set up	156	-0.236	-1.510, 1.038	0.715	0.079	-0.776, 0.935	0.855
Metal baffle	39	Baseline					
Metal paddle	39	2.821	-1.164, 6.805	0.164	2.277	-0.308, 4.862	0.084
Plastic baffle	39	3.00	-0.984, 6.984	0.139	3.90	1.301, 6.502	0.004
Plastic Paddle	39	-0.846	-4.830, 3.138	0.675	-0.249	-2.836, 2.338	0.850
***Trichuris* (Cycle 2)**							
Temperature	156	0.735	0.410, 1.061	<0.001	-0.575	-0.830, -0.319	<0.001
Time (weekly)	156	-3.210	-3.610, -2.813	<0.001	-3.896	-4.372, -3.420	<0.001
Experimental setup	156	-1.526	-3.678, 0.6270	0.163	-1.419	-2.653, -0.185	0.024
Metal baffle	39	Baseline					
Metal paddle	39	-1.590	-8.396, 5.217	0.645	-2.135	-6.009, 1.739	0.278
Plastic baffle	39	0.385	-6.422, 7.191	0.911	-0.146	-4.019, 3.728	0.941
Plastic Paddle	39	-5.744	-12.550, 1.063	0.098	-5.405	-9.274, -1.535	0.007

4.5.5 Viability of helminth eggs in final compost

The viability of helminth eggs were determined at the end of the composting process. The results from the microscopic evaluation of *Ascaris* and *Trichuris* are presented in Table*4-26*. Of the four experiments in Cycle 1, two (2) contained viable *Ascaris* eggs whereas the remaining two (2) did not record any eggs. MB experiment exhibited the highest average number of *Ascaris* eggs (2 eggs/gTS) compared with MP experiment with only 1 viable *Ascaris*egg (Table 4-26). No eggs were detected in PP and PB experiments at the end of the composting process. The situation was however not much different from that enumerated for *Trichuris* eggs. Only 1 viable *Trichuris* egg each was found in MB and PB experiments whiles no egg was detected in MP and PP experiments (Table 4-26).

During Cycle 2, viable *Ascaris* eggs were detected in all the four experiments, with MP presenting the average highest number of 2 viable eggs/gTS (Table 4-26). All the remaining three experiments that is, MB, PP and PB each exhibited 1 viable *Ascaris* egg/gTS. There was no viable *Trichuris* eggs detected in experiments MB, PP and PB. Meanwhile in experiment MP, 1 viable *Trichuris* egg was detected at the end of the composting process (Table 4-26). The results indicated that the temperatures obtained in all the experiments were able to destroy cells of the *Ascaris* and *Trichuris* as a result of the die off of cellular enzymes (Haug, 1993). The difference in the viability of *Ascaris* and *Trichuris* eggs in the final compost could be explained by the fact that thermal die off of pathogens (*Ascaris* and *Trichuris*) was a function not only of temperature and exposure time (de Bertoldi *et al.,* 1988) but also the behaviour of the pathogen.

It was seen that the viability of the counted eggs for both *Ascaris* and *Trichuris* decreased in the course of the experiment (Table 4-26). This was an indication that the quality of the compost obtained in PP and PB experiment met the WHO guidelines of ≤1 helminth egg/gTS for agricultural reuse without restriction.

Table 4-26: Prevalence of Ascaris and Trichuris eggs in compost

	Prevalence of *Ascaris* and *Trichuris* Eggs in Compost						
Cycle	**Compost Design**	***Ascaris* Eggs/g TS**			***Trichuris* Eggs/g TS**		
		Start of compost	**End of compost**	**Die off**	**Start of compost**	**End of compost**	**Die off**
Cycle 1	Metal Paddle	70	13 (1)	82%	36	4 (0)	88%
	Metal Baffle	75	7 (2)	91%	30	3 (1)	90%
	Plastic Paddle	72	1 (0)	99%	36	1 (0)	98%
	Plastic Baffle	63	5 (0)	92%	40	3 (1)	92%
Cycle 2	Metal Paddle	103	5 (2)	95%	52	1 (1)	98%
	Metal Baffle	95	3 (1)	97%	49	2 (0)	96%
	Plastic Paddle	105	0 (0)	100%	50	0 (0)	100%
	Plastic Baffle	98	2 (1)	98%	44	2 (0)	95%

NB: Number of Viable Eggs in Parenthesis

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This thesis piloted the composting of faecal sludge from peri-urban Ghana using the rotary drum technology. This was to assess the performance and feasibility of using the rotary drum as a means of managing faecal sludge in peri-urban areas where faecal sludge treatment facilities are usually absent.

5.1 Conclusions on Research Objectives

5.1.1 Assessment of faecal sludge management in peri-urban areas

The study showed poor faecal sludge management in the peri-urban and rural areas. That notwithstanding, faecal sludge in the peri-urban areas were relatively better managed than in the rural areas. However, there was the need to improve faecal sludge management in both the peri-urban and the rural areas. There were no arrangements in place to manage faecal sludge completely at the district level. There were no designated locations for disposal and treatment of faecal sludge in the study district for the treatment of sludge from septic tanks and pit latrines. For the household toilet, the faecal sludge management practice were as follows: households desludge their toilet with cesspit emptiers and transported it to the final disposal site in Kumasi, an average 40 km from the study areas. The few peri-urban respondents who desludged their toilets (3.7% with household toilets) use WCs with a septic tank. The respondents using dry sanitation technologies tried to postpone desludging by adding chemical additives such as dichlorodiphenyltrichloroethane (DDT) and calcium carbide which has long term effect on the environment.

5.1.2 Perception of peri-urban farmers on faecal sludge compost and its utilization

The study concluded that the majority of the farmers belonged to an economically active age group. The majority of farmers (about two-thirds) were not aware of the many advantages associated with the use of faecal sludge compost and the benefits associated with sanitation issues. Even those who admitted that it could be a good resource to the soil were not aware that it could be treated to give a final product that is easy and hygienic to use, as such the prejudice towards the idea of using it. A very helpful and effective means of addressing the disincentive of using faecal sludge and other organic fertilizers is through intensive education and public awareness creation on the advantages of using faecal sludge compost and its environmentally friendly nature. This is likely to encourage farmers to patronize this valuable resource. Lack of awareness appeared to play a key role in the unwillingness by a section of the farmers in peri-urban areas to use faecal sludge compost to fertilize their farms. Farmers seemed to be more concerned about how society will react towards them if they use faecal sludge compost. To most farmers the handling of any faecal sludge product was meant for a particular group of people, thus only "night soil men" should handle faecal sludge. This meant that cultural beliefs associated with the handling of faecal sludge was a barrier to its use as fertilizer. Although farmers showed some health concerns about the utilization of faecal sludge compost, the main factor that discouraged them from using it was the social rejection associated with the subject of faecal sludge.

5.1.3 Characteristics of faecal sludge from public latrines

The results of the study showed that faecal sludge from rural areas within the study site was slightly alkaline and presented a significant high salt concentration as compared to that of peri-urban areas. Nonetheless, the pH values measured from both peri-urban and rural areas were within favourable limits for the growth and activities of microorganisms. Generally, the result of analyses of faecal sludge samples over the study period showed some variations. These results therefore, indicate that the location, that is either peri-urban or rural have a significant influence on the variability of sludge. The study also showed that the values for EC, BOD, COD, NH_3-N, NO_3-N, TKN and nutrients for both peri-urban and rural sludge were generally high compared to that in literature. This confirmed that faecal sludge are potential pollution sources and should be treated before discharge into the environment.

Also, the levels of heavy metals and microbial quantities were generally higher in peri-urban areas compared to rural areas. The variations in monitored parameters could be explained by a high sludge age or a high retention time of sludge in rural public toilets which may increase the mortality of faecal microorganisms. However, heavy metals from both peri-urban and rural areas were much lower than the maximum soil metal concentrations for agricultural land application of biosolids.

5.1.4 Effect of bulking materials and mixing ratios on the characteristics of peri-urban faecal sludge compost

Composting of faecal sludge and bulking material is seen as a potential recycling tool. The study showed that the addition of bulking materials enhances the composting process as a result of its ability to accumulate and retain heat generated and achieve high organic matter degradation. Despite the differences in the bulking materials and mixing ratios, the characteristics of all the experimental trials with wood were quite similar to that of the maize cobs with the exception of temperature. All the experimental trials were not adequately exposed to high temperatures (below $45^{o}C$) during a sufficient period to guarantee pathogen die off.

The C/N ratio is widely used as an indicator of compost maturation and should become stable with time. The final C/N ratios of approximately 10 to 20 for all the experimental trials indicated that the compost were matured and they would be good sources of nitrogen. It can generally be concluded that wood chip and maize cob can be considered a good bulking material for use with faecal sludges. All the mixing ratios assayed allowed composting to develop adequately compared to the control. However, the experimental trial, Maize cob (1:2) produced the best compost compared with Wood (2:1), Wood (1:1), Wood (1:2), Maize cob (2:1) and Maize cob (1:1). This was due to the fact that it contained more NPK and also C which are essential nutrients for plant growth and for improving on the soil organic matter content respectively hence increasing its soil fertility improvement value. Although the final compost materials appeared to be suitable for agronomic use, the levels of the three major nutrient elements (N, P, and K) of the finished product of compost were not high enough compared to inorganic fertilizer.

5.1.5 Performance of the rotary drum composter on the die off of helminth eggs

The study showed that faecal sludge from public latrines in peri-urban areas of Ashanti region of Ghana was highly contaminated with helminth eggs (*Ascaris* and *Trichuris*). Even though helminth eggs were more resistant than other microorganisms, it was possible to significantly reduce their concentration by composting. It was found out that temperature affected the die off rate. The heat generated by the composting process exposed the helminth eggs to thermophilic temperatures for a sufficient duration hence high removal rate was achieved at the end of composting. There was a significant impact of different rotary drum materials and mixing configuration on the die off of helminth eggs. The helminth eggs population decreased significantly in all the experimental set-ups during the composting process. The average die off of helminth was similar in both Cycle 1 and Cycle 2 but highest in plastic paddle experiment than that of metal baffle, metal paddle and plastic baffle experiments. The results of all the experiments showed values very close to the WHO guidelines of 1 egg/gTS. The final compost of plastic paddle experiment showed impressive die off in eggs which are within acceptable ranges of no risk of less than 1 egg/gTS. This meant that plastic paddle experiment was favoured over metal baffle, metal paddle and plastic baffle experiments due to the fact that it contained less helminth eggs which satisfy the WHO guideline. Thus the type of composter had significant impact on the die off of *Ascaris* and *Trichuris*.

The study showed that composting of raw faecal sludge and shredded maize cobs using either plastic or metal rotary drum with baffle or paddle was an effective means of reducing helminths population in faecal sludge intended for agricultural use as soil conditioner or an organic fertilizer. The combination of plastic and paddle configuration was shown to be best for the composting of raw faecal sludge and shredded maize cobs.

5.2 Research Contribution to Knowledge

This research contributed to knowledge in a number of ways, specifically related to faecal sludge management in peri-urban areas. The study made an important contribution to understanding how the rotary drum composter could be used to improve the management of faecal sludge service delivery in peri-urban areas.

The design of a faecal sludge treatment facility required accurate data of status of faecal sludge management and faecal sludge characteristics and quantities to properly size and select operational parameters. The research confirmed the absence of no proper faecal sludge treatment facilities in the peri-urban and rural areas of Ghana. The research further provided information on how faecal sludge was managed in peri-urban areas, acknowledging that there are usually no faecal sludge treatment facilities in such areas. This meant that majority of inhabitants in peri-urban areas do not treat their faecal sludge before final disposal of reuse. Also, the research provided empirical evidence on the characteristics of faecal sludge from peri-urban areas.

The study contributed to the sanitation sector by providing information on the perception of peri-urban farmers in using faecal sludge compost as an organic fertilizer option. This allowed the use of faecal sludge compost to be compared with other organic and inorganic fertilizers. The research presented an argument for the need to focus more attention on creating awareness on the use of faecal sludge compost to ensure a reduction in the sanitation menace whiles achieving resource recovery.

Although different bulking materials had been used in different mixing ratios during the composting of faecal sludge, the study extended existing knowledge on the significance of bulking materials. The results from the research revealed that wood chips and shredded maize cobs could be considered good bulking materials for use with faecal sludge. The study suggested that experimental trial of Maize cob (1:2) was better than wood chips when used as bulking material for compost. The study supported the need to explore other bulking materials based on their availability in the community to improve compost produced from faecal sludge.

Although, rotary drum composter had been used to compost solid waste and sewage sludge around the world, to the best of the knowledge of the author, this study was the first to generate empirical data on the performance of the rotary drum composter on the die off of *Ascaris* and *Trichuris* eggs during composting of peri-urban faecal sludge. Besides the generation of knowledge on the performance of the rotary drum composter on the die off of *Ascaris* and *Trichuris* eggs during composting of peri-urban faecal sludge.

5.3 Practical Application of Rotary Drum Composter

The rotary drum faecal sludge composter can be applied in peri-urban areas. The experimental set up with a volume of 130 litres has demonstrated that the rotary drum composter is an efficient and promising technology to treat faecal sludge at the household level. In addition the technology can be extended for institutional and public/communal blocks Urine Diverting Dry Toilet (UDDT) latrines and other composting toilet technologies.

The specific component that can be applied is the rotating paddle (mixer). This technology will be used to turn the compost in the vaults of the latrine which was previously turned with a shovel. It can be used in the following situations:

- household double vault UDDT latrines
- institutional double vault UDDT latrines
- public and communal double vault latrines

Overall the technology will reduce the cost of hauling faecal sludge over long distances to treatment sites and also significantly reduce the human-faeces contact, thus improving public health.

5.4 Recommendations

Recommendations based on the findings of this research are discussed below:

- Farmers should be educated by agric extension officers on proper use and application of faecal sludge compost as an organic fertilizer option
- In other to obtain a coherent and consistent data of the characteristics of faecal sludge, there is the need to conduct further studies in different locations at different seasons to examine the factors that influence the variability between peri-urban and rural sludge.

- Further studies on the effect of aeration on the performance of the rotary drum composter during composting.
- It is recommended that pilot studies on the use of the rotary drum composter as faecal sludge treatment technology be carried out
- Finally, it is recommended that the full life cycle cost analysis be done on the rotary drum technology and compare with other non conventional faecal sludge treatment technologies.

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APPENDICES

APPENDIX A: Questionnaires and Interview Guides

Key Informant Interview Guide assembly member and water and sanitation management team

Name of Interviewer:	Date:
Region:	District:
Name of Interviewee:	Position:

1. How many people are in the community?	
Number of Children (Less than 18 years)	
Number of Male Adult	
Number of Female Adult	
2. What is your role in ensuring proper sanitation and faecal sludge service delivery in the community?	
3. What are the main toilet technologies available in the community?	
4. Where do households defaecate?	
5. Do households have easy access to toilet facilities?	
6. Are there households who practice open defaecation?	
7. What do households do when their toilets get full?	
8. Is there any faecal sludge disposal or treatment facility in the community?	
9. Where do you think people discharge their faecal sludge?	
10. Is there any faecal sludge service providers available in the community?	
11. How often do you educate community members on sanitation issues?	
12. What challenges do you face as a community with regards to faecal sludge management?	
13. What is your general impression about the sanitation and faecal sludge management situation?	

Public Toilet Attendants

Name of Interviewer:	Date:
Region:	District:
Name of Interviewee:	Position:

1. What is the type of toilet and the number of seaters?
2. How many privy rooms are for males and females respectively?
3. About how many years has the toilet been in existence and its current condition?
4. On the average how many people use toilet facility in a day?
5. When (morning, afternoon, evening or any other time) and Who desludge the toilet and how do they do it?
6. Do people pay for using toilet facility? (a) YES ....Gp (b) NO
7. What are the anal cleansing materials used by users of the toilet facility (graphics, toilet rolls etc.)?
8. How do you dispose of the anal cleansing materials?
9. If toilet is water closet with septic tank, where do you get the water for flushing and handwashing?
10. What do you do when the toilet gets full?
11. If public toilet is desludged, what is the mode of desludging? (Manual or mechanical?)
12. How much do you pay for desludging the toilet (also state the approximate capacity of the cesspit emptier)?
13. Do people use the toilet when it is being desludged?
14. Do you have any idea where faecal sludge is sent to after desludging?
15.What major problems do you face with people using the toilet (e.g behaviour, soiling the toilet seats or squat holes, people don't want to pay for using the toilet etc.)?
16. What major problems do you face in managing the toilet?

Household Survey

INTERVIEWER		**DATE**	
REGION		**DISTRICT**	
COMMUNITY		**FORM ID**	

CONSENT

Would you agree to participate in the interview?
□ *Yes* □ *No* *Location of Household* ______________________

Question	Response
Introduction	
1. Name of respondent	_______
2. Age of respondent	_______
3. Sex of Respondent	_______Male
	_______Female
4. Marital Status of respondent	_______Single
	_______Married
	_______Divorced
	_______Separated
	_______Living-in
4. Highest Level of education	_______No formal Education
	_______Primary
	_______Junior High School
	_______Senior High School
	_______Tertiary
5. Employment Status of household breadwinner	_______Subsistence Farming
	_______Trading
	_______Public Service
	_______Private Organization
	_______Trader
	_______Unemployed
	_______Other (Specify)
7. Respondents Household size	_______ 1-3
	_______ 4-6
	_______ 7-9
	_______10-12
	_______ >/=12
8. Monthly household income (GHS)	_______<100
	_______100-199
	_______200-299

	______300-399
	______400-499
	______ >/=500
9. Where do you and your household defaecate?	______Public toilet
	______Private(Household Toilet)
	______Open defaecation
10. What is the type of toilet you access	______VIP
	______KVIP
	______Traditional Pit Latrine
	______Water Closet with Septic Tank
	______NA
11. How old is the toilet facility you access?	______0-3 years
	______4-6 years
	______7-9 years
	______10-12 years
	______> 12 years
12. How often do you visit the toilet facility in a day?	______Once
	______Twice
	______Three times
	______NA
13. Do you pay any tariff to access the toilet facility?	______Yes
	______No
	______NA
14. If Yes in Q13, then how much do you pay to access toilet facility	______5 Gp
	______10 Gp
	______20 Gp
	______NA
15. What type of anal cleansing material do you use after visiting the toilet?	______Paper
	______Toilet tissue
	______Others
16. How often do you clean your toilet?	______Regular
	______Not regular

	______No cleaning ______NA (Open defaecators)
17. Do you wash your hands with water and soap after visiting the toilet?	______Yes ______No
18. Cost of soap for hand washing in a month	______GHS
19. Do you desludge faecal sludge from pits when toilets get full	______Yes ______No
20. What is the mode for faecal sludge desludging?	______Manual ______Mechanical ______NA
21. Where do you dispose of faecal sludge when pits are desludged?	______ Sludge sent to disposal site outside community ______Bush ______Buried i n pits ______No designated disposal site in community ______NA
22. Is there any treatment of faecal sludge generated?	______Yes ______No ______NA
23. How is the faecal sludge treated?	______At the treatment site/Waste Stabilization Pond ______Chemicals ______No treatment ______NA
24. Do you re-use sludge from latrine for agricultural purpose?	______Yes ______No ______NA (Households without toilets)
25. Are you willing to use treated sludge for agricultural purposes?	______Yes ______No ______NA

Farm survey tool

Form No.		**Date of Survey**	
Community		**District**	
Region		**Farm Size(Acres)**	

CONSENT

Would you agree to participate in the interview?
□ *Yes* □ *No* *Location of Household* ________________________

Question	
Socio Economic Characteristics of Respondent	
1. Name of respondent	_______
2. Age of respondent	_______
3. Sex of Respondent	______Male
	______Female
4. Highest Level of education	______No formal Education
	______Basic
	______Junior High School
	______Senior High School
	______Tertiary
5. Is farming your main occupation?	______Yes
	______No
6. Are you the main household breadwinner?	______Yes
	______No
7. Total monthly income (GHS) per planting season	______100-199
	______200-500
	______>500
Farming Practices	
8. What type of farming do you practice? Probe to find out whether it is vegetable or food crop farming	
9. For how long have you been farming?	
10. How did you acquire your farm land?	
11. On what scale will you classify your farming? (Note: Large, Medium or Small)	
12. Do you apply fertilizer to your farm	______Yes
	______No
13. Which type of fertilizer do you use?	______Organic
	______Inorganic fertilizer
	______Both organic and inorganic fertilizer
14. How many planting seasons do you have in a cropping year?	
15. What is your average crop yield per cropping year?	

Inorganic Fertilizer Application	
16. Why do you prefer inorganic fertilizer?	______Easy to come by
	______Cost effective
	______Easy application
	______Increase crop yield
17. How much do you spend on inorganic fertilizer for each planting season?	
18. Are inorganic fertilizers readily available to farmers	
19. How often do you apply the inorganic fertilizer per every crop season?	______Once
	______Twice
	______More than twice
20. How long do your crops last without preservation?	______Less than 3 days
	______1 week
	______2 weeks
	______1 month
	______More than 1 month
Assessment of farmers knowledge on faecal sludge compost utilization	
21. Have you heard of faecal sludge as a source of fertilizer?	______Yes
	______No
22. If yes have you ever used it as a source of fertilizer?	______Yes
	______No
23. Do you supplement it with any other fertilizer	______Yes
	______No
24. If Yes, what type of material?	______Cow dung
	______Poultry droppings
	______Dry leaves/Grass clippings
	______Inorganic fertilizer
25. For how long have you been using faecal sludge	
26. Why do you prefer organic fertilizer?	
27. What are the sources of faecal sludge used as fertilizer in your farms?	
28. Do you in any way treat the faecal sludge before you apply it in your farms?	
29. How often do you apply the faecal sludge for every crop season?	

30. What quantity of faecal sludge do you require for each application?	
31. Is faecal sludge readily available to farmers	
32. How long does it take to receive faecal sludge?	
33. Do you get the required quantity?	
34. How much do you pay for the faecal sludge?	
35. Will you be willing to produce your own compost?	
Cultural and social acceptability and health risks posed by using faecal sludge	
36. How long can your crops last before going bad without any preservation?	
37. How do you protect yourselves during the application of faecal sludge to your farms?	
38. Are consumers willing to purchase faecal sludge fertilized crops?	
39. Are you aware of any cultural beliefs in your community against the use of faecal sludge in crop production?	
40. Have you suffered any social discrimination due to the use of faecal sludge on your farm?	

APPENDIX B: Laboratory Analyses

Total Volatile Solids (TVS)

Apparatus

Evaporating dish, Furnace, Steam bath, Weighing Balance

Procedure

The evaporating dish was cleaned and heated in the oven at a temperature of 105oC for at least one (1) hour. The empty dish was then weighed using the weighing balance and its weight in grams recorded. The remains of the sample on which Total solids analysis has already been done is put in the empty dish and weighed. The sample is then ashed at 550oC for 3 hours. After cooling the sample is reweighed.

Calculation

Total Solids (mg/l) = $\frac{A-B}{W}\ X\ 100$

A = Weight of dish + Residue in grams.

B = Weight of empty dish in grams.

V = Weight of Sample grams

Total Solids (TS)

Apparatus

Evaporating dish, Desiccator, Drying oven, Steam bath, Weighing Balance

Procedure

The evaporating dish was cleaned and heated in the oven at a temperature of 105^{o}C for 24 hours. It was then removed and cooled in the desiccator to room temperature. The empty dish was then weighed using the weighing balance and its weight in grams recorded. The faecal sludge sample was well shaken and a volume of 100ml measured and poured into the weighed dish. The sample was then evaporated to dryness on the steam bath, and then transferred into the oven for drying at 105^{o}C to a constant weight. The dish was removed from the oven, cooled in the desiccator to room temperature, and then weighed.

Calculation

Total Solids (mg/l) = $\frac{A-B}{V}\ X\ 1{,}000{,}000$

A = Weight of dish + Residue in grams.

B = Weight of empty dish in grams.

V = Volume of Sample in ml (100ml).

Five day Biochemical Oxygen Demand (BOD_5)

The biochemical oxygen demand (BOD) was determined using the dilution method. A known volume of the sample was poured into a 300ml BOD bottle and mixed with dilution water until it overflowed and then stoppered. Another standard 300mL BOD bottle was filled with dilution water to represent the blank. The initial dissolved oxygen concentrations of the blank and diluted sample were determined using a DO meter. Both bottles were stored at 20°C in the incubator for five days. After 5 days the amount of dissolved oxygen remaining in the samples were measured with a DO meter. The BOD5 was then calculated as;

The 5-day BOD was computed using the equation below:

$$BOD_5, mg/L = \frac{D_1 - D_2}{P}$$

D_1 = DO of diluted sample immediately after preparation, mg/L,
D_2 = DO of diluted sample after 5 day incubation at 20°C, mg/L,
P = decimal volumetric fraction of sample used

Chemical Oxygen Demand (COD)

The Chemical oxygen demand was determined using the Open Reflux method 1g of $HgSO_4$ was transferred into the reflux flask followed by a known volume (10mL) of the sample and mixed. 10mL of 0.0417M $K_2Cr_2O_7$ solution was also added to the flask and mixed. 20mL of conc. H_2SO_4 was added slowly to the flask whiles simultaneously cooling the outside of the flask under running water after which 1mL of silver sulphate solution was added. The procedure was repeated for the same volume of distilled water as the blank. The solution was then boiled under reflux for 2 hours after which 45mL of distilled water was added and subsequently cooled under running water. 2 to 3 drops of ferroin indicator was added after which a light blue/green colour appeared. The residual solution was titrated with 0.1M Ferrous Ammonium Sulphate (FAS) solution to reddish brown endpoint. The COD was calculated using the formula below:

$$COD \text{ as } mgO_2/L = \frac{(A-B) \times M \times 8000}{mL \text{ sample}}$$

Where:
A = mL FAS used for blank,
B = mL FAS used for sample,
M = molarity of FAS (0.1M)
8000 = milliequivalent weight of oxygen × 1000 mL/L.

Nitrate-nitrogen

Cadmium Reduction Method

Principle

The cadmium reduction method was used to determine nitrate-nitrogen in the faecal sludge sample. The concentration of Nitrate-nitrogen was determined by selecting Program 353 N, Nitrate MR from the Hach Programs. A clean, round sample cell was filled with a known sample volume diluted to 10mL and the contents of one Nitra Ver 5 Nitrate Reagent Powder Pillow added to it. The sample cell shaken vigorously to mix the contents and the timer icon pressed to begin a one-minute reaction period. The timer icon is pressed again after the one-minute reaction for a five-minute reaction period to begin. Another sample cell was filled with 10mL distilled water (the blank) and placed in the cell holder of the spectrophotometer after thoroughly wiping it. The 'Zero' button was pressed and a 0.00 mg/L NO_3^-N concentration was displayed. After the five-minute reaction period, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of Nitrate-nitrogen was displayed in mg/L NO_3^-N.

Nitrogen-ammonia

Salicylate Method was used to determine Nitrogen-amonia concentration. Nitrogen-ammonia was determined by selecting Program 385 N, Ammonia, Salic. from the Hach Programs. A clean, round sample cell was filled with a known sample volume diluted to 10mL and another sample cell filled with 10mL deionised water (the blank). To each of these cells, the contents of one Ammonia Salicylate Powder Pillow were added. The cells were stoppered and shaken to mix the contents and the timer icon pressed to begin a three-minute reaction period. After this period, the contents of one Ammonia Cyanurate Powder Pillow were again added to each cell, stoppered and shaken to dissolve the reagent. The timer icon was pressed to begin a 15-minute reaction period. The blank was first placed into the cell holder after the reaction period and the 'Zero' button pressed. A 0.00 mg/L NH_3-Nconcentration was displayed. Subsequently, the prepared sample was also placed in the cell holder after wiping the sample cell and the 'Read' button was pressed. The concentration of Nitrogen-ammonia was displayed in mg/L NH_3-N.

Heavy Metals

The heavy metals included Copper (Cu), Iron (Fe), Lead (Pb), Cadmium (Cd), Zinc (Zn), Manganese (Mn) and Arsenic (Ar).

Principle:

The content of the heavy metals are measured in a digest obtained by treating samples with an acid mixture made from conc. nitric acid, conc. sulphuric acid, and perchloric acid, (Chapman and Pratt, 1961; Association of Official Analytical Chemist,1979). .

Reagents

1. Perchloric acid 60-62%, (2). HNO3 Conc. AR, (3). H2SO4 conc.AR

Procedure

1. 1.0 g of ground dried sludge material (oven-dry, 60 ºC) was weighed into a 125 ml Erlenmeyer flask which had been previously washed with an acid and distilled water.

2. 5 ml of Ternary mixture (20ml HClO4: 500ml HNO3: 50ml H2SO4) was added under a fume hood.

3. The contents was mixed and heated gently at low to medium heat on a hot plate under a perchloric acid fume hood.

4. Heating continued until dense white fumes appeared (i.e. fumes of sulphuric acid).

5. It was finally, heated strongly (medium to high heat) for half a minute.

6. Allowed to cool, and then added 40-50 ml distilled water. It was boiled for half a minute on the same plate at medium heat.

7. The solution was cooled and filtered completely with a wash bottle into a 100ml Pyrex volumetric flask. It was made up to the mark with distilled water (Whatman No.42 filter paper, 9cm used).

8. The solution was stored for heavy metal determination in Atomic Absorption Spectrophotometer (AAS), Perkin-Elmer Corp. (1968).

APPENDIX C: Tables and Figures

Characteristics of Public Toilet Sludge

Parameter	Unit	Accra	Kumasi	High strength Sludge	Public toilet Sludge
PH		-	8.1 -8 .5	-	7.77±0.13*
Conductivity	uS/cm	-	-	-	22.67±3.45*
BOD	mg/l	8,800 (3,800-15,000)	23,300 (14,200-52,000)	(20,000 - 50,000)	-
COD	mg/l	47,600 (10,400-97,000)	86,700 (36,600- 175,000)	-	50.32±28.78*
TS	mg/l	-	55,700 (31,300- 87,000)	-	36.64±7.73*
TVS	% of TS	62	-	-	-
TKN as N	mg/l	-	2,400 (700 - 4050)	-	3.58±2.07*
NH4-N	mg/l	-	-	(2,000 - 5,000)	-
NH3 - N	mg/l	-	-	-	-
TP as P	mg/l	-	-	-	-

Source: Accra- WRRI and SANDEC (1994); Kumasi- Doku (2002).; High Strength- Strauss *et al.* (1997), Public Toilet Sludge- EC in mS/cm*, COD, TS, TKN in g/l*-K -Kuffour *et al.* (2013).

Characteristics of compost during comparison of two BM

Parameter	Unit	Experimental Trial						
		Control	Wood (2:1)	Wood (1:1)	Wood (1:2)	Maize cob (2:1)	Maize cob (1:1)	Maize cob (1:2)
Initial compost feedstock								
Temperature	^oC	25.0	25.3	25.3	24.7	25.0	25.0	25.7
pH		8.6	7.6	7.6	7.8	7.8	7.4	7.7
Moisture content	%	66.70	66.60	65.87	65.20	66.30	65.27	65.17
Total Solids	%	33.27	33.40	34.10	34.80	33.70	34.70	34.90
Organic Matter	%	65.57	77.10	81.40	86.07	81.70	83.60	88.60
Ash Content	%	18.00	15.77	13.50	12.90	15.27	13.20	11.40
Total Carbon	%	17.52	36.32	42.63	46.41	35.34	38.41	44.82
Total Nitrogen	%	1.61	1.76	1.82	1.88	1.81	1.71	1.94
C:N		11	21	23	25	20	22	23
Phosphorus	%	1.26	1.29	1.34	1.43	1.34	1.32	1.51
Potassium	%	0.59	0.61	0.64	0.67	0.61	0.68	0.71

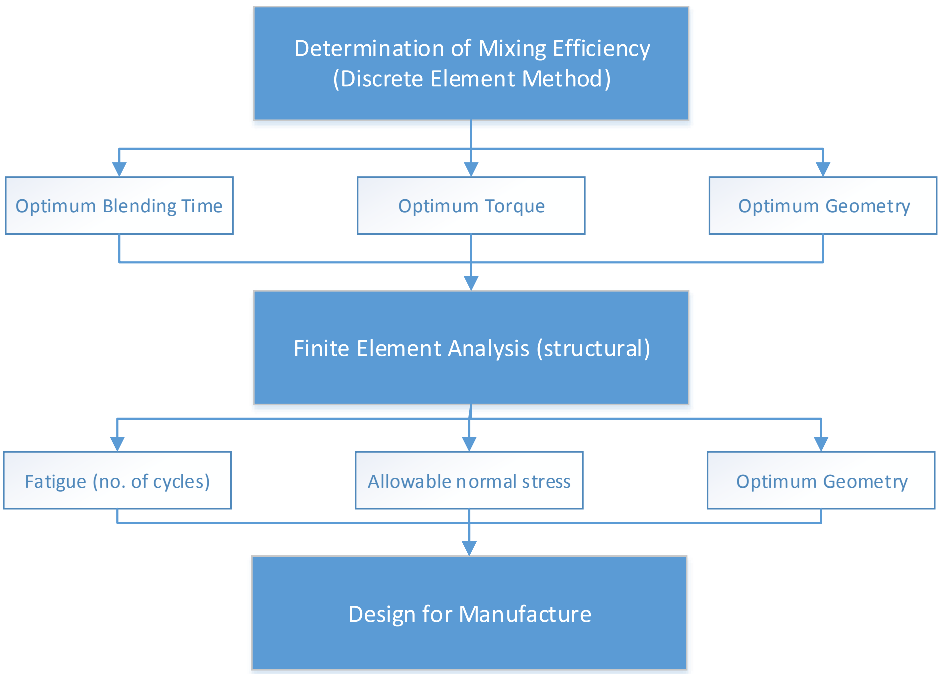
Final (Matured) compost								
Temperature	°C	24.0	25.0	25.0	25.0	25.0	26.0	27.0
pH		7.7	7.4	7.5	7.3	7.2	7.3	7.0
Moisture content	%	40.70	37.27	32.30	23.60	35.13	30.90	20.70
Total Solids	%	59.23	62.47	67.70	76.60	64.80	69.10	79.17
Organic Matter	%	50.60	54.90	61.37	62.33	60.50	62.10	61.93
Ash Content	%	46.40	39.10	38.70	37.57	39.50	37.90	38.70
Total Carbon	%	12.14	29.12	32.54	34.42	31.92	31.64	35.25
Total Nitrogen	%	1.22	1.40	1.53	1.69	1.72	1.56	2.12
C:N		10	21	21	20	18	20	17
Phosphorus	%	0.89	1.01	1.11	1.14	0.99	1.15	1.23
Potassium	%	0.25	0.31	0.48	0.52	0.36	0.48	0.52

Note: All experiments were mixed at proportions of volumes (v:v.); Total Carbon, Total Nitrogen, Total Phosphorus and Total Potassium were calculated on the basis of dry weight (d.w.); values are means (n=2) of analyses of the initial and final composting materials.

Results Of Discrete Element Method Software

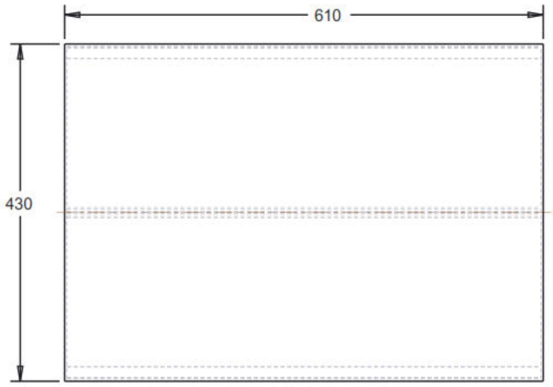
Overall Work flow

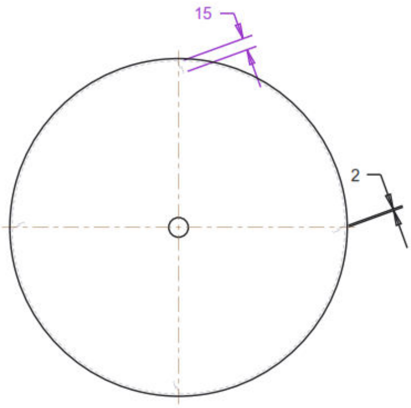
General Flow for design analysis of faecal sludge digester can be as depicted below.



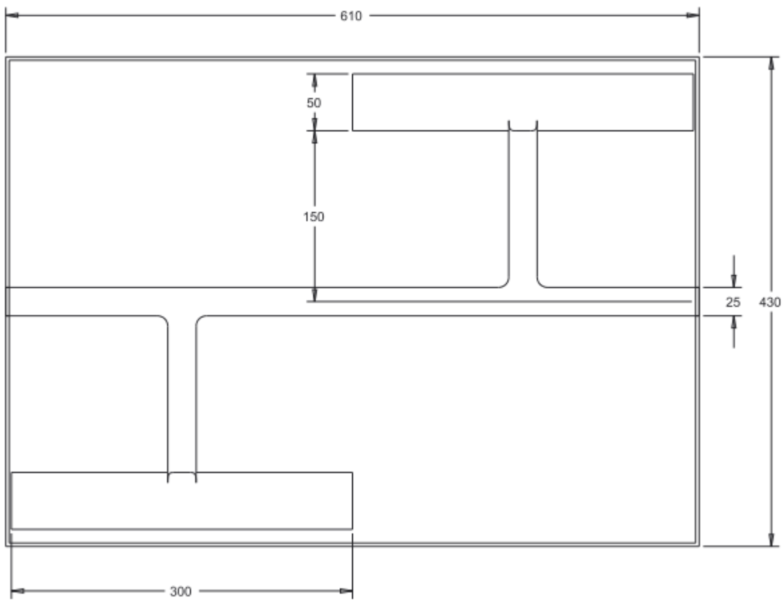
DEM Experimental Setup

Two design configurations were used in this design study, namely rotary baffle configuration and paddle design for DEM simulation.



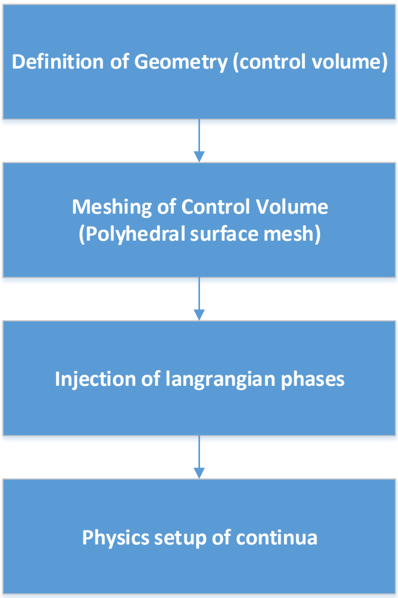


Rotary Baffle Design

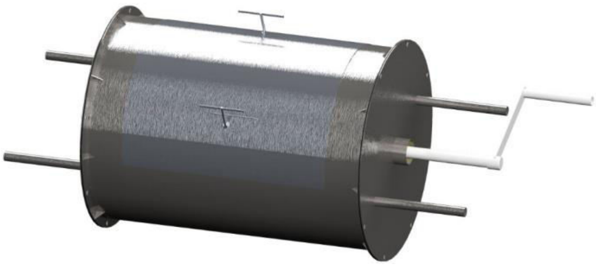


Paddle Design

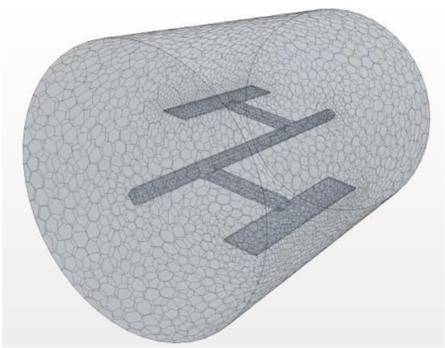
Flow for setup of DEM simulation is as shown below.



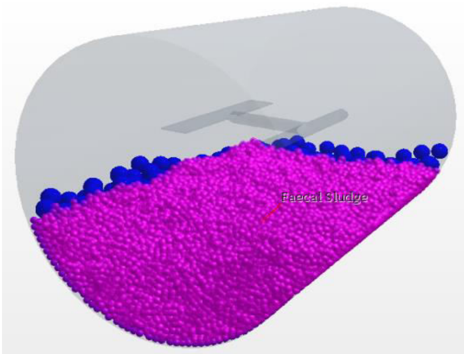
Definition of Geometry



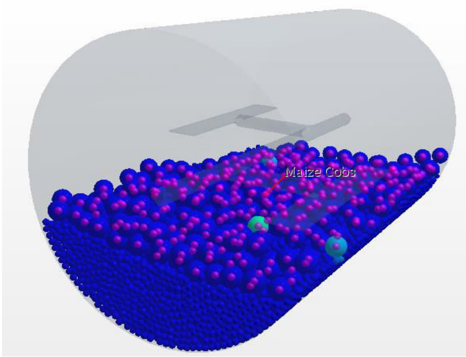
Meshing of Control Volume



Injection of Langrangian Phase



Faecal Sludge Phase



Shredded Maize Cobs Phase

Faecal Sludge

Parameters used for faecal sludge characterization are as shown in below table.

Parameters	**Values**
Particle size	15 mm
Rolling Coefficient of restitution	0.7
Bulk density (ρ_b)	1350.1 [kg/m^3]
Work of cohesion	0.50

Shredded maize Cobs

Parameters used for shredded maize cob characterization are as shown in below table.

Parameters	Values
Particle size	25 mm
Rolling Coefficient of restitution*	0.7
Bulk density (ρ_b)	282.38 [kg/m^3]
Work of cohesion	0.50

Multiphase Interactions

Parameter	FS - FS	SCC-SCC	FS - SCC	FS-WALL	SCC-WALL
Static coefficient of restitution	0.40	0.30	0.42	0.55	0.50
Normal coefficient of restitution	0.10	0.10	0.10	0.10	0.10
Tangential coefficient of restitution	0.05	0.05	0.05	0.05	0.05

Summary of Output of Simulation for manufacturing of Rotary Drum

Parameter	Design Criteria
Drum Volume (Litres)	130
Enclosure diameter	0.52 m
Enclosure length	0.61 m
% of Volumetric Capacity	50
Paddle Surface Area	0.015 m^2
Force Required at handle (N)	365
Speed (rpm)	5
Blending time (min)	1.0

Initial Characteristics of Rotary Drum Compost

CYCLE	Compost Design	Parameters					
		pH	MC (%)	C/N (%)	TS (%)	% Viable Ascaris	% Viable Trichuris
Cycle 1	Metal Paddle	7.3	52.9%	27.9	47.1%	68%	91%
	Metal Baffle	7.9	53.1%	28.4	46.9%	84%	73%
	Plastic Paddle	7.1	52.2%	27.2	47.8%	79%	84%
	Plastic Baffle	6.7	52.1%	26.8	47.9%	71%	87%
Cycle 2	Metal Paddle	6.9	50.3%	28.5	49.7%	81%	83%
	Metal Baffle	7.4	54.9%	25.9	45.1%	75%	69%
	Plastic Paddle	8.1	53.8%	26.3	46.2%	89%	82%
	Plastic Baffle	7.8	54.6%	27.3	45.4%	76%	79%

Percentage die off of Ascaris and Trichuris Eggs

Cycle	Compost Design	Ascaris Eggs/g TS			Trichuris Eggs/g TS		
		Start of compost	**End of compost**	**Die off**	**Start of compost**	**End of compost**	**Die off**
Cycle 1	Metal Paddle	70	13	82%	36	4	88%
	Metal Baffle	75	7	91%	30	3	90%
	Plastic Paddle	72	1	99%	36	1	98%
	Plastic Baffle	63	5	92%	40	3	92%
Cycle 2	Metal Paddle	103	5	95%	52	1	98%
	Metal Baffle	95	3	97%	49	2	96%
	Plastic Paddle	105	0	100%	50	0	100%
	Plastic Baffle	98	2	98%	44	2	95%

Mean (arithmetic) Ascaris and Trichuris eggs by experimental set-up and cycle

Parameter/variable	**N**	**Mean (SD)**	**Min, Max**	**p-value**
Ascaris (Cycle 1)				
Metal Baffle	39	30.05 (19.24)	6 - 77	0.0047
Metal Paddle	39	26.54 (16.40)	12 - 72	
Plastic Baffle	39	23.03 (14.34)	5 - 65	
Plastic Baffle	39	16.23 (19.00)	0 - 74	
Ascaris (Cycle 2)				
Metal Baffle	39	30.44 (29.86)	2 - 97	0.346
Metal Paddle	39	34.85 (28.52)	5 - 107	
Plastic Baffle	39	26.13 (28.47)	1 - 99	
Plastic Baffle	39	23.59 (30.39)	1 - 110	
Cycle 1	156	23.96 (17.94)	0 - 77	0.083
Cycle 2	156	28.75 (29.36)	1 - 110	
Trichuris (Cycle 1)				
Metal Baffle	39	7.56 (7.40)	2 - 30	0.135
Metal Paddle	39	10.38 (9.03)	4 - 37	
Plastic Baffle	39	10.56 (9.97)	3 - 41	
Plastic Baffle	39	6.72 (9.02)	0 - 36	
Trichuris(Cycle 2)				
Metal Baffle	39	14.77 (14.96)	2 - 49	0.268
Metal Paddle	39	13.18 (16.71)	1 - 52	
Plastic Baffle	39	15.15 (12.57)	2 - 46	
Plastic Baffle	39	9.03 (16.27)	1 - 51	
Cycle 1	156	8.81 (8.98)	0 - 41	0.0031
Cycle 2	156	13.03 (15.26)	1 - 52	

APPENDIX D: Photographs on Research work

Plate 1: Latrines identified during assessment of sanitation facilities

Plate 2: Experimental Set up for Testing different bulking materials and mixing ratios

Plate 3: Shredded Maize cobs and Saw dust used as bulking materials

Plate 4: Analysis of Compost Parameters

Plate 5: Pictures of Rotary Drum Composter

Plate 6: Sampling of Faecal Sludge for Compost

Plate 7: Sample Faecal Sludge Compost

APPENDIX E: Achievements during PhD

The following peer reviewed publications and conference presentation have resulted from work conducted as part of this PhD research.

1. **Eugene Appiah-Effah,** Kwabena Biritwum Nyarko, Eric Ofosu Antwi and Esi Awuah (2016). Effect of bulking materials and mixing ratios on concentration of nutrients during composting of raw faecal sludge from peri-urban areas, *Water Practice & Technology, 11(1): 234-242*

2. **Eugene Appiah-Effah,** Kwabena Biritwum Nyarko, Eric Ofosu Antwi and Esi Awuah (2015). Perception of Peri-Urban Farmers on faecal sludge Compost and Its Utilization; A case study of three peri-urban communities in Ashanti Region of Ghana; *Compost Science and Utilization*

3. **Eugene Appiah-Effah,** Kwabena Biritwum Nyarko, Eric Ofosu Antwi and Esi Awuah (2015). Heavy metals and microbial loads in raw faecal sludge fromlow income areas of Ashanti Region of Ghana (2015), *Water Practice & Technology (10):124-132*

4. Samuel Fosu Gyasi, **Eugene Appiah-Effah** and Bismark Dwumfour-Asare (2015): Perception of brewery pollution among inhabitants of Kaase in Kumasi, Ghana, *International Journal of Current Research Vol. 7, Issue, 01, pp.11464-11470*

5. **Eugene Appiah-Effah,** Kwabena Biritwum Nyarko, Samuel Fosu Gyasi and Esi Awuah (2014): Faecal sludge management in low income areas: a case study of three districts in the Ashanti region of Ghana; *Journal of Water, Sanitation and Hygiene for Development, 189-199*

6. **Eugene Appiah-Effah,** Kwabena Biritwum Nyarko And Esi Awuah (2014): Characterization of Public Toilet Sludge from Peri-Urban and Rural Areas of Ashanti Region of Ghana; *Journal of Applied Sciences in Environmental Sanitation, 9 (3): 175-184.*

7. **Oral Presentation**onHeavy metals and microbial loads in raw faecal sludge fromlow income areas of Ashanti Region of Ghana at Faecal Sludge Management 3 International Conference in Hanoi, Viet Nam, 2015.